

# Fourth International Agronomy Congress

**Agronomy for Sustainable Management of Natural Resources,  
Environment, Energy and Livelihood Security to Achieve Zero  
Hunger Challenge**

22–26 November 2016, New Delhi, India

## Extended Summaries Vol. 4

### LEAD PAPERS



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# Plenary Lectures







## Scaling innovations in natural resource management for sustainable agriculture

RAJ PARODA

*Former Secretary, Department of Agricultural Research and Education and  
Director General, Indian Council of Agricultural Research, New Delhi*

Recently, India celebrated the Golden Jubilee of Green Revolution which had led to an era of food self-sufficiency. Despite fourfold increase in population, the production of food grains rose by fivefold, thus making India a net exporting country from a status of Begging Bowl in early sixties. In the process, second generation challenges of Green Revolution have surfaced prominently such as factor productivity decline, poor soil health, lack of good quality water, increased incidence of pests and diseases, increased cost of inputs, decline in farm profits and above all the adverse impact of climate change.

Agriculture must be seen to liberate India from twin scourge of hunger and poverty, while ensuring sustainability of her natural resources. It must also address effectively the concern of malnutrition among children and empowerment of women and youth; being important sustainable development goals (SDGs). Hence, to address these, the needs and aspirations of resource-poor smallholder farmers must be met through innovation-led accelerated and sustainable agricultural growth. Historically, the adoption of high yielding dwarf varieties of wheat and rice under the 'Green Revolution' era addressed both hunger and poverty. However, of late, the yield gaps in agriculture and the income divide in farm and non-farm sectors have been widening; primarily due to the gaps in the required knowledge, technical skills and timely access to improved technologies due to poor extension system. Out scaling of relevant innovations for greater adoption and impact on smallholder farmers has of late emerged as a

major challenge. Why farmers are unable to access or adopt the new technologies, specially around resource conservation, secondary and speciality agriculture are the issues that haunt the policy makers, development officials and scientists alike. Further, the escalating input costs, access to market and its volatility and climate induced aberrations during the crop season make farming risky, non-profitable and unattractive. Therefore, it is paramount to ensure an inclusive growth in agriculture through innovative and synergistic approaches for achieving sustainable food and nutrition security. Thus, 'agriculture research for development' (AR4D) urgently requires a paradigm shift to 'agricultural research and innovation for development' (ARI4D). Another reorientation is now needed from earlier uni pillar approach (around improved germplasm) to twin pillar strategy aiming at good agronomic practices around conservation agriculture aiming at efficient natural resource management. Also climate smart agriculture would demand resilience in agriculture around farming systems mode requiring inter-disciplinary/inter-institutional approach in a landscape context.

The presentation would centre around new innovations, policy interventions, farmers' extension needs and some new exciting developments which have led to faster agricultural growth in the last one decade, especially in certain sectors of agriculture in India. Yet the challenges are enormous requiring urgent technology and policy related interventions to accelerate agricultural growth and to remain globally competitive.



## **Rice-based systems research and meeting the sustainable development goals**

**MATTHEW K. MORELL**

*International Rice Research Institute, Manila, Philippines*

The Sustainable Development Goals set out a compelling internationally developed and agreed goals to reduce hunger, poverty, improve health, and sustainability - through partnerships. As one of the three major cereal crops, improving rice production systems has a key role to play in addressing the

SDGs. In this presentation, I will outline how the International Rice Research Institute is developing integrated solutions to improve the lives of smallholder farmers and their dependents, while addressing overarching goals in food and nutritional security and climate change.

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## Nexus among poverty, hunger, water and energy in India

J.S. SAMRA

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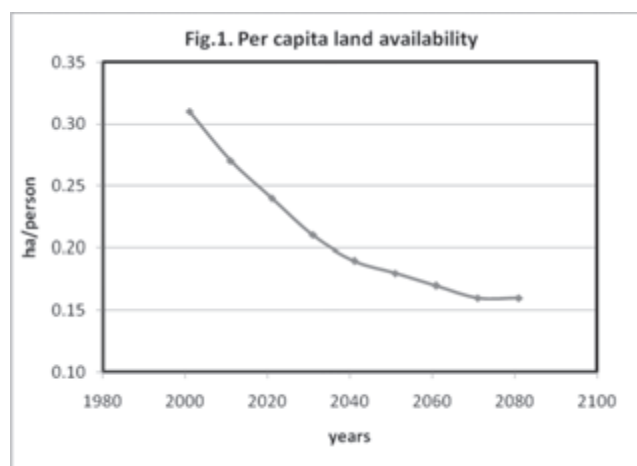
According to World Bank Report (2015) India's GDP of US \$2.074 trillion with current growth of 7.6% support a population of 1.311 billion with an inflation rate of 5.9%. It is fastest growing economy of the world but development is not inclusive or is lopsided with a wide gap between rural and urban sector, ethnic and social groups. According to the latest comprehensive socio-economic and caste census (2011) of India about 73% households are rural with direct and indirect dependence on agriculture for livelihood, environmental and food security. After the major economic reforms of 1991 GDP of India grew at an average rate of 6.8% and the real term per capita income increased five and half times in 25 years. However, contribution of agriculture to GDP in the same period declined from 30 to 13% indicating relatively faster growth in the non-agriculture sector. In the rural sector 74.52% of the highest earning members of the households earn less than Indian Rs.5,000 (US \$ 83), 17.18% in the range of Rs.5,000 to Rs.10,000/- (US \$ 83 to 166) and 8.29% more than Rs.10,000 (US \$166, @ Rs.60 per \$ ) per month (SECC, 2011). About 50% of mostly unskilled workers are still engaged in agriculture and large investments are being made for their skilling and re-skilling. Out of 1.3 billion populations the upper 100 richest Indians cornered 18% of increased wealth due to skewed growth (Forbes, 2015). Agriculture sector, therefore, is the major concern of poverty, hunger and inequitable development.

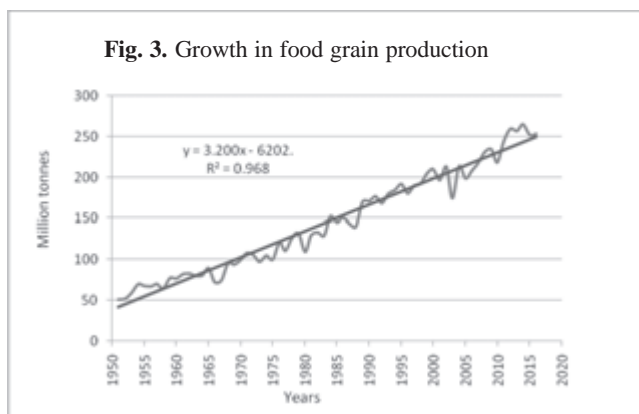
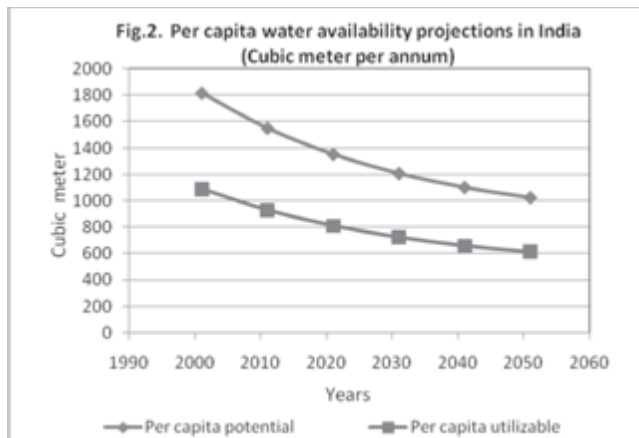
As per latest comprehensive assessment of poverty in India about 270 millions were below poverty line after the reduction of 137 millions over 2004-05 with an overall current percentage of 21.9% (25.7% in rural and 13.7% in urban sector) (Wikipedia, 2016). World Bank Global Monitoring Report (2014-15) on Millennium Development Goal also reported largest poverty reduction in India between 2008 and 2011 and lifted 140 millions out of absolute poverty. The latest Global Hunger Index (GHI) analysed on the basis of four indicators also reported reduction in hunger from 48% in 1990 to 29% in 2015 (Welthungerhilfe, 2015). GHI value (based on 3 factors) of 2011 ranged from 13.6 in Punjab state to 30.9 in Madhya Pradesh and indicated a lot of variation among regions, states, castes, social groups and gender. Unlike many

other countries, hunger in India is not affected by internal or external conflicts or wars and natural calamities like droughts, floods, hail storms, heat/cold waves etc are well managed by the adequate resources of National Disaster Management Authority of India enacted in 2005 (GOI, 2005b). Reduction in poverty and hunger was due to increased production of food grains, constitutional guarantee of food security, rural employment, education and social welfare schemes like Integrated Child Development, National Health Mission, Mid-day Meals in the school, etc. (GOI, 2013). Enabling policies of managing disaster and natural calamities (Samra et al, 2006) has also reduced poverty and hunger and there is still a long way to go for achieving zero hunger and SDG goals 2030 by promoting sustainable agriculture and rural development.

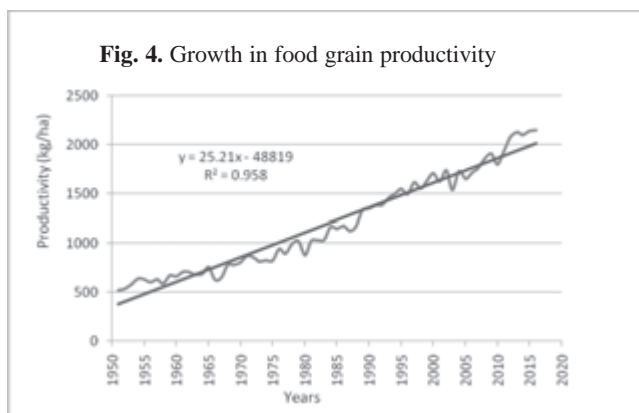
### 1. Resources, productivity and production

Per capita availability of inelastic natural resources of land (Fig. 1), water (Fig.2) and others is declining due to demographic growth and incremental needs of livelihood, environmental security, Sustainable Development Goals of 2030 for reducing poverty and hunger are expected to be realized by higher productivity of agronomic practices with highest efficiency of inputs and natural resources. Sustained high growth in the production of food grains, milk, fruits, meat, eggs, vegetables etc was harnessed in India (Fig. 3 & 4) during the past





40 years mainly by higher productivity with improved technologies, intensive inputs, investments in developing water resources, rural electrification, better extension services, enabling policies and good governance. It is evident from Fig. 4 that gains in productivity and cropping intensity provided food security since net cultivated area during past 40 years was almost constant around 142 million hectares.



The risk factors are also multiplying and confounding due to higher frequency and intensity of agronomically important extreme weather events like rainfall, floods, droughts, heat/cold waves, hail storms, gales, cyclones, super cyclones, etc. (Swaminathan and Rengalakshmi, 2016). Suicides by farmers

due to risks of market volatilities and climatic change, indebtedness, excessive social spending and illness are also on the rise and insurance is being promoted. Various missions with committed investments have been launched in India to adapt to the climate change (GOI 2008, DST 2009, DAC 2010). Among other factors climate smart agronomy for diversification with higher efficiency of water, energy, other inputs and other natural resources is called upon. In the context of climate smart agronomy, integrated and efficient management of inputs, all sources of water, different kinds of energy and other natural resources including human capital is very crucial.

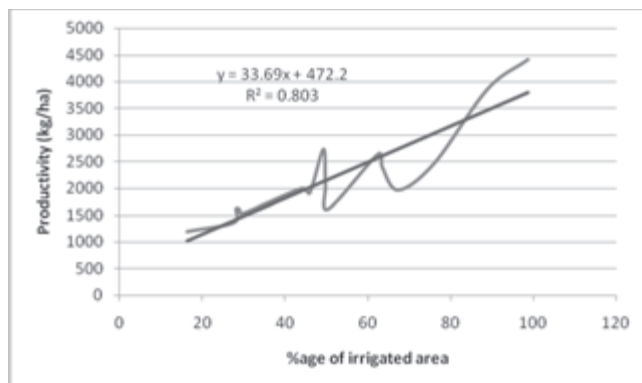
## 2. Present position of water development

On an average there are sufficient water resources to meet the demands upto 1950 projections as given in table 1 (MOWR 2008, GOI 2008). However, spatial and temporal variability, slow development of resources, large gaps in potentials developed and actually utilized, inefficient management and environmental impacts are very large and complicated issues of governance. Per capita water availability among 23 basins of India ranges from as low as 263 m<sup>3</sup> in Sabarmati basin to 20,136 m<sup>3</sup> (more than 76 times) in Ganga-Brahmaputra-Megna-basin (CWC 2015).

About 80% of rainfall is received during four months of moon soon period with very high intensity of events leading to erosion of natural resources and even flooding. *In situ* resources conservation, ground water recharging, storage of run off into millions of small structures, large dams, inter-basin transfer of water, canal irrigation systems and its conjunctive use with ground water, afluent etc. are being addressed to maximize various water utilities (Samra et al, 2002). During 1970s budget allocation to irrigation sector reached upto 23% of the total budget of India, ushered in green revolution and budgetary support has now come down to 6-7% only. Inter-regional, interstate, upstream down stream conflicts, environmental concerns and huge investment portfolios of inter-linking rivers are getting confounded. Water is a state subject in India and central government can play facilitating and advisory role only and that too through innovative incentives and capacity building rout.

## 3. Water productivity

Productivity and cropping intensity of irrigated agriculture is about 1.5 times more as compared to un-irrigated or rainfed agro-ecologies. Relationship of irrigated area and productivity of food grains at the macro level of very large and heterogeneous units of 15 food producing states of India is given in Fig. 5. In spite of very large variation in the geography, agro-ecology, socio-economic conditions, governance and human resource qualities among 15 states of Indian continent there is fairly good positive correlation of irrigation with the productivity and production. Productivity points above the trend lines represent predominantly ground water or conjunctively irrigated states and dots below the trend represent inefficient



**Fig. 5.** Relationship between food productivity and percentage irrigated area during 2013-14 in different agro-ecologies of 15 states of India.

canal irrigated states. Of course, cost of irrigation and carbon foot prints are higher in the ground water irrigation due to energy consumption especial diesel in some of the states like UP, Bihar etc.

#### 4. Surface water resources

Large public investments were made for the construction of multi-purpose hydropower dams for generation of green renewable energy, moderation of floods, expansion of irrigation, adapting to climate change, soil and vegetation conservation in the catchment and canals net works in commands especially after 1950s. Against total water availability of 1869 BCM storage capacity of major and medium dams is 253.4 BCM (13.6%) and another 51 BCM (2.7%) is under construction. Distribution of dams, canal network and efficiency is also highly variable across basins and states. Still there are lot of potentials for developing irrigation to reduce poverty and hunger (Table 1). Hardly 64% of the potentials are being actually utilized and there are low hanging fruits of 16% potential created which can be harnessed by making small investments mostly on command area development and completion of some minor activities.

**Table 1.** Ultimate irrigation potential (UIP), irrigation potential created (IPC) and irrigation potential utilized (IPU) till 2012 (million ha) in India

Sources	UIP	IPC	IPU
Surface water	75.85 (54%)	63.13 (56%)	47.44 (53%)
Ground water	64.05 (46%)	49.40 (44%)	41.82 (47%)
Total	139.90	112.53(80%)	89.26 (64%)

Overall very low irrigation efficiency of canal water (37%) led to rise in water table, water logging or water stagnation, surface ponding especially during rainy season, accumulation of salts in upper layers of soil or secondary salinization in semi arid and arid agro-ecologies and land degradation

lowered the productivity within 20 to 50 years of irrigation. In the good quality water logged canal commands of India millions of tube-wells were installed for vertical drainage after 1970, salinized soils were reclaimed with appropriate agronomy of diversification into gypsum application and paddy cultivation. Water table again declined indicating that more than seepage or leakage from the canal network was recovered by bore wells with an overall system level efficiency of 70 to 80%.

However in the semi-arid south-west Punjab (20% geographical area) adjoining parts of Haryana, Rajasthan states and elsewhere, seeping canal water picked up salts from the virgin desert soils and became unfit for recovery by investing into tube-wells for irrigation (vertical drainage by default), environmentally safe disposal of poorly quality drained water was not feasible and devastation continues. Salts of the shallow water table or stagnating water has even damaged buildings, very unique agronomy of aqua-culture is being experimented to restore livelihood earning, degraded land and environment qualities etc. Environmental impact assessment is now mandatory for preventing environmental damages.

#### 5. Ground water resources

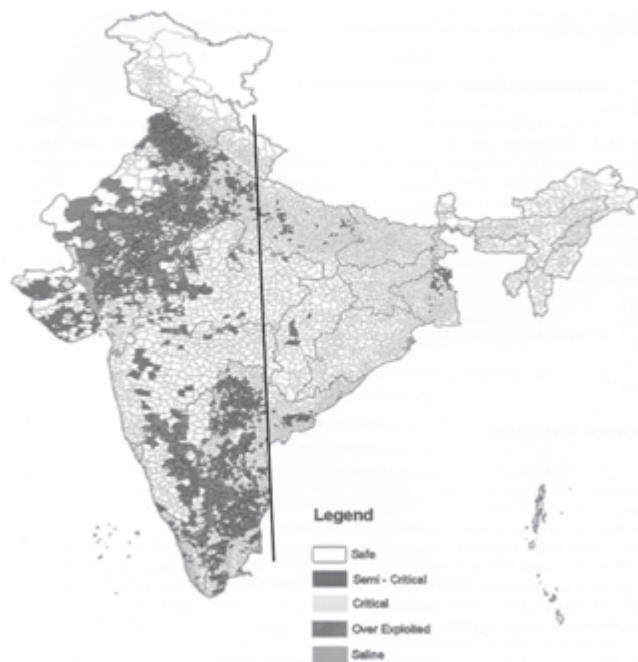
It contributes nearly 45% to the total utilizable irrigation potentials and currently meets 60% of irrigation, 85% of rural and 50% of urban drinking water as well as industrial needs. Ground water is the best bet for adapting to the climate changes especially an effective remedy for droughts, heat and cold waves. Unlike public investments in canal water supplies on rotational basis, privately invested ground water is available all the time of the year provided energy is available. Ground water based irrigation is self managed by the farmers and amenable to precision agronomy of high cropping intensity. There are about 30 million privately invested ground water structures for utilizing ground water in India. About 47% of the ground water has already been developed and its productivity and cropping intensity is 1.5 to 2.5 times more than that of canal irrigation. Subsidised or even free electricity supply by the states, effective operation of minimum support price for rice and wheat for ensuring food guarantee to the public and diversification in favour of cultivating water guzzling paddy cultivation has over exploited the ground water resources as shown in red colour (Photo 3). The utilization of 172% of the annually rechargeable potential is highest in Punjab state, followed by 137% in Delhi, Haryana etc. Table 2). Over all ground water in western India having relatively lesser poverty and hunger is over exploited. Re-investment cost in highly ground water depleted areas for replacing water extracting utilities, energy consumption and cost of cultivation has gone up and intensified risks and indebted of the farmers. In addition to the need of aquifer recharging, geogenic and anthropogenic pollution of ground water have become alarming in certain pockets.

High concentrations of nitrates, arsenic, selenium, fluo-

rides, etc. may afflict health of children, adults and need proper governance of open access or common property resources of ground water (Minhas and Samra, 2003). Drilling technologies for extracting aquifer water from safer depths in Arsenic contaminated aquifers have been pilot tested.

Some of the states have passed Acts to regulate agronomic practices to minimize ground water use and prevent pollution

**Photo 3.** Distribution of Ground Water Exploited Units (71% Blocks are under-utilized providing tremendous opportunities)



(Red colour indicates over exploitation and blue underutilization of ground water)

in 2003 (Tamil Nadu), 2009 (Punjab and Haryana), 2015 (Maharashtra) and other states ( Anonymous, 2003, 2009a, 2009b, 2015).

Ground water is still under utilized in about 71% of safe blocks or other assessment units mostly in high rainfall hunger and poverty ridden North-East India, hard rock pockets in Central and Southern peninsular India as detailed in Table 2, 3 and Photo 3 ( CGWB, 2014). Specific yield in hard rock area is low, open dug wells are feasible but irrigation is not very dependable and private investments are not forthcoming. Most of the safe blocks have been prioritized both for public and private investments into irrigation, crop diversification, etc. for reducing poverty and hunger.



**Table 2.** State-wise over utilized ground water resources availability, utilization and stage of development, India, March 2011 (Billion Cubic Meter)

S. No.	States / Union Territories	Annual replenishable ground water resource	Net annual ground water availability	Annual ground water draft	Stage of ground water development (%)
1	Punjab	22.53	20.32	34.88	172
2	Delhi	0.31	0.29	0.39	137
3	Rajasthan	11.94	10.83	14.84	137
4	Haryana	10.78	9.79	13.05	133
5	Daman & Diu	0.018	0.017	0.016	97
6	Puducherry	0.189	0.170	0.153	90
7	Tamil Nadu	21.53	19.38	14.93	77
8	Uttar Pradesh	77.19	71.66	52.78	74
9	Himachal Pradesh	0.56	0.53	0.38	71
10	Gujarat	18.57	17.59	11.86	67
11	Lakshdweep	0.011	0.0035	0.0023	67
12	Karnataka	17.03	14.83	9.41	64

## 6. Rainwater management

India receives an annual precipitation of 4000 billion cubic meters, hardly 28% is being utilized and 50% area will continue to be partially irrigated and totally un-irrigated or rains dependent with partial irrigation even after having developed all irrigation potentials. Productivity of these under invested, fragile, risky, diverse and complex agro-ecologies is very low and distress related seasonal out-migration for supplementing income is socio-economically unfortunate.

Participatory transparent integrated management of rainfall, land, vegetation and livelihood from ridge to valley sequence on a micro scale of naturally occurring geohydrological watershed units is being provided as shown in photo 6 (Samra *et al.*, 2002, NRAA, 2011). The agronomical practices consists of *in situ* moisture conservation, recharging ground water, rainwater harvesting into a whole range of structures for limited irrigation before sowing or subsequent critical stages and safe disposal of runoff. Un-irrigated rain dependent agriculture is highly vulnerable to climate change and needs various adaptations including livestock and deep rooted drought tolerant shrubs, multi-purpose trees and range-land management (GOI, 2008).

Over all irrigation by various resources improved livelihood, reduced both poverty and hunger to a variable extent depending upon ecological, socio-economic conditions, poli-

cies and governance commitments (Fig. 6). The relationship of irrigation with hunger (GHI) was relatively weaker (Fig. 7) because of massive top dressing with several social sectors investments for food entitlements at subsidised rates for poor, free mid day meal in schools, supplementary nutrition for pregnant and lactating women, National Rural Health Mission etc.

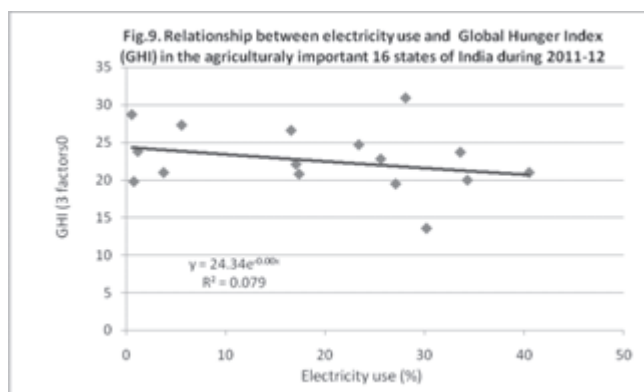
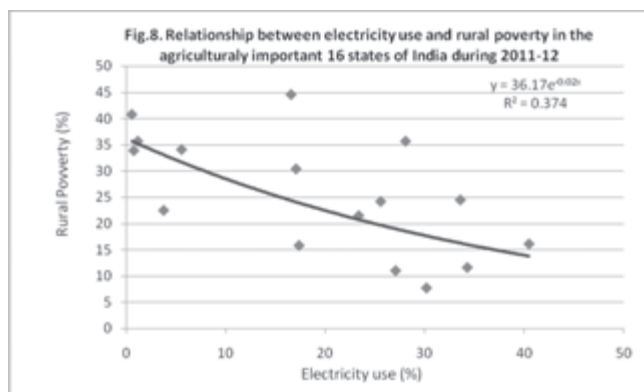
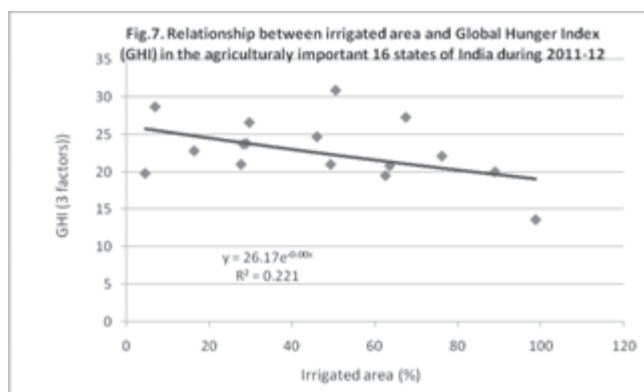
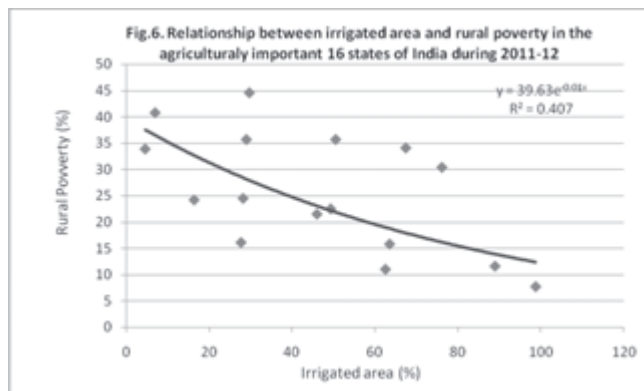
## 7. Electricity and governance

Canal irrigation in India is designed mostly on gravity flow without much of the energy consumption. However, farmers prefer ground water for various reasons explained earlier and that needs intensive input of energy and investments into rural distribution system. On an average about 21% of electricity generated in India is consumed in the agriculture sector mostly for lifting ground water (DAC, 2014). In addition to that 9 million bore wells are energised by diesel which is also subsidized generally during drought years.

In 2011-12, the arid state of Rajasthan consumed 40.5% followed by Haryana (34.3%), Karnataka (33.6%), and Punjab (30.2%) of their total electricity generation. Most of the electricity is highly subsidised or even free and ground water has been extracted recklessly for cultivating water guzzling crops like paddy, sugarcane, banana, etc. The farmers generally purchase cheap inefficient motors and pumps since inefficiency is paid by the government. In highly productive

**Table 3.** State-wise underutilized ground water resources availability, utilization and stage of development, India, March 2011 (Billion Cubic Meter)

S. No.	States / Union Territories	Annual replenishable ground water resource	Net annual ground water availability	Annual ground water draft	Stage of ground water development (%)
13	Madhya Pradesh	35.04	33.29	18.83	57
14	Uttarakhand	2.04	2.00	1.13	57
15	Maharashtra	33.95	32.15	17.18	53
16	Kerala	6.69	6.07	2.84	47
17	Andhra Pradesh	35.89	32.57	14.51	45
18	Bihar	29.34	26.86	11.95	44
19	West Bengal	29.25	26.58	10.69	40
20	Chhattisgarh	12.42	11.63	4.05	35
21	Jharkhand	6.31	5.76	1.86	32
22	Goa	0.24	0.145	0.04	28
23	Odisha	17.78	16.69	4.73	28
24	Sikkim	-	0.044	0.011	26
25	Dadara & Nagar Haveli	0.062	0.059	0.013	22
26	Jammu & Kashmir	4.25	3.83	0.81	21
27	Assam	28.52	25.79	3.49	14
28	Tripura	2.587	2.358	0.163	7
29	Nagaland	0.62	0.55	0.03	6.13
30	Andaman & Nicobar	0.308	0.286	0.013	4.44
31	Mizoram	0.030	0.027	0.001	3.52
32	Manipur	0.44	0.40	0.004	1.02
33	Arunachal Pradesh	4.51	4.06	0.003	0.08
34	Meghalaya	1.78	1.60	0.0017	0.08
35	Chandigarh	0.022	0.019	0.000	0.00



and intensively cropped state of Punjab there is one tube-well ( bore well) for each 3.2 ha of net cultivated area. In 2016 the state government paid subsidy to the electricity corporation @ Rs.13,266/- (US \$ 206) per ha per annum of net sown area. There are also policy triggered marketing and pricing distortions which have promoted cultivation of high water consuming crops. Preventing over exploitation of ground water needs good governance. Like irrigation higher energy consumption also reduced poverty and hunger Fig. 8 and 9. Relationship of GHI with energy use was relatively weaker because of distortions of subsidy, efficient marketing of rice and wheat for ensuring public distribution, heavy top dressing with investments into social sector schemes under right to food, education, employment in rural sector etc. as detailed earlier. Generation of environmentally green solar and wind energy is going to alter the inter connections among water, Carbon foot prints, livelihood and energy consumption especially for micro-irrigation (Photo 1).



**Photo 1.** Micro-irrigation being energised by photo voltaic solar energy in India

There are several agronomic possibilities to enhance efficiency of water and energy if competitive e-marketing is operationalized for all agriculture outputs.

### Multiple use of water for enhancing productivity

Land holding size in India is very small (Table 4), farmers need employment throughout the year and for that appropriate integrated farming system with multiple uses of land, water, energy and other resources is quite appropriate. One of such systems is shown in Photo 2 below. A large variation of such systems for different agro-ecologies and socio-economic groups have been demonstrated all over India with very attractive B: C ratios given below (Table 5).

These systems are based on the principles of cycling and recycling of water, energy, other fluxes and residues of different components of production. In the Photo 2 excreta of live stocks flows into the ponds, promotes growth of planktons and fishes, the nutrient enriched pond water is used for culti-



**Table 4.** Operational land holding size of 138 million holdings in India

Size (ha)	Number (millions)	%age	Average size (ha)
<1.0	92.8	67.1	0.39
1.0-2.0	24.8	17.9	1.42
2.0-4.0	13.9	10.0	2.71
4.0-10.0	05.9	4.2	5.76
>10.0	00.9	0.7	17.38
All	138.3	100.0	1.15

DAC (Agriculture Census 2011 (Phase 1))

**Table 5.** Cost-benefit analysis of some IIFS models

Sl. No.	Farming System	Cost: benefit ratio
North East India		
1	Agri-horti-silvi-pisci-culture	1:2.8
2	Agri-horti-silvi-cultural system	1:1.4
3	Agri-pisci-culture	1:3.4
4	Rice-fish-cattle	1:1.69
5	Rice-fish-goat	1:1.44
6	Rice-fish-poultry	1:1.41
7	Rice-fish-duck	1:1.31
8	Rice-pig-fish	1:1.31
9	Agri-horticulture system	1:1.57
10	Agro-pastoral system	1:1.45

vating and irrigating fodders for the livestock production. It also spreads out and scales up nutritional status of food including cereals, milk, meat, fish, egg, etc. in various permutation and combinations to reduce under nutrition and other factors of hunger. These systems provide employment and income flow throughout the year especially to small land holders.

## 9. Convergence of resources and water management

A unique, innovative and out of box convergence solutions for providing protective irrigation to each field in the country and produce per drop more crop (efficiency) was launched in 2014. Irrigation management and resources spread over four central ministries and 30 states are being coordinated, mutually complemented, supplemented and planned for realizing complete end to end solutions simultaneously with good governance. It will address water management especially in poverty and hunger inflicted agro-ecologies.

## 10. Impact of irrigation and power consumption on poverty and hunger

In general both poverty and hunger decreased with better irrigation and higher electricity consumption and some of the poor correlations are due to variation in agro-ecologies, socio-economic conditions, inadequate policies and governance

**Table 6.** Comparison of subsidised rates with the competitive market rates (per kg)

Cereals	Subsidised rates	Market rates
Rice	INR 3 (4.5 cents)	INR 20 (30 cents)
Wheat	INR 2 (3.0 cents)	INR 20 (30 cents)
Course cereals (Millets)	INR 1 (1.5 cents)	INR 10 (15 cents)

across the states of this very large country. Several natural resources related schemes like Food for Work Programme, Drought Prone Area Programme (DPAP), Desert Development Programme (DDP), Integrated Watershed Management Programme (IWMP), Integrated Tribal Development Programme and many other poverty alleviation schemes were taken up since 1970s to address poverty and hunger etc. Relationships of resources management were relatively weaker with GHI as compared to poverty because of direct cash transfer to poor and massive investments into various food, education and employments security entitlements which were incorporated into a very comprehensive National Food Security (Right to Food) Act 2013. Following schemes of the past were consolidated into the Act to pin down hunger directly through entitlement of free as well as subsidised food grains:

- A. Universal free coverage of hungry
  - i) Integrated Child Development Scheme which was already in operation since 2000
  - ii) Mid Day Meals in schools or take home already in operation since 2004
  - iii) Nutrition for pregnant women, lactating mothers and other special category of children
- B. Targeted Public Distribution System
  - i) Poorest of the poor (Antyodaya Anna Yojna of since 2000) constituting about 10% of families in the coun-

## Multiple use of water

**Photo 2.** Multiple uses of water in high rainfall eastern India

try were retained. This special category below poverty line is entitled to 35 kg of cereals/family/month at subsidised rate given subsequently.

- ii) Rest of 75% rural and 25% of urban poor 1 get @ 5Kg of cereals per person per month at subsidised rates given below

During 2004 to 2015 The National Rural Employment Guarantee Scheme alone provided jobs of unskilled 21.5 Billion person days, 57% was shared by women, wage rate in rural sector grew by 8% and poverty reduced by 32%. It also created durable productive assets of rain water management and irrigation, rural roads, land development etc. Therefore, poverty and hunger are being tackled in many dimensions in India.

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## Climate change and food security challenges: Our preparedness

PANJAB SINGH

Climate change and food security, in my opinion, are the two watch words of the survival of humanity at large irrespective of its origin whether it is developed, developing or under-developed country. The term, quite often exchanged with livelihoods, deals with the access to the food required for a healthy and productive life. Through the last century during which, the world witnessed with pride unprecedented scientific, social and economic achievements also witnessed worst of the documented disasters, both man-made and natural. During the period, the development in the agricultural production system also led to certain degree of stability in the developed and developing countries such as India and China. The surpluses in some parts of the world also led to the apparent complacency that the global food surpluses were sufficient to guarantee global food security. If one looked world as one unit may be, the scenario provides ground for achieving the definition of food security, per se. This, however, is too simple a situation to imagine as a real situation.

In our enthusiasm of realizing the potential of scientific developments in agriculture and industry, we ignored the harm we caused, sometimes, inadvertently and sometimes recklessly, on the natural environment that houses the life support system of the world. We now face the reality-the threat to environment. In other words, environmental degradation is now is equally prevailing reality, beyond a limit of which, all the achievements that insured food security to the world would suddenly become unsustainable or to say, environmental degradation is now being considered as one of the greatest risks to future world food security (Singh, 2014).

On the eve of UN conference on Environment and Development held in Rio de Janeiro in June 1992, the union of concerned scientists published an open letter titled, World's Scientists Warning to Humanity, which stated that, "human being and the natural worlds are on the collision course". It further stated that "If not checked, many of our current practices put at serious risk for future that we wish for the human society and plant and the animal kingdoms and may so alter the living world that it would be unable to sustain life in the manner that we know". This warning was signed by over 1600 scientists from leading scientific academies in 70 countries. The list included 104 Nobel Laureates (Swaminathan, 2005).

Recently acknowledged by the world community that the Climate change caused by excessive emission of Green House Gases (GHGs) is one of the greatest challenges facing our planet today. The atmosphere carries out critical function of

maintaining life sustaining conditions on earth. GHGs (for example carbon dioxide (CO<sub>2</sub>), methane (CH<sub>4</sub>), nitrous oxide (N<sub>2</sub>O), water vapour) re-emit some of the heat to the earth surface. If they did not perform this useful function, most of the heat energy would escape, leaving the earth cold (about -17o C) and unfit to support life. Increase in the level of GHGs could lead to greater warming, which, in turn could have an impact on the world climate-the phenomenon known as "Climate Change". Ever since industrial revolution began 150 years ago, manmade activities have added significant quantities of GHGs to the atmosphere. Atmospheric concentration of CO<sub>2</sub> has grown by 31%, CH<sub>4</sub> by 15% and N<sub>2</sub>O by 17% between 1750 and 2000 (IPCC 2001). A portfolio of measures on various sectors of economy like energy, agriculture, urban and rural habitat and all measures related to environmental protection and ecological sustenance are needed to combat this grave problem.

In India, where still about two-third of the population depends on agriculture and nearly half of the cultivated land is rain dependent makes livelihoods highly vulnerable to climate change. This poses a serious threat to the food security. Climate sensitive sectors like agriculture, forestry, water resources, human and animal health and so on, highly vulnerable to climate, will face serious consequences and will have the future effects through: continued change through this century and beyond; continuous temperature rise; longer frost free season (and growing season); changes in precipitation pattern; air will become more and more polluted; more drought and heat waves; more stronger and more intense hurricanes; sea level rise by 1-4 feet by 2100; arctic likely to become ice-free and so on and so forth. Latest WHO study shows that 92% of the world population breaths polluted air (Fig. 1). India accounts for 75% of 0.8 million air pollution related deaths in South East Asia region, over 0.6 million people die every year in India of ailments caused from air pollution such as acute lower respiratory infection, chronic obstructive pulmonary disorder, ischemic, heart diseases and lung cancer. Solution exists with sustainable transport in cities, solid waste management, access to clean household fuel and cook-stoves, as well as renewable energies and industrial emission reductions (TOI, Sept. 28, 2016).

### Climate change scenario and its impact

The UN-backed inter-governmental panel on Climate Change (IPCC) in its fourth assessment of global warming in



Fig. 1. World breathing bad air

2007 with 620 scientists together with representatives of 113 of the 192 member-nations met in Paris and arrived at a consensus on data about global temperature. The report says that the atmospheric concentration of green house gases, like CO<sub>2</sub>, CH<sub>4</sub> and N<sub>2</sub>O have by far exceeded the usual range of the last 6, 50,000 years. About 379 ppm is the concentration of CO<sub>2</sub> in atmosphere, the highest in 6, 50,000 years. The average surface temperature across the globe has shot up by 0.74°C in the past century (Fig. 2).

Carbon dioxide at all-time high in human history says World Meteorological Organisation (WMO). CO<sub>2</sub> levels in the atmosphere have surged past an important threshold and may not climb down for “generations” despite environmental actions. The 400-ppm benchmark was broken globally first time in recorded history last year. The WMO says 2016 will probably be the first full year to exceed the mark. Modern human beings, who evolved in only 200,000 years ago, have never lived under such high atmospheric carbon dioxide levels. Although 2016 is the first full year when the entire world has crossed the 400-ppm threshold for CO<sub>2</sub>, isolated places have breached the mark in the past few years. It was recorded over the Arctic in 2012 and in Mauna Loa in 2013. The last

time CO<sub>2</sub> was regularly this high was 3 million to 5 million years ago. Before 1800, atmospheric levels were around 280 ppm, expert say. Other greenhouse gases, including methane and nitrous oxide, have been growing alarmingly. Last year, methane levels were 2.5 times greater than in the pre-industrial era that started around 1800. Nitrous oxide was 1.2 times above the historic measure. The study points to the impact of these increased concentrations of warming gases on the World's climate. “Without tackling CO<sub>2</sub> emission, we cannot tackle climate change and keep temperature increases to less than 2 degrees C above the pre-industrial era” (TOI, 2016).

The number may seem insignificant but it is an unprecedented rise. In last 50 years 11 hottest years were witnessed since 1995. Worst, the arctic is warming twice as rapidly as the rest of the world and there is a direct possibility of the Greenland Ice Sheet collapsing altogether and pushing sea level by several meters. Mega coastal cities in India, like Mumbai could be in trouble with the sea making inroads into land, leading to displacement of millions of people and many more effects because of that (Fig.3).

With the rise in sea level, island countries like the Maldives and Bangladesh would experience severe flooding

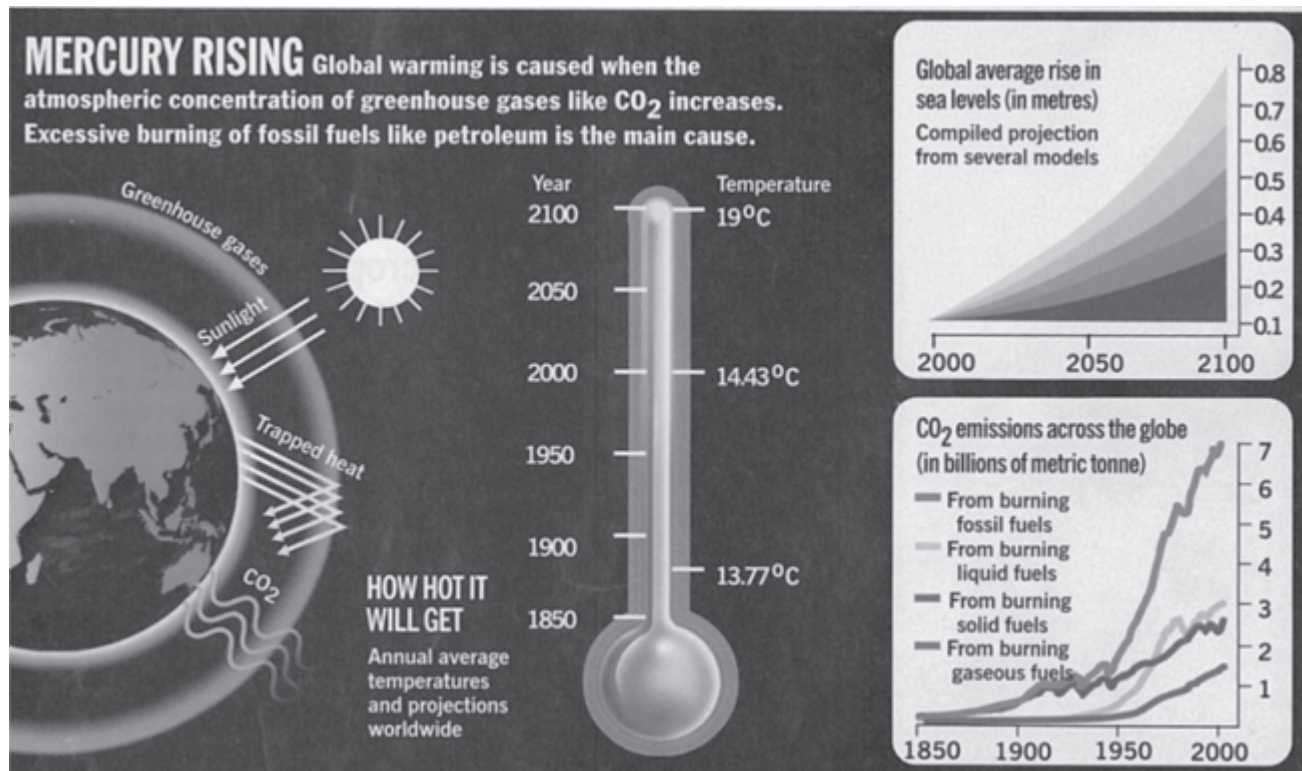


Fig. 2. Global warming Scenario



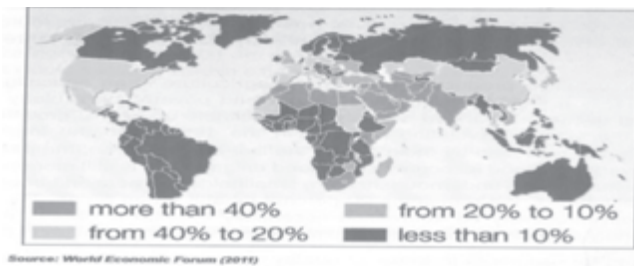
Fig. 3. Global warming effects

and erosion of land. Vast stretches of mangroves and salt marshes would be destroyed across the world and, in the process, ecospheres rich in biodiversity would disappear. UN Panel reports warn that if the trends of global warming continue unchecked, the glacial across the Himalayas will melt at the alarming rate and may disappear altogether by 2035. Such an event will not only have severe impact on Himalayan ecol-

ogy and the people living in the region but will also cause a wide swath of miseries downstream. This is because most of the India's great rivers, like the Ganga and the Jamuna, are dependent on the glaciers for perennial water supply. If all this continues, it is expected that gross per capita availability of water in India will decline from a current 1820 m<sup>3</sup> a year to as low as 1140 m<sup>3</sup> a year in 2050-a thirty per cent drop. It is a figure close to 1000 that has been classified by the UN as a water scarcity zone. In the long run, water availability will decline and uncertainty of the availability will increase considerably, putting 30 per cent of global crop production at risk by 2025 (Singh,2014), let alone the volatile fluctuations in production (Fig. 4).

Over half-a-billion people-or half of the country's population-would be adversely affected by such a steep drop in water supply. The impact on agriculture will be particularly acute. Productivity of food grains could drop by as much as 30 per cent in the next thirty years. Reports say that even 0.5° rise in water temperatures could reduce wheat yields by 0.45 ton per hectare-a 17 per cent drop in productivity. Almost similar impact would be on rice cultivation. Equally deadly would be impact on India's coastline where sea level is expected to rise by 40 cm by turn of the century, flooding the residence of millions of people living in low lying areas. On different front, desertification is likely to increase as natural grass cover drops (Fig. 5).

Up to 50 per cent of the total biodiversity is also at risk,



**Fig. 4.** Climate change effect on water availability

with 25 per cent of plants and animal species facing extinction, if the temperature increase exceeds 1.5 to 2.0 degrees (Fig. 6). Humans have wiped out 58 per cent of wild life in 42 years. Human appetites and activities have driven to extinction over half of animals with the back bone-fish, amphibian, birds, reptiles and mammals, says the living planet report by WWF-Zoological Society of London. Global wildlife populations declined by 58 per cent between 1970 and 2012, and could decline by 67 per cent by 67 per cent by 2020. Agriculture, which uses 70 per cent of water and one-third of land is the biggest cause of habitat loss. Biggest factors to blame human activity resulting in habitat loss, wildlife trade and climate change and over-exploitation of resources. Worst suffer-

ers have been animals in lakes, rivers and wetlands. Thirty-one per cent of global fish stocks overfished. Factory fishing has emptied the seas of 40 per cent of sea life, 9 out of 10 fisheries in the world are either over-or full-fished. Marine and land vertebrate populations have dropped 36 per cent and 38 per cent respectively. Sharks too are overfished. The report tracked over 14,000 vertebrate populations, of over 3,700 species from 1970 to 2012. It says increased human presence is using up natural resources faster than they can be replenished, particularly in fresh water habitats. Mike Barrett, head of science and policy at WWF says "if it is business as usual we will see continued declines in these wildlife populations. But I think now we have reached a point where there isn't any excuse to let this carry on." In Indian scenario about 70 per cent water is polluted, 60 per cent of ground water will reach critical stage-where it cannot be replenished-in the next decade and 25 per cent of India's land faces desertification. Indian wildlife threatened with extinction are, fresh water fish 70, amphibians 57, reptiles 46, mammals 41 and birds 7 per cent. Between 1970-2022, the per cent decline will be -38 in terrestrial, -81 in fresh water and -36 in marine (Fig. 7). Earth may be heading into sixth "mass extinction events": when species vanish at least 1,000 times faster than usual. (TOI, Oct.31,2016).



**Fig. 5.** Climate change effects on glacial melt and desertification



Fig. 6. Global warming and biodiversity

The impact on human health will be as devastating. The impact, as per UN panel report, for India could be summed up as under:

- Thirty-eight per cent drop in per capita water availability by 2050 for Indians as great dries becomes frequent.
- Sea level will rise 40 cm higher by 2010 and 50 million people in coastal India would be displaced by flooding.
- In the plains, winter precipitation would decline, causing water shortage, shrinking grasslands and triggering a fodder crisis.



Fig. 7. Human impact on wildlife

- Seventeen per cent will be the fall in wheat yields in India if temperatures rise by even half-a-degree centigrade.
- By 2035 Himalayan glaciers may totally disappear, causing catastrophic disruptions.
- The glaciers on the Tibetan plateau will shrink rapidly from 5 lakh km<sup>2</sup> to 1 lakh by 2030.
- The glacial meltdown will first result in river being flooded and then drying up. The Ganga delta would turn infertile.
- About 5 degrees is the expected rise in overall global temperatures by the end of 21st century.
- Vector born diseases, the dengue and malaria, are expected to rise sharply across India as changes in temperature make it conducive for mosquitoes to thrive.
- Deaths from diarrhoeal diseases associated with floods and droughts could go up. Coastal water temperature would help spread cholera, heat stress would cause deaths.
- Warmer ocean temperatures would lead to bleaching and destroy vast tracts of India's coral reefs.
- Ocean acidification would lead to shell dissolution, severely affecting marine life and fisheries.
- With erratic rainfall and decrease in precipitation levels, India's forest would deplete rapidly.
- The country's mangroves that are rich in biodiversity would be wiped out because of rising sea levels.
- About 25 per cent of flora and fauna would become extinct by 2030.

As AL Gore, a tireless champion for action on global warming says "This is our only home and that is what is at stake-our ability to live on our planet earth, to have a future as a civilisation".

Some predict that higher levels of CO<sub>2</sub> may stimulate photosynthesis in certain plants (30-100%), especially in C<sub>3</sub> plants and may suppress photorespiration, making them more water efficient. The protein content of the grain decreases under combined increases of temperature and CO<sub>2</sub>. For rice, the amylase content of the grain, a major determinant of cooking quality, is increased under elevated CO<sub>2</sub>. With wheat, elevated CO<sub>2</sub> reduces the protein content of grain and flour by

9-13 per cent (Singh, 2014).

Indirectly, there may be considerable effect on land use due to snow melt, availability of irrigation water, frequency and intensity of inter-and intra-seasonal droughts and floods, soil organic matter transformations, soil erosion, changes in pest profiles, decline in arable areas due to submergence of coastal lands, and availability of energy. The climate change and direction of change as indicated by IPCC Fourth Assessment Report is given in (Table 1).

The negative effects of climate change on yields of wheat and paddy in parts of India due to increased temperature, increase in water stress and reduction in number of rainy days are already felt. This year (2016-17) has reported 5 per cent of deficit rainfall against 14 and 12 per cent deficit in 2015 and 2014, respectively, but adequate rainfall in July-August, especially in water stressed areas, where it was needed during peak sowing season, has sent positive signal and the projected production is set at 270.30 million tons for food grains and 20.75 million tons for pulses for 2016-17 (TOI, 2016, Fig. 8).

Significant negative effects have been projected with medium term (2010-2039) climate change, e.g. Yield reduction by 4.5-9.0 per cent depending on magnitude and distribution of warming, eroding roughly 1.5 per cent GDP per year.

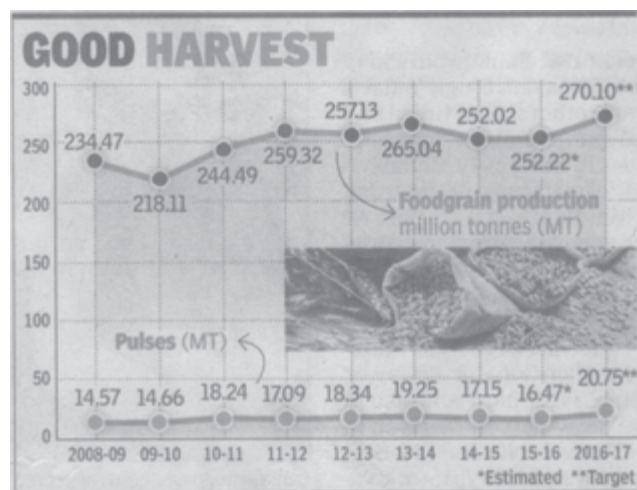


Fig. 8. Rains raise hope of record food grain yield this year

Table 1. Principal conclusions of the IPCC Fourth Assessment Report

Climate change impact and direction of trend	Probability of trend*	
	Recent decades	Future
Warmer and fewer cold days and nights over most land areas	Very likely	Virtually certain
Warmer and more frequent hot days and nights over most land areas	Very likely	Virtually certain
Frequency of warm spell/heat waves increases over most land areas	Likely	Very likely
Frequency of heavy precipitation events increases over most land areas	Likely	Very likely
Areas affected by drought increases in many regions	Likely	Likely
Intense tropical cyclone activity in some regions	Likely	Likely

\*Probability classes (probability of occurrence): likely >66%; very likely >90%, virtually certain >99%.



Since agriculture makes up roughly 14 per cent of India's GDP, a 4.5-9.0 per cent negative impact on production implies the cost of climate change to be roughly at 1.5 per cent of GDP per year. Despite a fall in share of agricultural GDP, from about 55 per cent in 1950-51 to about 14 per cent now, the role of agriculture remains crucial on counts of nutrition and employment security. Enhancing agricultural productivity, therefore, is critical for ensuring household level food and nutritional security and for alleviation of extreme poverty.

Water availability and scarcity will be influenced by long term climate change. However, it is also to a large extent is determined by changes in the demand influenced by socioeconomic changes in the society. In fact, studies show that impending global scale changes in population and economic development over the next 25 year will dictate the future relation between water supply and demand to a much greater degree than changed in mean climate (Vorosmarty *et al.*, 2001). For this reason, understanding vulnerability to economic changes in India is critical in order to understand the impact of climate change on the agriculture sector. In order to account for shifting patterns of rural vulnerability resulting from these different types of global changes, a more dynamic conceptualisation of vulnerability is required. Such a concept should capture the extent to which environmental and economic changes are influencing the capacity of farmer to respond to various types of both natural and socioeconomic shocks.

### Our preparedness to combat the challenge

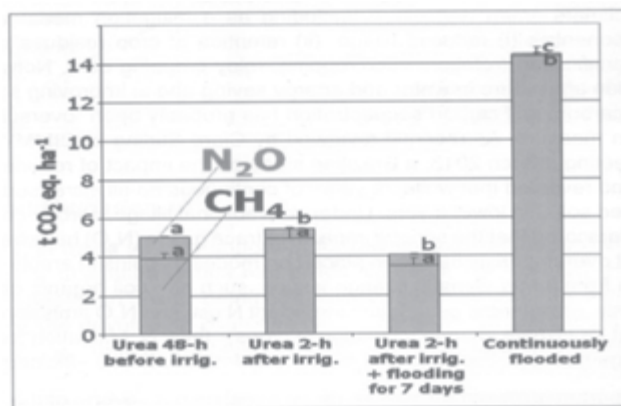
In India, agriculture accounts for about 17 per cent of the GHG emission against 22 per cent by the industry and 58 per cent by energy sectors. In agriculture sector, the contribution of livestock is 63 per cent, rice 21 per cent, agricultural soils 14 per cent, residue burning 2 per cent and manure management 1 per cent. It also accounts for 80 per cent of the water withdrawal in the country. Therefore, major mitigation strategies would encompass: livestock feeding and enteric fermentation management, especially development of Probiotics and feed supplements; improved method of rice cultivation to reduce rice emission; efficient use of water, fertilizer and other inputs and crop management; conservation of land, water, biodiversity and other natural resources; conservation of energy and development and production of renewable energy sources; development and wide adoption of conservation agricultural and carbon sequestration practices; and formulation and implementation of science-informed policies coupled with suitable incentives for effectively adopting adaptation and mitigation measures.

India essentially needs a sustainable development of its agriculture, not only to meet the food demand of its people, but also its poverty reduction through economic growth by creating employment opportunities in non-agriculture sector. The ongoing agrarian crisis in rural India could be catalysed by climate change into a migratory route, driven by greater

monsoon variability, endemic drought, and flooding and resource conflict. It is possible that the climate change may force the pace of rural-urban migration (rurbanisation) over the next few decades. Right kind of technologies and policies are required to strengthen the capacity of communities to cope effectively with both climatic variability and changes. Adaptive action may be taken to overcome adverse effect of climate change on agriculture. The adaptation and mitigation potential is nowhere more pronounced than in developing countries where agriculture productivity remains low and the direct effect of climate change are expected to be especially harsh. Creating the necessary and harnessing them to enable developing countries to adapt their agricultural system to changing climate would require innovations in policies and institutions as well. Noteworthy innovations to reduce adverse impact of climate change will include: improvement and forecasting in early warning system; establishing hazards and vulnerability mapping; augmenting public awareness; creating community based forest management and afforestation; improvement in irrigation systems and management, diversification and design of crop production management systems including water management etc.

Climate change mitigation falls into two broad categories: (I) increasing removal of GHG primarily through carbon sequestration, and (II) reducing emissions, which in the case of crops effectively means reducing  $N_2O$  emission by improving efficiency of N use, and in case of rice paddies and ruminants it relates basically to reducing methane emission (Singh, 2014). Fig. 9 shows that methane is predominant emission under alternate wetting and drying water management, whereas under continuous flooding only methane is emitted. Only under alternate drying and flooding  $N_2O$  is emitted.

The most serious climate change risk to Indian economy and its people is the increased intensity, frequency and coverage of drought. Higher temperatures, increased evapo-transpiration and decreased winter precipitation may bring about



Source: Ladha, J.K., 2013

Fig. 9. Global warming potential of  $CH_4$  and  $N_2O$  under alternate wetting and drying

more droughts. The climate change mitigation generally involves reduction in human emission of GHGs which can be achieved by increasing the capacity of carbon sinks. Use of renewable energy and nuclear energy and expanding forests are the mitigating priorities. Long term adaptation will need additional knowledge, information, technologies, investments, infrastructures and institutions integrated with the decision support system. Insurances, safety nets, cash transfers and other risk management options to reduce vulnerability to shocks are also important aspects.

The government of India has initiated and institutionalised National Action Plan for Climate Change (NAPCC) and has constituted eight missions (Box1) and the Expert Group on Low Carbon Strategies for inclusive growth to have multipronged approach to tackle to the problem (Singh 2011).

#### **Box 1. National action plan for climate change**

- National Solar Mission seeks to deploy 20,000 MW of solar electricity capacity in the country by 2020.
- National Mission for Enhanced Energy Efficiency creates new institutional mechanisms to enable the development and strengthening of energy efficiency markets. Various programmes have been initiated, including the Perform, Achieve and Trade (PAT) mechanism to promote efficiency in large industries, and the Super-Efficient Equipment Programme (SEEP) to accelerate the introduction of deployment of super-efficient appliances.
- National Mission on Sustainable Habitat promotes the introduction of sustainable transport, energy-efficient buildings, and sustainable waste management in cities.
- National Water Mission promotes the integrated management of water resources to increase water use efficiency by 20 per cent.
- National Mission for sustaining the Himalayan Ecosystem establishes an observational and monitoring network for the Himalayan environment so as to assess climate impacts on the Himalayan glacier and promote community-based management of these ecosystems.
- National Mission for a 'Green India' seeks to afforest an additional 10 million hectare of forest lands, waste lands and community lands.
- National Mission for Sustainable Agriculture focuses on enhancing productivity and resilience of agriculture to reduce vulnerability to extremes of weather, long dry spells, flooding and variable moisture availability.
- National Mission on Strategic Knowledge for Climate Change identifies challenges arising from climate change, promotes the development and diffusion of knowledge on responses to these challenges in the areas of health, demography, migration and livelihood of coastal communities.

India as a fast-growing economy is pursuing Strategic

Knowledge Mission for focussed research in area of climate change. Our R&D in carbon capture and sequestration (CCS) will be initially focussing on Post Combustion Carbon Capture on coal fired power plants. India has declared to reduce its GHG intensity by 33-35 per cent by 2030 and contemplating to sequester 2.5-3.0 billion tons of CO<sub>2</sub> through additional forest and tree cover. A larger focus is assigned on climate change adaptation in energy generation and use, agriculture, forest, water and livelihood.

The Paris Agreement in Climate Change has come in force on November 4, paving the way for the participating countries to frame rules and guidelines for its implementation. On December 12, 2015, 196 countries and EU adopted the agreement on climate change in Paris. India signed on day 1-April 22, 2016 and 191 countries have so far signed it. On October 2, 2016 India joined the agreement by depositing its instrument of ratification (the final step) and so far, 73 countries and EU have completed this process. This step, besides others, will help making a global blue print for reporting and accounting for climate action of participating countries (TOI, Oct.2016).

National Initiative on Climate Resilient Agriculture (NICRA) of the ICAR is focussing on the complex challenges like multiple abiotic stresses on crops and livestock, shortage of water, land degradation and loss of biodiversity on a long term basis. The scheme attempts to develop and promote climate resilient technologies in agriculture which will address vulnerable areas of the country. The project focuses on: strategic research to address long-term climate change; demonstration of innovative and risk management technologies in different parts of the country; funding competitive research; and capacity building of different stake holders for greater awareness and community action.

As the smallholder farmers are most vulnerable to climate change, an affordable and effective National Insurance Scheme is being implemented to cover the risk and the related miseries. Similarly, price support system and marketing infrastructure will cover price related risks of the farmer.

Research on genetic improvement, promotion of resource conservation technologies and diversification will help small farmers in empowering them to adapt to and cope up with the situations. Crop diversification along with efficient water and nutrient management will help get over the water imposed reduction in agriculture production. Breeding crop varieties tolerant to various biotic and abiotic stresses and combating desirable yield and other agronomic characters is the most effective way to develop climate resilient agriculture system. Research on organic recycling, alternate sources of energy and enhanced and efficient biomass production and utilization will have high pay off. Use of IT, especially mobile phones, for carrying the viable technologies, weather forecast and weather related information, market information, pests and diseases management need to be promoted. Role of cooperatives, Farmers Producer Organisations (FPOs) supported by

government will help promoting these activities. Several new initiatives like Make in India, Start-up India, Skill Development etc. will help build confidence and enable them to bear the risk of their agriculture failure. Recent initiative of the government to double farmer's income in next five years is an added step which, directly or indirectly, will help farmers to sustain the risk of effects of climate change.

Our multipronged strategy for sustainable growth in agriculture must focus on, defending the productivity gains so far made, extend the gains to semi-arid and marginal environment, and work for a new gains using blend of frontier technologies and traditional ecological prudence. The problem of generating adequate purchasing power to enable families living in poverty to have economic access to food will confront us. This is where job-led economic growth strategy based on micro-level planning, microenterprises, and microcredit will be of great help. Integrated production and postharvest technologies and on-farm employment strategies will be needed to provide livelihoods for all in rural areas.

In new century we are experiencing three major science and technology revolutions Viz., The Gene Revolution, The Eco technology Revolution, and The Information and Communication Revolution, which will influence agriculture and industry. These three types of advances-when coupled with improvement in management and governance- greatly improve the power of a scientific approach to genetic improvement, the integrated approach to natural resources and the management of local and regional development strategies especially addressing to the problems arising out of climate change.

International efforts towards Mitigation of Climate Change (Sethi, 2016)

1. **1995: COP 1, The Berlin Mandate: 28th March to 7th April 1995:** It voiced concerns about the adequacy of countries' abilities to meet commitments under the Body for Scientific and Technological Advice
2. **1996: COP 2, Geneva, Switzerland: 18 July 1996:** Called for "legally binding mid-term targets
3. **1997: COP 3, The Kyoto Protocol on Climate Change: December 1997:** Most industrialized countries and some central European economies in transition agreed to legally binding reductions in greenhouse gas emissions of an average of 6 to 8% below 1990 levels between the years 2008–2012
4. **1998: COP 4, Buenos Aires, Argentina: November 1998:** Adopted a 2-year "Plan of Action" to advance efforts and to devise mechanisms for implementing the Kyoto Protocol
5. **1999: COP 5, Bonn, Germany: 25 Oct to 05 Nov. 1999:** It was primarily a technical meeting
6. **2000: COP 6, The Hague, Netherlands: 13 to 25 November 2000:** Some compromises between US & EU on Emission reduction but talk collapsed.
7. **2001: COP 6, Bonn, Germany: 17 to 27 July 2001:** The agreements included: Flexible mechanisms, Carbon sink & Compliance, Financing
8. **2001: COP 7, Marrakech, Morocco: 29 Oct to 10 Nov. 2001:** The main decisions at COP 7 included: Operational rules for international emissions trading among parties to the Protocol and for the CDM and joint implementation
9. **2002: COP 8, New Delhi, India: 23 Oct to 01 Nov 2002:** The Kyoto Protocol could enter into force once it was ratified by 55 countries, including countries responsible for 55 per cent of the developed world's 1990 carbon dioxide emissions
10. **2003: COP 9, Milan, Italy: 01 to 12 December 2003:** The parties agreed to use the Adaptation Fund established at COP7 in 2001 primarily in supporting developing countries better adapt to climate change
11. **2004: COP 10, Buenos Aires, Argentina: 06 to 17 Dec 2004:** To promote developing countries better adapt to climate change, the Buenos Aires Plan of Action was adopted
12. **2005: COP 11, Montreal, Canada: 28 Nov to 09 Dec 2005:** The Montreal Action Plan was an agreement to "extend the life of the Kyoto Protocol beyond its 2012
13. **2006: COP 12, Nairobi, Kenya: 06 to 17 Nov 2006:** Despite such criticism, certain strides were made at COP12, including in the areas of support for developing countries and clean development mechanism
14. **2007: COP 13, Bali, Indonesia: 03 to 17 Dec 2007:** The Ad Hoc Working Group on Long-term Cooperative Action under the Convention was established as a new subsidiary body to conduct the negotiations aimed at urgently enhancing the implementation of the Convention up to and beyond 2012.
15. **2008: COP 14, Poland: 01 to 12 Dec 2008:** Negotiations on a successor to the Kyoto Protocol were the primary focus of the conference.
16. **2009: COP 15, Copenhagen, Denmark: 07 to 18 Dec 2009:** The accord was notable in that it referred to a collective commitment by developed countries for new and additional resources, including forestry and investments through international institutions that will approach USD 30 billion for the period 2010–2012
17. **2010: COP 16, Mexico: 28 Nov to 10 Dec 2010:** It recognizes the IPCC Fourth Assessment Report goal of a maximum 2 °C global warming and all parties should take urgent action to meet this goal
18. **2011: COP 17, Durban, South Africa: 28 Nov to 09 Dec 2011:** There was progress regarding the creation of a Green Climate Fund (GCF) for which a management framework was adopted
19. **2012: COP 18, Doha, Qatar: 26 Nov to 07 Dec 2012:** The conference made little progress towards the funding of the Green Climate Fund

20. **2013: COP 19, Warsaw, Poland: 11 to 23 Nov 2013:** Discussed modalities of 1997 Kyoto Protocol. The protocol having been developed under the UNFCCC's charter
21. **2014: COP 20, Lima, Peru: 01 to 12 Dec 2014:** Discussed modalities of 1997 Kyoto Protocol the protocol having been developed under the UNFCCC's charter
22. **2015: COP 21, Paris, France: 30 Nov to 12 Dec:** Negotiations resulted in the adoption of the Paris Agreement on 12 December, governing climate change reduction measures from 2020. India's Initiative: Declared 33% reduction in Carbon Intensity & Suggested that the Country between tropic of Cancer & Capricorn to unite for accelerated growth of solar technology

### CONCLUSION

Climate change is a much larger threat to global prosperity and world peace than a rough economy. Despite clear evidences of the consequences of doing so, we pollute the fragile climate in which we live, inadvertently destroying the environmental resource upon which, we as a species, depend. In an endless drive for profit, we destroy the forest which is needed to produce oxygen and reduce the carbon dioxide- a large contributor to the heating of our planet, and through our addiction to hydrocarbons, we continue to pollute the air we breathe and water we drink. Many societies have collapsed from overexploiting their own resources. This is exactly what we are doing now, but on a much larger, global scale. We know the problem that we are sorting for ourselves, but our constant short term approach and lack of political will to make unpopular decisions mean that we do nothing about it. We live in a state of denial. We may be immediately adaptable as a species, but with the world's population now at 7 plus billion, and projected to be 10 billion by 2050, it is becoming more and more likely that competition over resources such as wa-

ter will increase to a critical point. Unless we begin to think in the long term over the short term, and do something to preserve our valuable resources, we will end up fighting over them, and then the future is very likely to consist of intolerance, warfare, starvation and genocides, as it has done in the past.

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## Sustainable management of natural resources for improving rural livelihood and nutritional security

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### Setting the Stage

In 2012, UN secretary general Ban Ki-moon has called on world leaders, business and civil society to step up our efforts to end hunger and launched the Zero Hunger Challenge at Rio+20 in which the draft document highlighted the need to “address the root causes of excessive food price volatility” and manage the risks associated with high and volatile commodity prices to realize global food security and nutrition and empower smallholder farmers. Over time, the Zero Hunger Challenge focused on five goals to be realized by 2030.

- All food systems are sustainable: from production to consumption
- An end to rural poverty: double small-scale producer

incomes and productivity

- Adapt all food systems to eliminate loss or waste of food
- Access adequate food and healthy diets, for all people, all year-round
- An end to malnutrition in all its forms.

On September 25, 2015 at the 71<sup>st</sup> UN General Assembly, the Sustainable Development Goals were launched and agreed to by 193 nations to ensure all people can lead healthy productive lives while we live within the ecological boundaries of our planet. The 17 Goals are lead off with no poverty (Goal 1) and zero hunger (Goal 2). These goals are underpinned by 169 targets yet the indicators to track our progress to achieve



these goals are still being finalized though a provisional list was published by the UN in March 2016 (See reference).

Global commitment to set goals and realize equitable and sustainable growth is a tremendous achievement but we must go beyond these declarations and deliver on these promises. Given that greatest burden of poverty and malnutrition are in rural communities of sub-Saharan Africa and South Asia and that youth (15-25) constitute the largest decadal age demographic, agriculture research for development will be key to modernizing agriculture to ensure it is economically, socially, and environmentally sustainable to support 9.3 billion consumers by 2050. This paper will highlight the major trends, emerging approaches and convergence of partners (Public-Private-Producer-Partnerships) required to realize these goals with urgency and ownership – in the end, we all own these goals to ensure a bright future for our grandchildren and our planet we all share.

### **Demand-driven innovation: asking your customer what they want?**

Agronomy research has delivered tremendous benefits to society by increasing productivity, reducing food prices that in turn have enabled societies to specialize, innovate in other sectors and realize economic growth. However, this growth has not been equal, especially for smallholder farmers in sub-Saharan Africa and South Asia who were bypassed by the Green Revolution technologies, infrastructure, markets and policies. In part, these was due to not fully understanding the diversity of farming systems in these ecologically diverse geographies and the risks (especially weather and markets) that discourage farmers from making investments in agriculture productivity. Following from the lessons learned during the first Green Revolution, scientists are increasingly using participatory approaches to engage with farmers and other value chain actors to understand the key constraints that impeded agriculture productivity. However, much remains to be done on understanding the anthropology of what motivates farmers to adopt and dis-adopt technologies, what will motivate consumers to make more environmentally and health-conscious decisions in the supermarket and how policy makers design policy that will steer development in the direction of the SDGs.

Our challenge is how to engage with so many actors in real-time that will allow agriculture research to respond to changing demands while also recognizing that agriculture science takes time. We believe the response to this question is the application of Information Communication Technology (ICT), Advanced Analytics enabled by Cloud computing and Data Ecosystems that have structure (ontologies) that enable global collaboration at the scale required to achieve the SDGs. However, our challenge is not so much technical as behavioural as we look to issues of data sharing, big-data governance and the protection of Personal Identification Information (PII), equitable value capture and

acknowledgement, and institutional incentives that drive collaboration within and between organizations, between the public and private sectors and across sectors such as agriculture, ICT, finance, health, education and energy – to name a few. Until we address this issue, our innovation cycles will be slow, focused on single rather than holistic and sustainable solutions for society.

### **Call for convergence: we can do this TOGETHER**

Diversity of opinion, culture, discipline, age and gender often leads to the most innovative and robust solutions to complex problems. In the case of the Zero Hunger Challenge this is exactly the need of the hour and yet we need to ask ourselves: What are the institutional incentives to drive this change? What is the framework by which we support convergence? How are human, financial and capital (e.g. research facilities) optimized under a convergence model that minimizes transaction costs?

ICRISAT is now taking on these questions within its own operational model and focusing on partnerships that embrace diversity, engagement with allied sectors (IT, finance, energy, education, health) and orienting towards national priorities and working with a broad range of actors to develop national/state strategies, roadmaps to implementation and indicators and real-time monitoring systems to ensure we are accountable, agile and learn to respond to rapidly evolving needs of farmers and consumers as part of modern food systems. While still in the early stages of deployment, this approach of convergence lead by national/state governments has been well received and gaining momentum to ensure our science serves society in a more timely, targeted and tangible manner.

### **Science of delivery**

During breakfast conversations with Dr. Norman Borlaug during the author's time at CIMMYT, the topic of why technology was not enjoying higher rates of adoption by farmers came up. Dr. Borlaug often stated – 'it doesn't count unless it is in a farmer's field'. In his final words, Dr Borlaug challenged all of us to 'take it to the farmer'.

When we look at the process of designing, developing and delivering technology, we have been more inclusive of engaging farmers and value chain actors and yet we struggle to see technology adoption go beyond the pilot stage (1000s of farmers) to large scale implementation (millions of farmers). While we do see large-scale adoption of improved varieties in which knowledge is packaged into the genetic code of a seed and replicated, the same large-scale successes are not found in agronomy beyond the use of fertilizer applications and agrochemicals to protect plants and animals from pests and diseases. While single point interventions are focused and enjoy higher rates of adoption, the need for farmers to manage risks (production and market) is a holistic approach that takes into consideration input costs, labor, price volatility, water requirements, and increasingly energy associated with modern crop

production and processing practices.

ICRISAT refers to this gap between pilots and large scale adoption as the “death valley of development”. This gap is created in large part because all the actors feel that scaling is someone else’s job. In fact, it is the job of all of us in order to respond to the call of Dr. Borlaug of ‘taking it to the farmer’. Implementation of integrated solutions is complex, involving many actors, logistics and a framework for coordination so that people and institutions work in concert towards a shared goal. ICRISAT refers to this process as the Science of Delivery in which the stages of design, development and delivery of demand-driven solutions that give agency to farmers and incentives to all development actors are aligned and recognized that enables all actors to strategic contribute along the impact pathway. With the advent of Business Intelligence tools to support commercial enterprise, the same is now being applied to support agriculture development in the implementation of large, integrated programs.

### Upstream science for downstream applications

In addition to making a positive impact on farmers lives by delivery the best technologies, ICRISAT continues to undertake demand-driven high-quality science for developing the better technologies for ensuring continuous delivery in future. For instance, ICRISAT mandate crops have a high yield potential, their potential is not being realized in farmers’ fields. Amongst many issues, the two key issues are low genetic gains in breeding programs at ICRISAT and its NARS partners and second is the poor varietal replacement in farmers’ fields. In this context, ICRISAT is addressing these important issues by harnessing the potential of germplasm (>120,000 accessions) stored in its genebank with modern genomics and molecular biology tools. Until recently, the ICRISAT mandate crops were referred as ‘orphan crops’ due to unavailability of genomic tools. However, advances in genomics technologies and power of partnership have elevated these crops as ‘genomic resources rich crops’ in last five year or so. For instance, ICRISAT led consortia generated genome sequence assemblies for pigeonpea, chickpea, groundnut, pearl millet and finger millet. Genomics tools developed so are being used to characterize and mine germplasm collections and pre-breeding populations carrying superior alleles are being developed and used in breeding. In parallel, genomic tools coupled with breeding populations for abiotic and biotic stress tolerance are allowing identification of molecular markers and alleles associated with tolerance – the same is now true for market and nutritional traits. These markers are being used in forward breeding approaches for developing superior lines with a suite of traits of agronomic and commercial importance. The traits for which genetic variation is not available in germplasm, genetic engineering approaches are being ex-

plored such as CRISPER-Cas9 for genome editing. Once better varieties are developed and released by NARS partners, ICRISAT is working with public and private sectors partners to accelerate varietal replacement in farmers’ fields. In addition, ICRISAT is working closely with national breeding programs of NARS partners as together we integrate diagnostic markers, precision phenotyping and databases to accelerate genetic gains and trait integration.

Examples of the above approach include: (i) superior lines of chickpea with 12-24% higher yield, (ii) superior lines of chickpea with enhanced resistance to Fusarium wilt and Ascochyta blight, (iii) superior lines of groundnut with enhanced resistance to rust and with 56-96% higher yield, (iv) superior lines of groundnut with increased oleic acid in the range of 62-83%. Several molecular breeding lines have been transferred to the Indian Council of Agricultural Research (ICAR) for multi-location trials under the All India Coordinated Research Project (AICRP)-Chickpea and AICRP-Groundnut. Some of these lines are in advanced stages of testing for release, with the same approach being replicated in Ethiopia and Kenya. The first marker-assisted variety for ICRISAT in partnership with ICAR was an improved pearl millet hybrid called “HHB 67- Improved” that was released in 2006. It has resulted in significant benefits to the small holder farmers, and capacity building of the partners. HHB 67-Improved continues to be grown on more than 850,000 ha every season, and benefit the farmers of North and North-Western India from up to 30% losses from the downy mildew pathogen.

In brief, the high-quality upstream science is being used to develop the best varieties that will be used for large scale adoption as mentioned in “Science of Delivery” section.

### CONCLUSION

As 2016 draws to a close, we now have 14 short years to realize the SDGs – 28 cropping seasons most agriculture zones. This brings into share focus the need to act urgently and in a focused and coordinated manner to accelerate the design (with farmers), development, and delivery of agriculture innovations (with public and private sector partners) that will increase productivity to feed over 9.3 billion people by 2050. In the short term, we must urgently agree on the key performance indicators that will drive sustainable (social, economic, environmental) growth. Only by having shared goals and indicators to track our progress, create accountability and shared ownership will we be able to achieve the SDGs. The more granular we are in building out roadmaps to achieve these goals, the more likely we are to succeed – together.

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**Symposium 1**  
**Climate Smart Agronomy**





## Climate change and greenhouse gases mitigation from agriculture: Where are the big wins?

CLARE M. STIRLING<sup>1</sup>, TEK SAPKOTA<sup>2</sup> AND M.L. JAT<sup>2</sup>

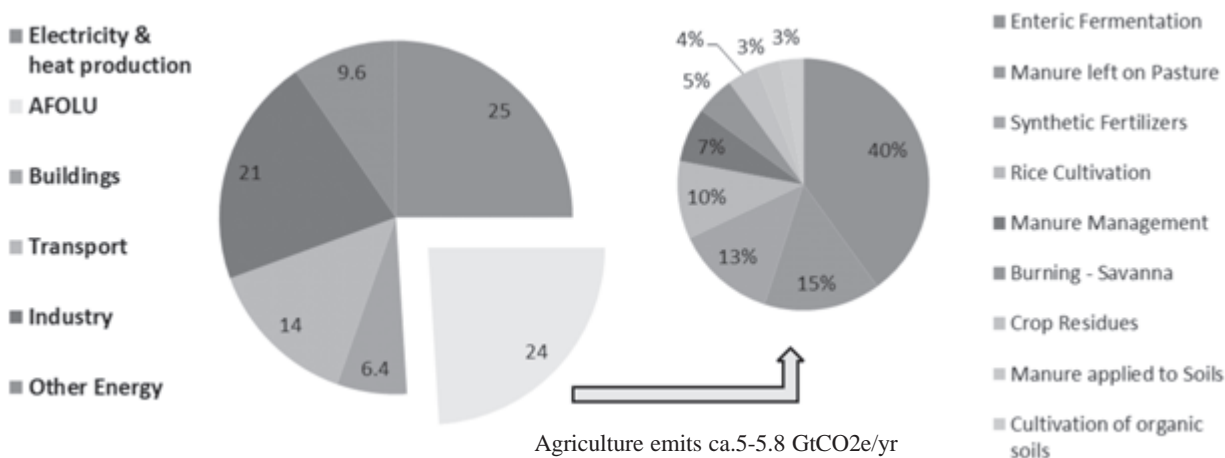
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The 20–30-year lag in the global climate system means that regardless of any measures that may be taken now or in the future to stabilise greenhouse gas emissions, we are already committed to a warmer world. Global temperature will be, on average, 0.6°C warmer by the end of the century and this will be accompanied by changes in rainfall patterns although the precise nature of this is presently difficult to predict. Whether much greater temperature increases are experienced largely depends on how countries respond now in terms of reducing their greenhouse gas (GHG) emissions. Based on current trajectories, the IPCC (2013) calculated that the CO<sub>2</sub> emissions threshold above which we risk being locked into a 2°C warmer world (above pre-industrial levels) will be reached within 30 years. In the absence of aggressive greenhouse gas (GHG) mitigation actions, the world is at risk of entering the realms of ‘dangerous’ climate change (Jaeger and Julia, 2011). GHG mitigation should be viewed as intrinsically linked to climate change adaptation strategies and not a separate and optional set of actions.

### Scale of emissions from agriculture globally

The Agriculture, Forestry and Other Land Use (AFOLU) sector emits just under a quarter (ca. 10–12 GtCO<sub>2</sub>eq yr<sup>-1</sup>) of all anthropogenic GHG emissions; the largest emissions are from deforestation followed by agricultural emissions from livestock, soil and nutrient management. Annual GHG emissions from agricultural production in 2000 – 2010 accounted for about 11% of total anthropogenic GHG emissions globally and between 5.0 to 5.8 GtCO<sub>2</sub>eq yr<sup>-1</sup> (Fig. 1; Smith *et al.*, 2014). However, due to the complexity of the natural systems that are the source of agricultural emissions, uncertainties in estimates remain particularly high compared with other sectors. Uncertainty in estimates of emissions from agriculture range between 10–150% compared with 10–15% from fossil fuels (IPCC, 2006). A summary of the various AFOLU sources are shown below.

Agriculture is the main source of global anthropogenic non-carbon dioxide (CO<sub>2</sub>) GHGs, accounting for 56% of emissions in 2005 (U. S. EPA, 2011) and emitting nearly 60%



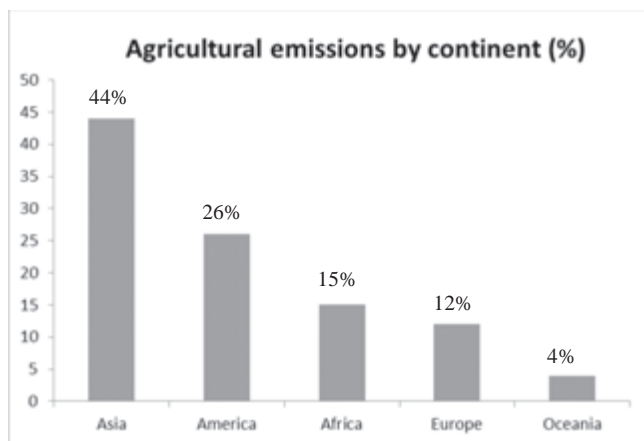
**Fig. 1.** Summary of direct global greenhouse gas emissions (%) from all major sectors during 2010 together with a more detailed breakdown of the share of emissions from different sources contributing to the agricultural emissions component of AFOLU. Adapted from IPCC WIII (2013) and FAO (2014).

of nitrous oxide (N<sub>2</sub>O) and nearly 50% of methane (CH<sub>4</sub>). Both N<sub>2</sub>O and CH<sub>4</sub> are powerful greenhouse gases with global warming potentials 310 and 21 times greater, respectively than CO<sub>2</sub> (IPCC, 2013). The main cause of agricultural N<sub>2</sub>O and CH<sub>4</sub> emissions are shown in Figure 1 with most N<sub>2</sub>O emissions from organic and synthetic fertiliser application to soils whilst the majority of CH<sub>4</sub> emissions are from enteric fermentation (40%) and rice cultivation.

In terms of continental contributions to global emissions from agriculture, the largest emissions are from Asia (44%) followed by America and then Africa which has overtaken Europe as the third largest emitter since 2000. Both Asia (2.3% yr<sup>-1</sup>) and Africa (2.0% yr<sup>-1</sup>) had the highest average annual emissions growth rates for the period.

### Country commitments of GHG mitigation in agriculture

By the end of 2015, the UN Framework Convention on Climate Change (UNFCCC) had received INDC (Intended



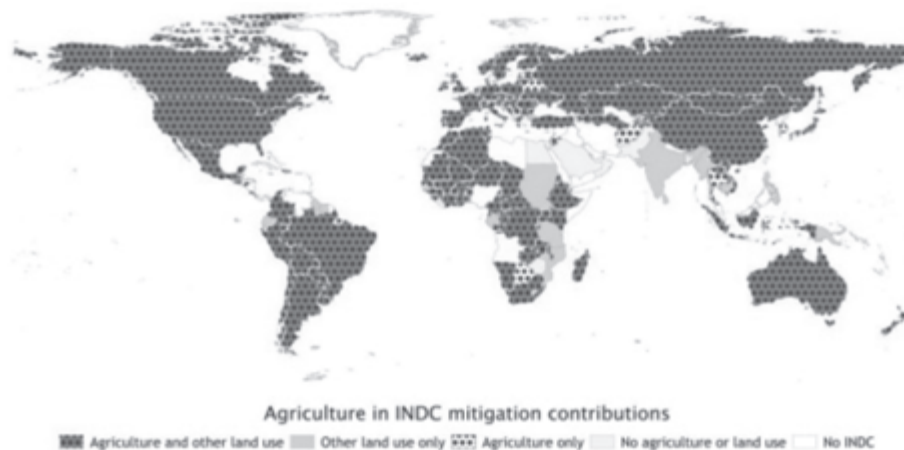
**Fig. 2.** Greenhouse gas emissions from agriculture (2001-2011) showing the percentage of global total by continent. Data from FAO (2014).

Nationally Determined Contributions) submissions from 160 Parties with over 60% of these having included agricultural as part of their mitigation targets (Feliciano *et al.*, 2015). This reflects the growing realisation that all sectors will have to play their part if emission targets are to be achieved.

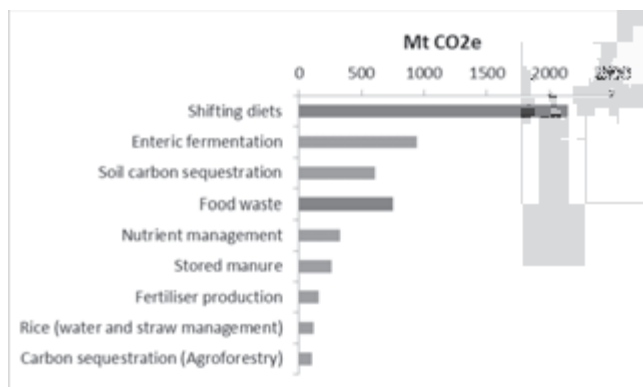
**Mitigation options in agriculture:** So where are the big wins as far as mitigation from agriculture is concerned? This varies with agro-ecology. Emissions can be reduced by both supply-side actions, for example by reducing GHG emissions intensities of animal and crop products or demand-side actions such as shifting away from largely meat-based diets and reducing food waste. The potential mitigation ‘wins’ from these different options was neatly summarised by Dickie *et al.* (2014) as shown in Fig. 4 below. It is clear that the biggest wins lie in reduced beef consumption and food waste followed by better nutrient management and production. Agriculture is a unique sector in that it not only emits GHGs but has the potential to lock up GHG emissions through carbon sequestration in standing biomass and soils. There is much uncertainty still regarding the extent to which certain practices such as zero tillage can contribute to soil carbon sequestration (Powlson *et al.*, 2014) or store carbon in above ground biomass although a recent paper suggests that existing tree cover, which has so far been overlooked in most global calculations, has the potential to make a major contribution to the carbon stock of agricultural lands (Zomer *et al.*, 2016).

### GHG emissions from agriculture – case study in India

India is the world’s fourth largest economy and fifth largest greenhouse gas (GHG) emitter, accounting for about 5% of global emissions with further increases expected in the future. Agriculture is the second largest source of GHG emission in India accounting for 18% gross national emissions according to 2008 estimate (INCCA, 2010). In view of the trends in population growth (<http://www.populstat.info/Asia/>



**Fig. 3.** Global map showing extent of INDC submissions that include agriculture in their mitigation contributions (Source: Richards *et al.*, 2015).



**Fig. 4.** Mitigation potential by 2030 (MT CO<sub>2</sub>e) for different supply-side (blue) and demand-side (green) categories. Adapted from Dickie *et al.* (2014).

indiac.htm) and dietary change (Fraiture *et al.*, 2007), absolute emissions from agriculture are likely to continue to increase unless interventions that deliver GHG abatement without loss of production are identified and adopted at scale.

Fig. 5 shows a map of spatial distribution of GHG emissions from the crop sub-sector in India indicating the locations, state wise, where the highest and lowest emissions occur. The highest emissions are associated with those regions where cropping systems are dominated by rice and wheat (Uttar Pradesh), rice (West Bengal), sugarcane and cotton



**Fig. 5.** Summary of greenhouse gas emissions from agricultural crops in India by state. Based on 2010 National Dataset.

(Maharashtra), rice and cotton (Andhra Pradesh). Mitigation options with these crops then naturally fall into those practices whereby methane emissions can be reduced through better water management and N<sub>2</sub>O emissions through more efficient use of N fertiliser. Examples of the scale of GHG savings achieved by such approaches will be discussed.

## CONCLUSION

This paper examines greenhouse gas emissions (GHG) from agriculture from a global point of view and identifies those areas where mitigation targets are a priority. Whilst big wins can be made from demand-side emissions savings such as changes in diet and reductions in food waste, the focus of this paper will be mainly on supply-side emissions. After summarising the most recent findings at the global level, a closer look will be taken of greenhouse gas emissions and mitigation options in agriculture in India and what the implications are for policy measures.

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## Cropping system modelling in South Asia: managing production risks under current and future climates

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Rice based cropping systems in both the Eastern Gangetic Plains and East India Plateau are influenced by year to year climate variability. Farmers in these regions seek to sustainably intensify their productivity and to manage production risks for current and future climates. Farming households' production goals (for example food security, cash profit, or a mix of these) differ according to their resources and appetite for risk (Williams *et al.*, 2016). Consequently different management strategies are appropriate for different groups of households.

Most rainfall in South Asia is received during the July to October wet season. The annual quantum varies in terms of onset, timing and duration (Hijioka *et al.*, 2014). Additional water for irrigation is generally economically and/or environmentally expensive (Ladha *et al.*, 2007). Under projections of likely future climates, both temperature and rainfall variability are forecast to increase. In the short term (to 2040) changes in rainfall patterns are likely to be of greater moment for current cropping systems than (relatively mild) increases in both maximum and minimum temperatures (Hochman *et al.*, 2016).

Agronomic field trials are a valuable tool which enable researchers and farmers to investigate and quantify different aspects of cropping system performance under different management options. Generally field trials are relatively short term (three to four years) or, in longer trials, take many (seven to ten and more) years to produce meaningful results. In either case, due to resource limitations only a subset of potential cropping system management options can be examined and climate is nearly always restricted to current conditions.

Cropping system models, such as APSIM (Holzworth *et al.*, 2014), DSSAT (Jones *et al.*, 2003), and InfoCrop (Aggarwal *et al.*, 2006) extend and complement traditional agronomic research by, for example: i) increasing the understanding of interactions within a cropping system by examining crop-crop interactions as well as soil-plant interactions, and the effects of water and nutrients within a system under different management strategies; ii) quantifying the risk and

variability, in terms of crop production or other metrics such as labour and inputs, of different management options; iii) providing a means to rapidly examine many potential management options and identify those most likely to be attractive to different groups of farming households; and, iv) examining how current management options are likely to perform under future climates, and identifying options to reduce farmers' exposure to risks associated with increasing climate variability and change.

Here we present three case study examples from current research which highlight how one cropping system model, APSIM, is being applied in South Asia.

### Research approach

APSIM, the Agricultural Production System Simulator, has been widely applied in South Asian cropping systems, with a high degree of confidence in simulation output (Gaydon *et al.*, 2016). The model is currently being used to model rice-based smallholder cropping systems as part of Australian government-funded agricultural research in the alluvial Eastern Gangetic Plains (Bihar and West Bengal in India, the eastern Terai in Nepal, and in northwest and southern Bangladesh) and in medium uplands in Jharkhand and western West Bengal. In general, farmers seek to reduce labour and yield variability while sustainably increasing overall cropping system productivity: the scenarios modelled reflect these aspirations.

In each research area APSIM is locally parameterised, calibrated and validated to ensure the model accurately and reliably captures local conditions. This is a non-trivial data-intensive process which requires detailed local information on crops, management, soil and climate; these data were acquired from local researchers and participating farmers. Validation activities are concluding in the projects' research areas: consequently we present here interim results of three case study simulations which illustrate how cropping system modelling enhances field trials and provides information on the variability and risk of different management options.

## Case study results

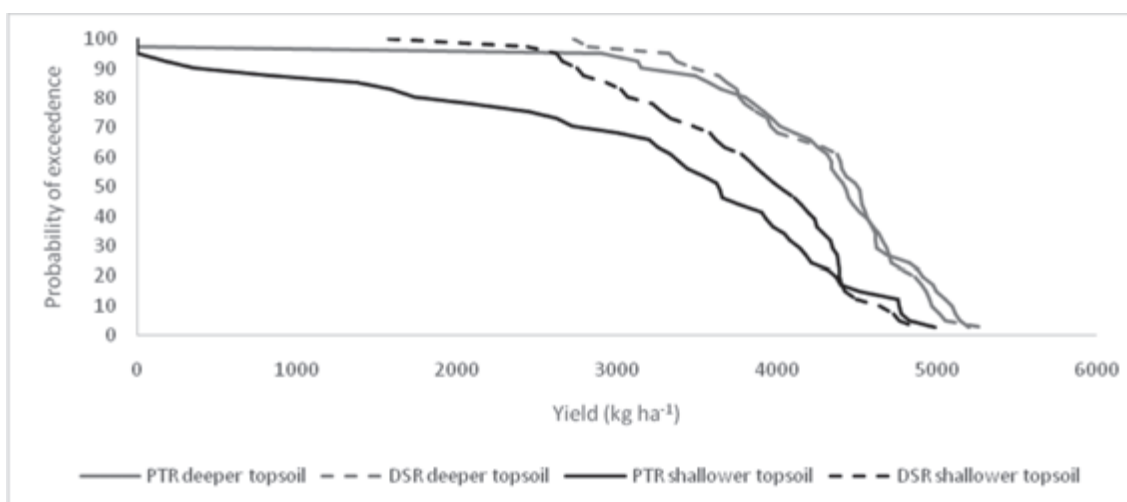
### 1. Mechanised rice establishment – East India Plateau

On the East India Plateau, including Jharkhand and western West Bengal, traditionally transplanted wet season rice (PTR) sown in middle topequences is at high risk of crop failure due to unreliable ponding (Cornish *et al.*, 2015a). Direct seeded rice (DSR) is established earlier in the wet season and requires less water than is necessary for transplanting to produce a comparable yield (Cornish *et al.*, 2015b).

APSIM modelling, using 40 years' recent historic climate data and two soil types (a deeper soil with a higher plant available water capacity (PAWC), and a shallower soil with a lower PAWC), shows that under traditional PTR crop failure (i.e. a yield of 0 t/ha) occurs in about five to 10 per cent of years (Figure 1). This failure is associated with very late monsoonal rains, leading to poor transplanting, late crop development and exposure to terminal heat stress. Yields on the shallower soil, with less plant available water are lower than those on the higher soil: under PTR average yields on the drier soil are 3.6 t/ha (range 0.0-5.0 t/ha) while on the wetter soil PTR yields average 4.4 t/ha (range 0.0-5.2 t/ha). Under DSR, the risk of crop failure reduces as (relatively) large amounts of water are

no longer required for transplanting, and a comparable crop can be produced with less water. Additionally, the crop can be established earlier in the season and runs less risk of terminal heat stress. On the shallower soil average yields (4.0 t/ha; range 1.6-4.9 t/ha) increase relative to PTR while on the deeper soil average yields (4.5 t/ha; range 2.7-5.3 t/ha) are comparable to those achieved under PTR.

Weed management under DSR is critically important and differs from traditional practice as standing water can no longer be relied on to suppress weeds. Many farmers prefer to manage weeds manually rather than increase input costs through fertiliser application. Even including the additional labour required for manual weed control, significantly less labour is necessary to produce a crop under DSR than under PTR (Table 1). On the deeper soil with good manual weed management, where comparable average yields are achieved under both establishment methods, the labour required to produce a crop under DSR is 52 person days per hectare; under PTR it is 73 person days per hectare. The associated gross margins are USD \$385/ha for DSR and USD \$252/ha for PTR. Where weeds are poorly managed additional labour is required under both establishment methods (though more labour is required under DSR) and both yields and gross margins are reduced.



**Fig. 1.** Probability of exceedence of rice yields (kg/ha) for PTR (solid lines) and DSR (dashed lines) on a deeper soil with higher PAWC (grey lines) and on a shallower soil with lower PAWC (black lines)

**Table 1.** Average labour requirements and gross margins for PTR and DSR on a soil with higher PAWC

Treatment	Average yield (t/ha)	Labour for establishment (person days/ha)	Labour for weed control (person days/ha)	Total labour <sup>1</sup> (person days/ha)	Gross margin (USD/ha)
PTR + good weed management	4.4	31	11	73	252
DSR + good weed management	4.5	8	16	52	385
PTR + poor weed management	2.2	31	11	66	69
DSR + poor weed management	2.3	8	32	68	173

<sup>1</sup>Includes additional labour required in all treatments for fertiliser application, at harvest and for post-harvest processing



## 2. Rice production under climate change – East India Plateau

Projections of medium term climate change suggest that, relative to a late 20<sup>th</sup> century historical baseline, rainfall in the period centred on 2030 (2021-2040) is likely to increase by around 20 per cent, while average maximum and minimum temperatures are likely to increase by around 0.8 and 1.5 °C respectively (Kokic *et al.*, 2011). These predictions have been applied to the PTR and DSR systems described in case study 1, above, and result in small average yield increases under both PTR and DSR (Figure 2). On the deeper soil with higher PAWC, average yields under PTR increase from 4.4 t/ha (range 0.0-5.2 t/ha) under an historical climate to 4.7 t/ha (range 0.0-5.5 t/ha) under a 2030 climate. Under DSR, yields increase from 4.5 t/ha (range 2.7-5.3 t/ha) in the historical climate to 4.9 t/ha (range 2.7-5.5 t/ha) in the 2030 climate. Under DSR risk of crop failure reduces in both the historical and future climates relative to PTR due to the reduction in water required to establish and sustain the crop, and the earlier finishing time. On the poorer soil with lower PAWC (data not shown), average yields under PTR decrease around 5 per cent (from 3.6 to 3.4 t/ha) under the 2030 climate as increased rainfall variability increases the chance of water stress at transplanting. Average yields under DSR under the 2030 climate increase by around 5 per cent (4.0 to 4.2 t/ha) which is comparable to results simulated on the higher PAWC soil under a 2030 climate.

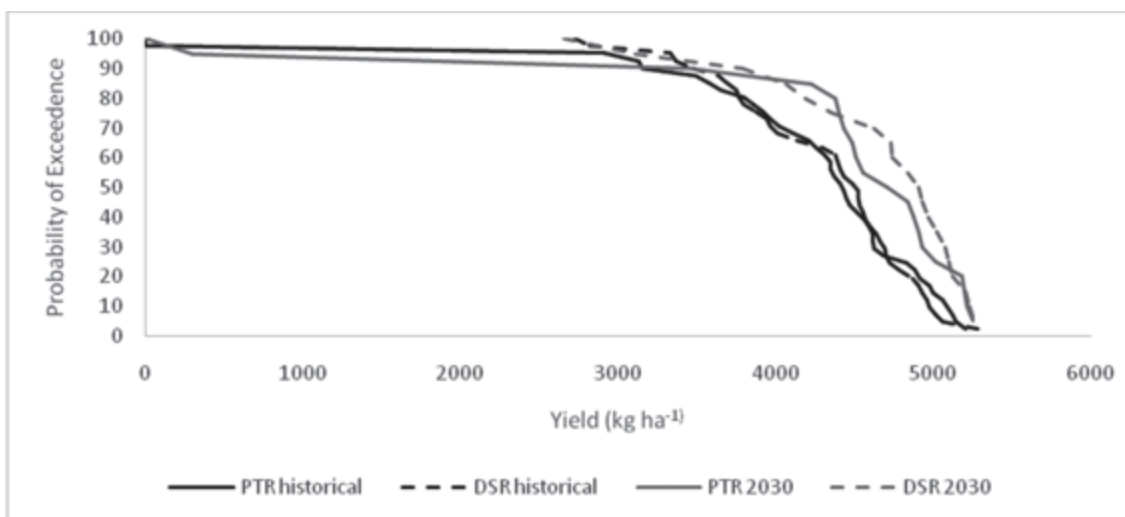
## 3. Cropping system options – Eastern Gangetic Plain

We have used APSIM to compare total system productivity (TSP, in terms of rice-equivalent yield (REY) per hectare) and water productivity (WP, in terms of REY per hectare per millimetre of water (both rainfall and irrigation) applied to

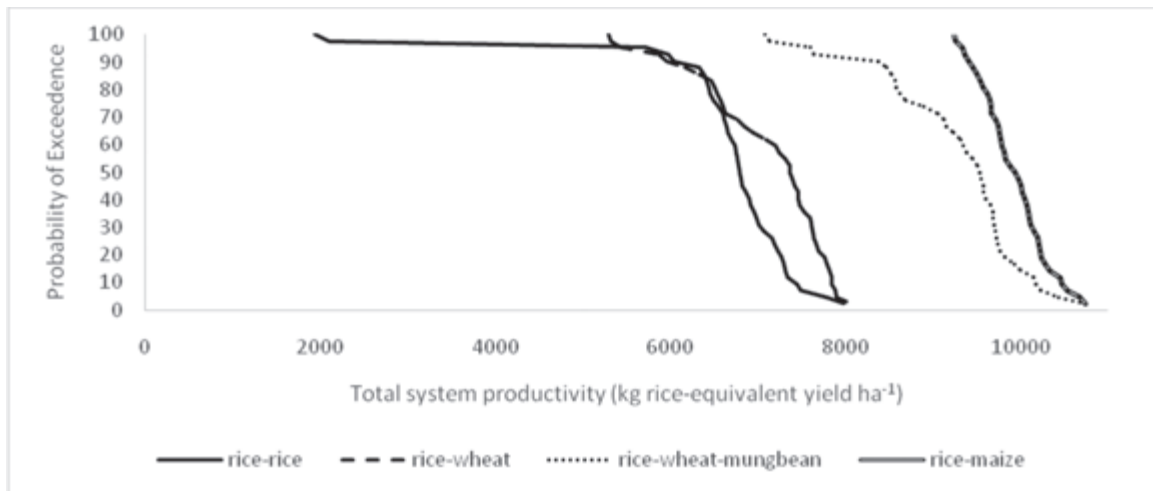
produce the crop) for common cropping systems in the EGP including rice-rice, rice-wheat, rice-maize, and rice-wheat-mungbean systems. The control (rice-rice) system with limited irrigation (i.e. historic farmer practice) is the least efficient system in terms of both TSP (average 6.7 t REY/ha, range 1.9-8.4 t REY/ha; Figure 3) and WP (average 2.2 t REY/ha, range 1.3-2.8 t REY/ha; Figure 4): as well it is riskiest with some boro crop failures reducing TSP. The rice-wheat and rice-wheat-mungbean systems have increasingly greater average TSP and reduced risk relative to the control. A rice-maize system is low risk and is the most productive in terms of both TSP (average 9.9 t REY/ha, range 9.2–10.9 t REY/ha) and WP (average 6.2 t REY/ha.mm, range 3.4–9.4 t REY/ha.mm) reflecting the efficiency of water use in maize.

## Ongoing research

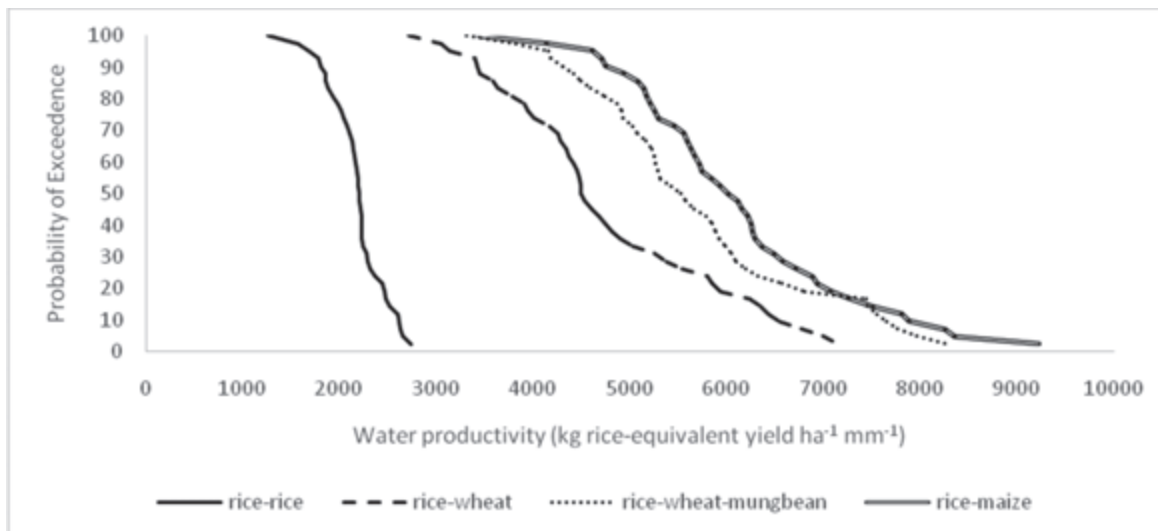
We continue to work with agronomists, farmers and research colleagues to extend cropping system simulations to enable us to examine in greater detail the effects of mechanisation and conservation agriculture practices (e.g. stubble retention, reduced/no tillage and crop diversity) on cropping systems in South Asia. We examine these systems in terms of production risk and variability as well as water and nutrient use efficiency and system economics, and under both current and future climates. Output from these research projects will inform the farming and farming-support (extension, NGO, researcher) communities, and will be used to underpin decision support tools for these stakeholders, recognising that different household groups have different risk profiles and agronomic aspirations. Additionally, our results will inform policymakers, e.g. through outscaling regional results to quantify the water demand of common cropping systems across catchments.



**Fig. 2.** Probability of exceedence of rice yields (kg/ha) on a deeper soil with higher PAWC for PTR (solid lines) and DSR (dashed lines) under a late 20<sup>th</sup> century historical climate (black lines) and under a 2030 climate (grey lines)



**Fig. 3.** Probability of exceedence of total system productivity (rice-equivalent yield per hectare) in rice-rice (solid line), rice-wheat (dashed line), rice-wheat-mungbean (dotted line), and rice-maize (double line) cropping systems



**Fig. 4.** Probability of exceedence of water productivity (rice-equivalent yield per hectare per millimetre of water applied) in rice-rice (solid line), rice-wheat (dashed line), rice-wheat-mungbean (dotted line), and rice-maize (double line) cropping systems

## CONCLUSION

Cropping system modelling extends and enhances traditional agronomic research in South Asia. Our results indicate that DSR is a feasible long term establishment alternative to PTR, attractive to many smallholder farming households for its potential to produce comparable or better yields on less water for lower labour inputs. Cropping system modelling has great value in comparing production metrics, such as TSP and WP, across different cropping systems and for different establishment, tillage and stubble management options. As well, the cropping system modelling brings additional value to agronomic research by quantifying the likely effects of future climate variability and change on current and alternative management practices. Cropping system modelling does not re-

place fundamental agronomic research, such as on-station and on-farm trials and farmer engagement. It enhances and extends this research and facilitates the sustainable and resilient intensification of smallholder farming systems.

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## Climate smart agriculture practices led business cases: Some examples

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Agriculture faces the enormous challenge of feeding the world's growing population. Although crop yields have grown impressively in the last few decades, production still requires an increase by another 60-70% by 2050 to meet the demand (Grist, 2015). Climate change poses additional challenges to agriculture, particularly in developing countries. Although the impacts of climate change on agricultural systems vary by region, most agriculture is rainfed and highly vulnerable to changes in temperature (especially extremes) and increased variability in precipitation. By 2100 global average temperature will get risen between 2.6 and 4.8°C, but some parts of the world, may experience temperature increases of up to 11°C. This, in turn, will alter precipitation patterns, including where, when and how much precipitation falls. Combined, these changes will increase the frequency and intensity of extreme weather events such as floods, heat waves, snowstorms and droughts. This may further lead to sea level rise and salinization. All of these changes will have profound impacts on agriculture (FAO, 2013). In general, the lower latitudes will experience lower crop and livestock productivity. Short term impacts are less well understood due to modelling uncertainties and inability to isolate direct causality, but evidence to date shows that extreme events are increasing in frequency and significantly damage food crops. Sub-Saharan Africa will face the most significant decreases in yields by 2100, according to the Met Office (2014). Wheat and maize yields will decline in the Indian subcontinent, while rice and soybean production are likely to increase (Met Office, 2014).

The relationship between agriculture and climate change is a two-way street: agriculture is not only affected by climate change but has a significant effect on it in return. Agriculture is a significant and increasing source (19-29%) of anthropogenic greenhouse gas (GHG) emissions, primarily through livestock gut fermentation processes, the use of manure and synthetic fertiliser, and wet rice cultivation in intensive and extensive agriculture (Campbell *et al.*, 2014). If no mitigation action is taken, agricultural emissions are expected to increase by another 30% in the next 35 years (Lipper *et al.*, 2014).

### Scaling climate smart agriculture through business development

Of the approaches developed to take account of climate change in agriculture, climate-smart agriculture (CSA) has rapidly taken precedence. CSA is defined by three objectives: firstly, increasing agricultural productivity to support increased incomes, food security and development; secondly, increasing adaptive capacity at multiple levels (from farm to nation); and thirdly, decreasing greenhouse gas emissions and increasing carbon sinks. The relative priority of each objective varies across locations, with for example greater emphasis on productivity and adaptive capacity in low-input smallholder farming systems in least developed countries.

One of the key challenges facing Climate Smart Agriculture (CSA) is scale. Good examples of CSA are emerging from pilot studies and some are starting to be scaled up to similar contexts. One overarching definition of scaling up CSA is that it is expected to bring more quality benefits to a larger population over a wider geographical area, in a quicker, more equitable, and lasting way (IRR, 2000, Franzel *et al.*, 2001). There are a variety of approaches to scaling up climate-smart agriculture practices and technologies, including: policy engagement, strategic partnership in innovation platforms, information and communication technologies, agro-advisory services, value chains and private sector involvement (Bayala *et al.*, 2016; Westermann *et al.*, 2015). In this paper we discuss our experiences with private sector integration to scale CSA technologies. Our findings are based on the work in the **Climate Change, Agriculture and Food Security (CCAFS)** project "Recommendation domains, incentives and institutions for equitable local adaptation planning at sub-national level and scaling up climate smart agricultural practices in wheat and maize systems" in India. Through business development, we link the needs of smallholder farmers in Haryana and Punjab and climate smart technologies with private sector interest as a novel way of scaling. Below, we discuss the business case for the Happy Seeder, a climate smart technology allowing farmers to sow wheat without any burn-

ing of rice residues, which is of use for wheat –rice farming systems. Participatory research involving farmers CIMMYT, the Borlaug Institute and other stakeholders, generated insights into technical issues as well as into costs and benefits of the technology. The positive results have boosted the emergence of service providers selling and leasing the technology to farmers in the area.

**Climate smart business model**

Business models describe how a firm, e.g. entrepreneurial farmer, farmer cooperative, service provider or any other type of SME, can generate revenue from a set of operations. A viable business model addresses a customer’s problem or need, creates revenue, mitigates risks and/or reduces costs. The core elements of a climate smart business model (Lundy *et al.*, 2012; Boons and Lüdeke-Freund 2013) includes the articulation of:

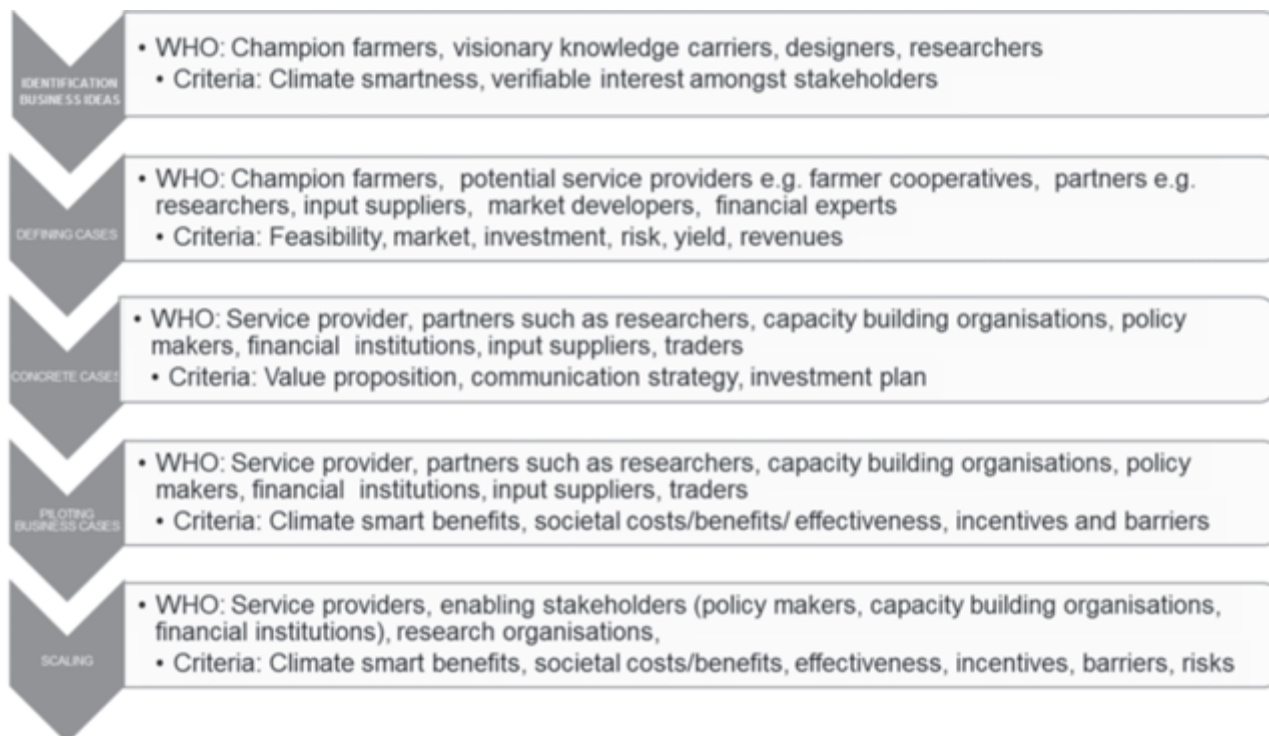
- Value proposition - how value is generated for the different customer’s segments, which one of the customers’ problems are being addressed;
- Customer segment - who the users or customers will be, what are their needs and interests;
- Revenue streams - how revenue is generated (e.g. by selling, leasing, prescription or member fees).
- Customer relationships - how the business engages with its customers;
- Channels – through which channels a product or service are delivered;

- Key activities - activities required to carry out the other business model functions;
- Key resources - the critical assets (human, financial, bio-physical) needed and how these assets will be generated;
- Key partners - those actors that are critical to delivery of the value proposition (e.g. research, input suppliers, financial institutes);
- Cost structure
- Societal costs and benefits (i.e. contribution to food security, resilience, reduction in GHG emissions and/or carbon sequestration)

The development of a climate smart business model follows a process involving 5 phases. It starts from identifying promising business ideas and via defining business cases it heads towards piloting and scaling of business cases. Each phase is informed by a set of criteria and involves discussions with specific stakeholders (Fig. 1).

**The Happy Seeder business model for the cooperative Noorpur Bet**

Noorpur Bet is a cooperative in Haryana, India. It started in 1957 as a merger of two smaller existing cooperatives. It represents 757 members, mostly labourers and farmers covering six villages. The activities of the cooperative entail running a petrol station, a small supermarket, a shop for agricultural inputs and the provision of machinery services and loans to farmers. The cooperative offers farmers multiple benefits including the ability to access loans with comparative low



**Fig. 1.** Phase in the development of a climate smart business model, examples of selection criteria and stakeholders involved

rates, access to input for a steady and reliable price and through the service provisions, farmers are able to access climate smart technology without the need to purchase the machinery themselves. Through field research it became apparent that important reasons for farmers to adopt new technologies are implementation by neighbouring farmers, and the returns.

In the last few years, CIMMYT, in close collaboration with farmers, the Borlaug Institute and other stakeholders, has conducted several field trials to further develop and optimize the use of Happy Seeder in maize –wheat systems. Due to the positive results of the technology, the cooperative Noorpur Bet decided to include the leasing of Happy Seeder to its members as well as to non- members in the service provision. Next, a business model has been developed to explore the financial viability of leasing the Happy Seeder and the scaling of the business model through cooperatives to other areas (Fig. 2). In 2015 and 2016, a literature review was carried out as well as a detailed household study (Sharma, 2015). In addition, to further develop the business case, six focus group discussions were conducted with the members of the cooperative Noorpur Bet, other farmers, Happy Seeder manufactur-

ers, input suppliers and researchers.

The value proposition in the model illustrates that farmers (cooperative members and non-members) are willing to pay for the service provided by the cooperative as the technology improves soil moisture content, decreases the risk of drought, reduces the need for inputs such as labour, fuel, irrigation water and fertiliser and, increases yield (Sidhu *et al.*, 2015). As such the technology positively contributes to the three objectives of climate smart agriculture i.e. food security, climate resilience and a reduction of GHG emissions.

The model shows that the Happy Seeder machine offers an interesting business model for the cooperative. The costs of Happy Seeder is 125,000 INR, the first year a subsidy of 50,000 INR is provided by the government. The economic lifespan of a Happy Seeder is about 10 years (depreciation). The time window of using the Happy Seeder before the wheat season is around 30 days. For the rice season this is approximately 10 days. For the use of the Happy Seeder farmers are charged 1200 Rupees per acre. Variable costs include tax & insurance (5%), storage costs (5%), the diesel (500 INR/acre), leading to the following equilibrium formula  $(125,000-50,000 + 12,500 + 6,250+6,250) + 500A = 1,200A$ . Following this

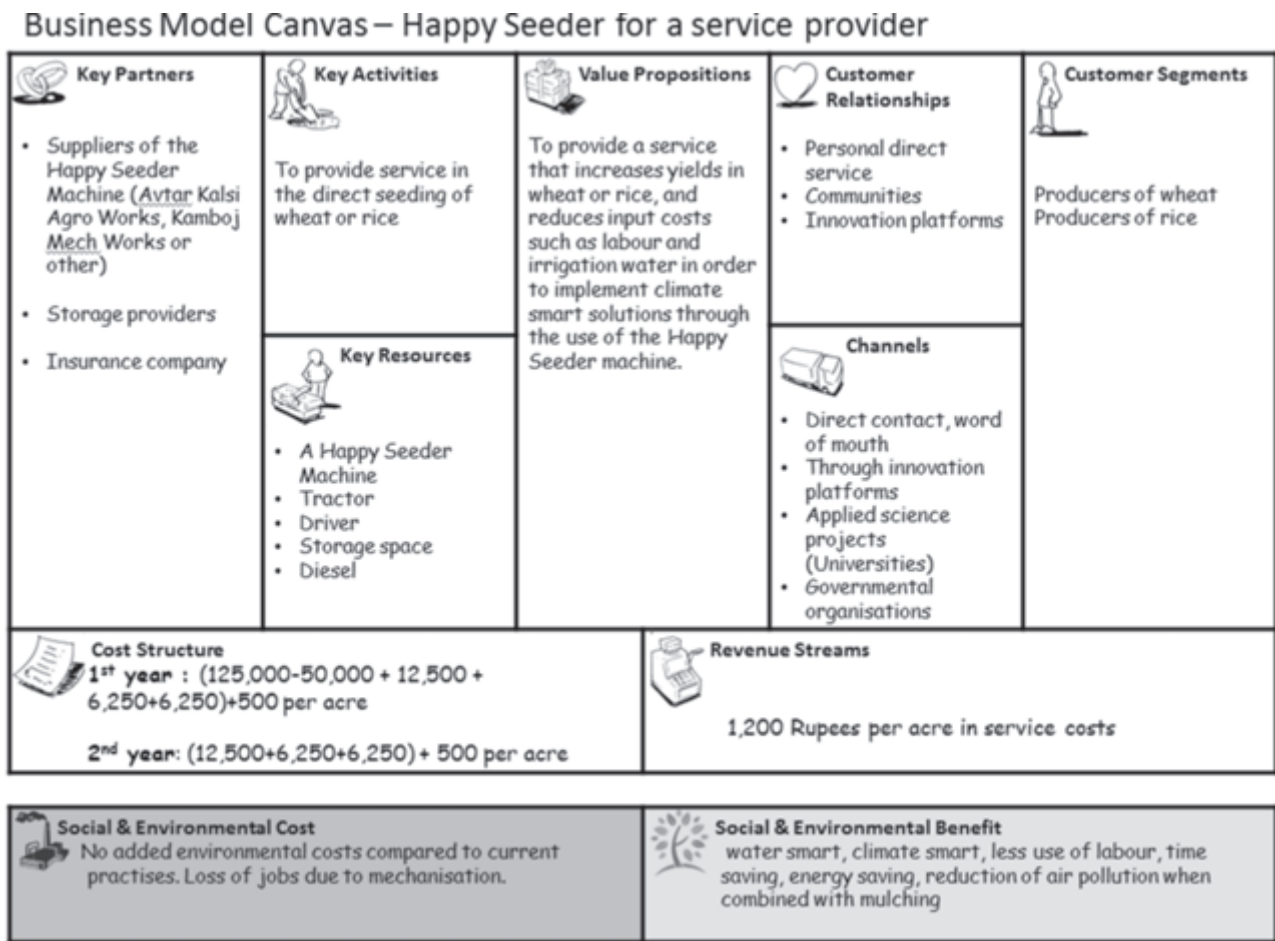


Fig. 2. Business model for the Happy Seeder in the case of cooperative Noorpur Bet

formula we can deduct an equilibrium acreage of 142.86. For the cooperative, the Happy Seeder will have to work on 143 acres in order to break even, and continue its work after the economic lifespan of the machine. The Happy Seeder can be utilised for approximately 5.5 acres per day, resulting in a break even period of  $143/5.5 = 26$  days. As the year consists of 40 workable days, the cooperative will be able to earn back the investment within one year provided that they are granted with a subsidy. Without government subsidy, the return on investment will be two years.

Although the leasing of a Happy Seeder also offers interesting business opportunities for an individual service provider, the benefit of implementing the business model through a cooperative rather than through an individual is that it is easier to combine the technology with loans for investments. The effect on the uptake by other farmers is faster and larger in the case the model is implemented through a cooperative.

Regarding the scalability of the Happy Seeder business model towards other regions we can put forward the following considerations:

- There is need for a detailed market assessment to draw conclusions on the scalability of the model towards other cooperatives in Haryana, other Indian states and countries where maize –wheat farming systems prevail. The example of Noorpur Bet shows that per Happy Seeder there is need for at least 143 acres to make the leasing of the technology a financially viable business activity;
- Partners such as CIMMYT and the Borlaug Institute for South Asia (BISA) have played an essential role in demonstrating the use and effect of the Happy Seeder on yield and input requirements to farmers. As such their contribution is of high importance for the success of the business model. Scaling the Happy Seeder business model towards other cooperatives and areas without partners fulfilling these tasks will adversely influence the uptake of the technology;
- The long term sustainability of the business model is influenced by the government's subsidy policy. It very likely that the subsidy on the Happy Seeder has supported the adoption of technology in the early stage of its development. In the long term, however, such subsidy can create a dependency syndrome on public support. This can be disruptive for market mechanisms.

## CONCLUSION

The support of appropriate and effective business models is noted as a promising strategy for enhancing large scale uptake and private investment in climate smart technologies (Long *et al.*, 2016; Westermann *et al.*, 2015), but some key considerations are relevant:

- There is a long tradition with smallholder agri-business development as a key approach to scale up sustainable rural development initiatives. The scaling of climate smart agriculture should build upon these existing expe-

riences. Simultaneously it increases value by its goal of achieving adoption at scale for context specific CSA practices and technologies, whilst engaging with multiple stakeholders to understand the impact of climate change on their livelihood and to develop adequate responses;

- As scaling of climate smart agriculture is relatively new, learning about success factors and barriers is critical to overcome some of the constraints to scaling up. Experiments with business models as mechanism for scaling climate smart agriculture should incorporate monitoring and evaluation to identify the specific requirements regarding information, finance and guidance;
- For scaling climate smart agriculture, the use of existing aggregators such as farmer cooperatives is promising. Cooperatives can bring together multiple farmers within a geographical area, make better use of economy of scale, have more bargaining power than individual farmers, and lower transaction costs for production factors such as capital;
- The provision of government subsidies can be legitimate to foster technology uptake in an early stage of the development process. However, subsidized technologies such as the Happy Seeder or subsidies on energy can create a dependency syndrome on public support and threaten the long-term sustainability of a business. This can be disruptive for market mechanisms. Creating an enabling environment for private sector investment includes supporting farmers and small- to medium enterprises to mobilize their own resources to invest in climate smart agribusiness.

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## Climatic vulnerabilities in Indian agriculture: Adaptation and mitigation strategies

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Climate change is reality. It is considered as biggest environmental threat in human history and the defining human challenges in twenty first century. Consequences of climate change are already felt throughout the earth system. The real injustice of climate change is that those who have contributed least to its causes are suffering most from the effect. Vulnerability to climate change is the degree to which geophysical, biological and socio-economic systems are susceptible to and unable to cope with adverse impacts of climate change. Vulnerability assessment is the analysis of the expected impacts, risks and the adaptive capacity of a region or a sector to the effects of climate change. This assessment encompasses more than simple measurement of the potential harms caused by events resulting from climate change. It includes an assessment of the regions or sectors ability to adapt.

There are several types of climatic vulnerabilities that adversely affect the Indian agriculture; the most important of these are drought, flood, cyclone, heat wave, hailstorms and extreme weather events.

### General trend of climate change

The changes in climate parameters are being felt globally in the form of changes in temperature and rainfall pattern. The global atmospheric concentration of carbon dioxide, a greenhouse gas (GHG) largely responsible for global warming, has increased from a pre-industrial value of about 280 ppm to 387 ppm in 2010. Similarly, the global atmospheric concentration of methane and nitrous oxides, other important GHGs, has also increased considerably resulting in the warming of the climate system by 0.74°C between 1906 and 2005 (IPCC, 2007). Of the last 12 years (1995–2006), 11 years have been recorded as the warmest in the instrumental record of global surface temperature (since 1850). The global average sea level rose at an average rate of 1.8 mm per year over 1961 to 2003. This rate was faster over 1993 to 2003, about 3.1 mm per year (IPCC, 2007). There is also a global trend of an increased frequency of droughts as well as heavy precipitation events over many regions. Cold days, cold nights and frost events have become less frequent, while hot days, hot nights and heat waves have become more frequent. It is also likely

that future tropical cyclones will become more intense with larger peak wind speeds and heavier precipitation. The IPCC (2007) projected that temperature increase by the end of this century is expected to be in the range 1.8 to 4.0°C. For the Indian region (South Asia), the IPCC projected 0.5 to 1.2°C rise in temperature by 2020, 0.88 to 3.16°C by 2050 and 1.56 to 5.44°C by 2080, depending on the future development scenario (IPCC 2007). Overall, the temperature rise is likely to be much higher during the winter (*Rabi*) rather than in the rainy season (*Kharif*). These environmental changes are likely to increase the pressure on Indian agriculture, in addition to the on-going stresses of yield stagnation, land-use, competition for land, water and other resources and globalisation. It is estimated that by 2020, food grain requirement would be almost 30-50% more than the current demand. This will have to be produced from the same or even the shrinking land resource due to increasing competition for land and other resources by the non-agricultural sector.

### Impacts of climate change on agriculture

Global climatic changes can affect agriculture through their direct and indirect effects on the crops, soils, livestock and pests. An increase in atmospheric carbon dioxide level will have a fertilization effect on crops with C3 photosynthetic pathway and thus will promote their growth and productivity. The increase in temperature, depending upon the current ambient temperature, can reduce crop duration, increase crop respiration rates, alter photosynthate partitioning to economic products, affect the survival and distribution of pest populations, hasten nutrient mineralization in soils, decrease fertilizer-use efficiencies, and increase evapo-transpiration rate. Indirectly, there may be considerable effects on land use due to snow melt, availability of irrigation water, frequency and intensity of inter- and intra-seasonal droughts and floods, soil organic matter transformations, soil erosion, changes in pest profiles, decline in arable areas due to submergence of coastal lands, and availability of energy. Equally important determinants of food supply are socio-economic environment, including government policies, capital availability, prices and returns, infrastructure, land reforms, and inter and intra-national

trade that might be affected by the climatic change.

### Adaptation and mitigation strategies

Adaptation involves adjustments to decrease the vulnerability of rice production to climate changes, while mitigation focuses on reducing the emission of greenhouse gases from rice production. There are a range of technological options that are presently available or which can potentially be developed in the near future for enhancing the rice production systems' ability to adapt to and mitigate the effects of global climate changes.

#### Adaptation strategies

**Rain water harvesting:** Rain water is the important source of water for agriculture. Rainfed agriculture accounts more than 60% of Indian agriculture. In the present scenario of climate change the number of intermittent dry spell and intense rainy days has increased considerably without much change in rainfall quantity. Thus, due attention has to be paid for in-situ and ex-situ conservation of rain water to address the rainfall variability. Summer ploughing is one of the important in-situ conservation practices and water harvesting structure is one of the important ex-situ conservation practices. Farm pond is one of the low cost water harvesting structures in up and medium lands in farmer's field itself for collection and storage of rain water during the peak period of runoff and judicious utilization of stored water during the dry spell. Lining the farm pond with 8 cm thick plaster of 6:1 soil: cement mixture can increase the period of storage which can take care of the kharif crop during the intermittent dry spell and also can increase the possibility of growing short duration high value crops in rice fallows.

**Adjusting cropping season:** Adjustment of planting dates to minimize the effect of temperature increase induced spikelet sterility can be used to reduce yield instability, by avoiding having the flowering period to coincide with the hottest period. Adaptation measures to reduce the negative effects of increased climatic variability as normally experienced in arid and semi-arid tropics may include changing of the cropping calendar to take advantage of the wet period and to avoid extreme weather events (e.g., typhoons and storms) during the growing season. Cropping systems may have 14 Climate Change Impact, Adaptation and Mitigation in Agriculture to be changed to include growing of suitable cultivars (to counteract compression of crop development), increasing crop intensities (i.e., the number of successive crop produced per unit area per year) or planting different types of crops. Farmers will have to adapt to changing hydrological regimes by changing crops.

**Crop diversification:** It is one of the best adaptation strategies to climatic vulnerability. In the process of diversification either the variety or if needed the crop is substituted with high value remunerative crops to fit to the present situation. Rice being the dominant crop and staple food of the nation, devel-

opment of rice varieties that have not only high-yielding potential, but also a good degree of tolerance to high temperature, salinity, drought and flood, would be very helpful under the environment of global warming. Efforts to increase the trehalose biosynthesis in rice by introducing *ots A* and *ots B* genes from *Escherichia coli* have resulted in transgenic rice with a higher level of tolerance to drought and salinity (Garg *et al.*, 2002). Similarly, FR13A (one of the submergence tolerant donors) has been used to develop improved rice cultivars with submergence tolerance. Wherever it is thought that rice crop is profitable any alternative low water requiring remunerative crops like maize, groundnut, greengram, blackgram, arhar, vegetables etc can be fitted into the system.

**Efficient water use:** Climate change is going to require a re-examination of current approaches in water management. Sustainable water management in agriculture aims to match water availability and water needs in quantity and quality, in space and time at reasonable cost and with acceptable environmental impact. There is an urgent need to switch over from the surface flooding method of irrigation to other controlled surface methods like furrow, boarder strip and check basin and whosoever practicing controlled surface methods to pressurized irrigation like sprinkler and drip method to increase the water use efficiency and addressing the climate change related issues. Besides nursery raising puddling is a typical pre-planting management practice which needs huge quantity of water in conventional puddled transplanted rice. In recent years, there has been a shift from TPR to other alternative method of rice establishment like DSR, SRI and Aerobic rice in several countries of Southeast Asia. This shift was principally driven by water scarcity issues, climate change related problems and expensive labour component for transplanting under acute farm labour shortage. These alternative methods of rice cultivation are considered as the water saving methods which save water to the tune of 25-50 % as it eliminates rising of seedlings in a nursery, puddling, transplanting under puddled soil and maintaining 4-5 inches of water at the base of the transplanted seedlings. The yield levels are comparable with the transplanted rice or even surpasses in many cases.

**Efficient energy use:** Under aberrant weather conditions the operational window available for different agricultural operations has decreased to a greater extent with increased uncertainty which not only declined the crop coverage but also affected the crop productivity adversely. The functionality of environmentally friendly agricultural management practices is highly dependent on suitable mechanisation technologies. Agricultural mechanization removes the drudgery associated with agricultural labour, overcomes time and labour bottlenecks to perform tasks within optimum time windows and can influence the environmental footprint of agriculture leading to sustainable outcomes. On the other hand, inappropriate mechanisation can place pressure on fragile natural resources by increasing soil erosion and compaction, promoting overuse of chemical inputs and encouraging farmers to open

lands that currently serve as valuable forest and rangelands.

**Sustainability:** Degradation of soil fertility due to many drivers is a serious constraint for sustainable agriculture. Top soil erosion is the most detrimental form of soil degradation and likely to be aggravated by long term removal of crop residues and the increased number of intense rainy days during the wet season. Conservation tillage, integrated nutrient management, cover crop, crop rotation and rotational grazing are the important practices in farm soils whereas agroforestry or tree plantations are the important measures to increase carbon stock in soil through the process of carbon sequestration. The new paradigm of “sustainable production intensification” recognizes the need for productive and remunerative agriculture that conserves and enhances the natural resource base and environment, and which positively contributes to the delivery of environmental services. Sustainable crop production intensification must not only reduce the impact of climate change on crop production but must also mitigate the factors that cause climate change by reducing emissions and by contributing to carbon sequestration in soils. Intensification should also enhance biodiversity in crop production systems both above and below the ground in order to improve ecosystem services for better productivity and a healthier environment. This concept is very well described in the recent FAO publication titled “Save and Grow,”<sup>1</sup> which explains how agricultural practices in the future could still result in increased production while conserving the natural resource base.

**Better Weather Forecasting and Crop Insurance Schemes:** Weather forecasting and early warning systems will be very useful in minimizing risks of climatic adversaries. Information and communication technologies (ICT) could greatly help the researchers and administrators in developing contingency plans. Effective crop insurance schemes should be evolved to help the farmers in reducing the risk of crop failure due to these events. Both formal and informal, as well as private and public, insurance programs need to be put in place to help reduce income losses as a result of climate-related impacts. However, information is needed to frame out policies that encourage effective insurance opportunities. The recently launched Pradhan MantriFasalBimaYojana (PMFBY) is a new initiative in crop insurance sector which addresses all loaned and non loaned farmers and also the tenant farmers who are having written agreement of tenancy with the owner.

## Mitigation strategies

**Rice establishment methods:** Flooded rice culture with puddling and transplanting is considered one of the major sources of methane (CH<sub>4</sub>) emissions and accounts for 10-20% (50-100 Tg/year) of total global annual CH<sub>4</sub> emissions (Reiner and Milkha, 2000). Due to individual or combined effects of various factors as soil characteristics, climatic conditions, and management such as soil pH, redox potential, soil texture, soil salinity, temperature, rainfall, and water management, amount of CH<sub>4</sub> emission varies between different crop establishment techniques. Methane emission starts at redox potential of soil below -150 mV and is stimulated at less than -200 mV (Masscheleyn *et al.*, 1993). Direct seeding has the potential to decrease CH<sub>4</sub> emissions. Methane emitted from paddy soils can be controlled by various management practices such as reducing the number of irrigations, multiple drainage system during the crop cycle, alternate wetting and drying, *Azolla* application, semi-dry cultivation, arbuscular mycorrhiza and methanotrophs application (Zhao *et al.*, 2006). Most reports claim lower emission of methane gas under DSR compared to other traditional practices (Table 1). Studies comparing CH<sub>4</sub> emissions from different tillage and crop establishment methods (CEM) under similar water management (continuous flooding/mid-season drainage/intermittent irrigation) in rice revealed that CH<sub>4</sub> emissions were lower in DSR than with CT-TPR (Tyagi *et al.*, 2010). In Wet-DSR, the reduction in CH<sub>4</sub> emission increased from 16 to 22% under continuous flooding to 82 to 92% under mid-season drainage or intermittent irrigation as compared with CT-TPR under continuous flooding (Corton *et al.*, 2000).

CH<sub>4</sub> emission and global warming potential were highest under conventional transplanted rice and emission of N<sub>2</sub>O was highest under direct-seeded rice crop with conservation practice of brown manuring because the addition of organic matter to soil increased the decomposition rate, which resulted in higher emission of GHGs. These results suggest the need to deploy strategies to reduce N<sub>2</sub>O emissions from direct-seeded rice for minimizing adverse impacts on the environment. This tradeoff between CH<sub>4</sub> and N<sub>2</sub>O emission is a major hurdle in reducing global warming risks and therefore, strategies must be devised to reduce emissions of both CH<sub>4</sub> and N<sub>2</sub>O simultaneously. There is a need to developing water management practices in such a way that soil redox potential can be kept at

**Table 1.** Comparison of methane gas emission (kg CH<sub>4</sub>/ha) under DSR and TPR

Sl. No.	Location, Country (Year of study)	TPR	DSR	% Change from TPR	References
1	Pantnagar, India(2004)	315	220 (dry)	-30	Singh <i>et al.</i> , 2009
2	Modipuram, India(2000 – 2005)	60	25 (dry)	-58	Pathak <i>et al.</i> , 2009
3	South Korea (1998-2000)	414	371 (wet) 269 (dry)	-10 -35	Ko and Kang, 2000
4	Suiman, Japan(1994 – 1997)	271	129	-52	Ishibashi <i>et al.</i> , 2007
5	Maligaya, Phillipines(1997)	89	75	-16	Corton <i>et al.</i> , 2000

an intermediate range (-100 to +200 mV) to minimize emissions of both CH<sub>4</sub> and N<sub>2</sub>O (Hou *et al.*, 2000).

System intensification of rice is another approach which can reduce 30-60% methane emission with judicious utilization of water. Although aerobic rice may reduce CH<sub>4</sub> emissions from rice fields, it may result into increased N<sub>2</sub>O emissions. The N<sub>2</sub>O is having 310 times global warming potential than CO<sub>2</sub>. The trick is to find a way to maximize the benefit of positive aspects and minimize the environmentally negative effects. These authors also suggested that N<sub>2</sub>O emissions can be mitigated using an appropriate combination of irrigation timing and N application.

*Midseason drainage:* In common practice, water is drained out of the field during vegetative period. Shifting drainage time from vegetative period to reproductive period can reduce methane production and emission. Shorten drainage day also help reduce nitrous oxide emission. The effect of midseason drainage are in controlling nitrogen absorption, keeping oxidative soil condition, increasing productivity and quality of rice and decreasing methane emissions. Wassmann *et al.*, (2009) reported that midseason drainage and intermittent irrigation reduce methane emission by over 40%.

*Fertilizer management:* The four management factor that help to reduce N<sub>2</sub>O emissions from applied N fertilizers are commonly known as 4Rs as Application of nitrogen at right quantity from right source at right time and right placement. In Egypt, studies indicate that by switching the N-fertilizer from urea to ammonium sulfate (NH<sub>4</sub>)<sub>2</sub>SO<sub>4</sub>, a substantial reduction in methane emissions can be achieved, up to 55% (EEAA, 1999). Inhibitory effect of sulfate in CH<sub>4</sub> formation causes 10–67% reduction in methane emission when ammonium sulfate is used instead of urea (Wassmann *et al.*, 2000).

*Crop management (short duration varieties):* Generally, methane emissions are proportional to the number of days the crop is flooded. By switching from long duration varieties to short duration varieties of rice cultivars, the number of flooded days will decrease. Normally, the paddy soil should be dry for a month before harvesting, which equals one fourth of the growing season of the short duration varieties. Thus, by converting to short duration varieties like Sakha 102, methane emissions will be decreased by about 25% (EEAA, 1999).

*Carbon Sequestration:* Cultivated lands have the potential to contribute significantly to climate change mitigation by improved cropping practices and greater number of trees on farms. The global estimated potential of all GHG sequestration in agriculture ranges from 1500 to 4300 ml CO<sub>2</sub> e/yr. with about 70% from developing countries, 90% of this lies in soil carbon restoration and avoided net soil carbon emission.

## CONCLUSION

Development of submergence tolerance, heat and drought tolerant and pest resistant varieties of major crops, identification of production systems which are most resistant to climate change rather than trying to manage a particular climate re-

gime, including development of new agronomic practices and water management system, rain water harvesting, soil conservation measures and suitable cropping patterns for maximum in-situ retention of rain water; developing decision support system, combining databases (crop, soil and climate) and modern information tools (simulation models, remotely sensed information, geographic information system) to establish drought/ flood alerts, monitor the vegetation conditions, develop crop yield forecasts, identify best agronomic practices and to define land use suitability classes; afforestation in the hills of Asom and neighbouring states to stop siltation of Brahmaputra and its tributaries; reduce sedimentation in the upstream catchment areas of river Brahmaputra; and desiltation of river beds to reduce structural and functional damage to river banks for reduction of flood risks are some of the adaptation measures to be taken up in a war –forting to minimize the ill effects of climate variability or climate change.

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## Resilient agronomic management: options and learning's through NICRA experiences

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Evidences over the recent past have conclusively established the climate change a reality. Accelerated and indiscriminate anthropogenic activities especially industrialization and destruction of natural environment raised the concentration of greenhouse gases (GHG) in the atmosphere that lead to global warming. It has been projected that by 2100 the earth's mean temperature will rise by 1.4 to 5.8°C, while precipitation will decrease in the sub-tropical areas and the frequency of the extreme events will increase significantly (IPCC, 2007). Although, the impacts of climate change are global, but countries like India are more vulnerable in view of the dependence of high population on agriculture.

Climate being central to agriculture production; any significant shift in climate variables may challenge the traditional production cycle. In Haryana, above normal night temperature by 3°C during February-March 2004 resulted into declined productivity of wheat from 4106 to 3937 kg/ha (Ranuzzi and Srivastava, 2012). In general, climate change may affect the agricultural production system by intensifying abiotic and biotic stresses which influences germination, growth, reproduction, pollination, fertilization and maturity processes of crops besides crop durations and incidence of diseases and pests, enhanced photosynthesis and water use efficiency, limiting water availability for irrigation, and enhancing frequency of extreme weather events (Sikka *et al.*, 2016). The impact of changing climate and its variability are already being experienced in many crops and regions of the country. This changing climate scenario requires a paradigm shift in farming approach to minimise risk, enhance resilience and maximise yields. This calls for identifying vulnerabilities of farming to weather aberrations, identification of location specific climate resilient agriculture (CRA) practices, aggressive dissemination technologies, and capacity building for faster and higher adoption of CRA technologies.

### Vulnerability of Indian agriculture to changing climate

The climate change has become major concern for India to ensure food and nutritional security of growing population. It may cause most impending disasters to Indian agriculture due to its variable striking capacity. A gradual shift in climate variables viz. rainfall and temperatures may lead to creeping di-

saster, while increased extreme events viz. floods, hailstorm, cyclones, heat waves, frost etc. are resulting into impulsive disaster to farming. The losses due to impulsive disasters are difficult to quantify in advance since they are highly heterogeneous and location specific. However, creeping impacts of climate change could be modelled and predicted.

The Government of India through the Indian Council of Agricultural Research (ICAR) initiated a National Network Project on Climate Change (2004-13) to assess the impact of medium term (2010-2039) changing climate on Indian agriculture especially crops. The study indicated average reduction in productivity by 4-6% in rice, 6% in wheat, 18% in maize, 2.5% in sorghum, 2% in mustard and 2.5% in potato besides significant regional variability (Naresh Kumar *et al.*, 2012). The crop yields are projected to be more vulnerable in Central and East India for wheat; Punjab, Haryana and Rajasthan for irrigated rice; Maharashtra, Odisha, Chhattisgarh and Assam for rainfed rice; Central India for mustard; and Punjab, Bihar, Jharkhand, Uttar Pradesh and West Bengal for potato. In total, agriculture makes up roughly 16% of India's GDP, an averaged 4.5-9.0% negative impacts on production implies a cost of climate change to be up to 1.5% of annual GDP. However, the study demonstrated that appropriate climate resilient interventions could greatly negate the impact of climate change.

### Resilience of Indian agriculture

Presently, the Indian agriculture is at cross-road; the hypotheses of green revolution are no longer valid. Of late, these technologies have started showing fatigue and widening risk to climate variability. This gives way for the adoption of climate resilient agriculture. In other words, green revolution technologies must be mutated into CRA practices to become relevant under changing climate scenario. CRA is not a new concept, but are sustainable technologies gradually disowned in favour of yield maximising green revolution technologies. However, changing climate brought CRA back to central place more as a necessity rather than an option. Technically, CRA means embodying adaptation, mitigation and other agricultural practices that enhance the capacity of the agro-ecosystem to relieve, resist, respond and recover from climate

related disturbances. The CRA options available to Indian farmers could primarily be either adaptive or mitigating. The options that make farming adjusted to future climate are adaptive measures, while efforts that moderate variables contributing to climate change are mitigating measures. Some of the adaptation and mitigation options with emphasis on agronomic practices are briefly discussed here.

### Adaptation options to climate change

Adaptation refers to 'adjustments in ecological-social-economic systems in response to actual or expected climatic stimuli, their effects or impacts' (Smit *et al.*, 2000). In other words, it represents adjustment in some practices directly reducing vulnerability of agriculture to climate change. The adaptation options include (1) technological developments, (2) Government programs and insurance products, (3) farm production practices, and (4) farm financial management (Smit and Skinner, 2002). These options are not mutually exclusive, and their typology depends on the scale and the level of involvement. The first two categories require efforts at macro-scale by public and agri-business agencies, while later two involve farm-level decision-making by producers. However, all adaptation efforts are often interdependent but supplementary to each other.

**Technological developments:** Adaptation technologies are primarily developed through research programs of public and/or private sectors, and often targets on development of tolerant crop varieties, strengthen real-time forecast system, and efficient management of resources to effectively deal with of climate-related risks. Tailoring crop varieties elastic to climate variables viz. temperature, moisture, wind etc. has great adaptation potential. Such varieties could fit well to new farming and weather conditions. The adaptability of varieties could further be augmented through bringing convergence with improved agronomic and crop management practices. Refined crop management practices such as adjustment in planting dates and cropping calendar could negate the effect of temperature, possibly escape extreme weather events and efficiently use the wet periods. In addition, crop rotations, intercropping, integrated weed and pest management, integrated nutrient management (INM), site-specific nutrient management (SSNM), agroforestry etc. are important components of strategic adaptation to climate change in India.

The adaptation of farming to climate change could further be strengthened through adoption of resource conservation technologies (RCTs). The key RCTs for Indian context include *in situ* moisture conservation, rainwater harvesting and recycling, efficient use of irrigation water, conservation agriculture, energy efficiency in crop production and irrigation and use of poor quality water. However, these adaptations require thorough characterization of bio-physical and socio-economic resources.

Another type of technological advance is the development of information systems capable of forecasting weather and

climate conditions. Weather predictions over days or weeks have relevance to the timing of agricultural operations such as planting, spraying or harvesting, while seasonal forecasts have the potential to aid risk assessment and production decisions over several months. In addition, information on longer-term climate projection can inform farmers about future norms and variability, and the probability of extreme events. Similarly, development of technological innovations in resource management also has the potential to address climate-related stimuli (Smit 1996).

**Farm production practices:** It includes farm-level decisions with respect to farm production, land use, land topography, irrigation, and the timing of operations. Customizing farm production activities have capacity of reducing exposure to climate-related risks and increasing flexibility of farming under changing climate conditions. Adaptable production options include diversification of crops and crop varieties, changes in the intensity of production besides use of agrochemicals, energy, capital and labour. Altering crop varieties, including the substitution of plant types, cultivars and hybrids designed for higher drought or heat tolerance, has the potential to increase farm efficiency in changing temperature and moisture stresses (Smit *et al.*, 1996; Chiotti *et al.*, 1997). While, altering the intensity of chemical (i.e., fertilizers and pesticides), capital and labour inputs has the potential to reduce the risks in farm production (Hucq *et al.* 2000). Similarly, rotating or shifting production between crops and livestock, and shifting production away from marginal areas has the potential to reduce soil erosion and improve moisture and nutrient retention. Changing land topography through land contouring and terracing, and the construction of diversions, reservoirs, and water storage and recharge areas (Easterling, 1996), reduces farm production vulnerability by decreasing runoff and erosion, improves the retention of moisture and nutrients, and improves water uptake (de Loe *et al.*, 1999). Water management could improve farm productivity and enable diversification of production with respect to climate-related changes. Changing the timing of operations involves production decisions, such as planting, spraying and harvesting has the potential to maximize farm productivity during the growing season and to avoid heat stresses and moisture deficiencies.

### Mitigation to climate change

Agriculture is both source and sink for greenhouse gases (GHG). Farming releases CO<sub>2</sub> largely through microbial decay or burning of plant litters (Smith, 2004; Janzen, 2004), CH<sub>4</sub> through decomposition of organic materials under oxygen-deprived conditions, enteric fermentation in ruminants, stored organic manures and flooded rice (Mosier *et al.*, 1998), and N<sub>2</sub>O through microbial transformation of nitrogen in soils and manures (Smith and Conen, 2004). Although, agricultural GHG fluxes are complex and heterogeneous, but could effectively be mitigated using available technologies for reducing

emission, enhancing removals, and avoiding (displacing) emissions (Smith *et al.*, 2007). Globally, technical mitigation potential of agriculture is expected to be 5500-6000 Mt CO<sub>2</sub> equivalents per year by 2030 (IPCC, 2007). Agricultural mitigation measures often have synergy with sustainable development policies, and usually influence social, economic, and environmental aspects of sustainability. Many options also have co-benefits (improved efficiency, reduced cost, environmental co-benefits) as well as trade-offs (e.g. increasing other forms of pollution). It necessitates balancing these effects for successful implementation. Some of the mitigation options available for crop lands are briefly discussed here.

**Crop management:** Improved agronomic practices that increase yields and produce higher carbon residue could augment soil carbon storage. Important agronomic practices include improved crop varieties, extended crop rotations especially with perennial crops that allocate more carbon below ground, avoiding fallows (West and Post, 2002; Lal, 2003, 2004), balance nutrition (Alvarez, 2005), reduced reliance on fertilizers (Paustian *et al.*, 2004), and catch/cover/intercrops to enhance soil cover (Barthes *et al.*, 2004).

**Nutrient management:** Nitrogen applied through fertilizers, manures, bio-solids, and other N sources is not always used efficiently by crops (Galloway *et al.*, 2004; Cassman *et al.*, 2003). Improving N use efficiency can reduce N<sub>2</sub>O emissions and indirectly reduce GHG emissions from N fertilizer manufacture (Scanhlesinger, 1999). Integrated Nutrient Management (INM) and Site-Specific Nutrient Management (SSNM) have the potential to mitigate effects of climate change. For example, adoption of INM and SSNM practices under flooded rice significantly improves the yield, net CO<sub>2</sub> assimilation, and nitrogen use efficiency while decreases GHG emission over traditional practices. Similarly, simultaneous application of urease inhibitor, hydroquinone (HQ), and a nitrification inhibitor, dicyandiamide (DCD) with urea is an effective technology to reduce N<sub>2</sub>O and CH<sub>4</sub> emission from rice fields.

**Tillage/residue management:** Soil disturbance tends to stimulate soil carbon losses through enhanced decomposition and erosion (Madari *et al.*, 2005), while reduced or no tillage agriculture often results in soil carbon gain (West and Post, 2002; Ogle *et al.*, 2005) and usually lower N<sub>2</sub>O emissions. Advances in weed control methods and farm machinery now allow many crops to be grown with minimal tillage (reduced tillage) or without tillage (no-till). These practices are now increasingly adopted throughout the world (Ceri *et al.*, 2004). In addition, recycling crop residues tends to improve soil carbon, while burning of residues promotes emissions of aerosols and GHGs

**Water management:** Expanding area under irrigated agriculture or adoption of more efficient water management practices can enhance carbon storage in soils through enhanced yields and residue returns (Lal, 2004). For example, intermittent flooding in rice could reduce global warming potential by

25-30% over continuous flooding (Pathak, 2015). Similarly, adoption of the micro irrigation technology will not only result in saving of water but also saving of energy (Shah, 2009) and reducing carbon emission. Resource conserving technologies (RCTs) like zero or minimum tillage (with or without crop residues), bed planting of crops and direct-seeded rice have a substantial scope in improving irrigation efficiency and saving energy for groundwater withdrawal. However, some of the gains may get neutralized due to energy used to deliver the water (Mosier *et al.*, 2005) or from N<sub>2</sub>O emissions from higher moisture and fertilizer N inputs (Liebig *et al.*, 2005).

**Agroforestry:** Agroforestry systems buffer farmers against climate variability, and reduce atmospheric loads of greenhouse gases. Agroforestry can both sequester carbon and produce a range of economic, environmental, and socio-economic benefits. However, the amount of carbon sequestered and other tangible benefits largely depend on the type of agroforestry systems besides environmental and socio-economic factors that determines its composition. In general, the above-ground carbon sequestration rate in major agroforestry systems ranges between 0.29-15.21 Mg/ha/year (Nair *et al.*, 2009).

**Land cover and landuse Change:** Lands differ in their ability to grow plants and resilient capacity to weathering forces. Usually, a climax ecotype for a land use is thermodynamically the most efficient system that often leads to lowest GHG emission and maximum carbon sequestration. Any deviation from climax vegetation causes imbalances and accelerates entropy. Thus, reverting a crop land to another land cover, typically one similar to the native climax vegetation is one of the most effective methods of reducing emissions. However, such land cover changes often increase carbon storage, but comes at the expense of lost agricultural land. It is usually an option only on surplus agricultural land or on croplands of marginal productivity (Smith *et al.*, 2007).

### Interaction of adaptation and mitigation strategies

In farming, mitigation and adaptation action could be implemented simultaneously, but they differ in their spatial and geographic characteristics. Most mitigation measures are robust to future climate change (e.g. nutrient management). And, the benefits of mitigation measures to climate change are realized over decades. In contrast, the impact of adaptation actions to climate change is usually visible in short and medium term.

### National innovation on climate resilient agriculture (NICRA)

The studies on climate change in India and abroad suggest possibilities of making Indian agriculture resilient through adaptation and mitigation measures. Thus, Government of India accorded high research and development priority towards climate resilient agriculture (CRA) and also identified agriculture as one of the eight national missions under the



prime Minister's National Action Plan on Climate Change (NAPCC). The Government through ICAR launched mega project "National Initiatives on Climate Resilient Agriculture (NICRA) during 2010-11 for the XI Plan. The project aims at enhancing resilience of Indian agriculture to climate change and its variability through strategic research on adaptation and mitigation measures, their refinement and validation for local and regional needs; and extensive demonstration in dynamic mode. The project is continuing in XII plan as National Innovations on Climate Resilient Agriculture (NICRA) with special emphasis on arid regions, hill and mountain ecosystem, pollinators, hailstorm management, and socio-economic dynamics including adaptation financing. To achieve the goals, the project operates through four major components, namely, strategic research, technology demonstration, capacity building and sponsored/competitive grants for basic research.

The strategic research component aims at assessing the vulnerability of major agro-ecosystems, monitoring GHG emissions, pest dynamics, pest/pathogen-crop relationship; develop tolerant breed/varieties; evolve adaptation and mitigation options for climate change regulated abiotic and biotic stress on crops, livestock and fisheries; and real-time contingencies at leading ICAR research institutes in a network mode. The Technology Demonstration Component (TDC) deals with showcasing of proven adaptable technologies in a participatory mode in selected vulnerable districts of the country by Krishi Vigyan Kendras (KVKs). Critical researchable issues like impact on plant pollinators, fisheries in estuarine habitats, hail storm management, hill and mountain ecosystem, small ruminants and socio economic aspects of climate change etc. are addressed under the Sponsored and Competitive Grants Component. Since climate change is an emerging area of science, capacity building of young scientists and other stakeholders is important component of the programme. Training to scientist on state of art technologies and subjects are being imparted in India and abroad, while more than 100 training programs have been organized across the country covering 50000 farmers to create awareness on climate change and appropriate adaptation and mitigation options.

### NICRA experiences

Since 2010-11, NICRA efforts has resulted into generation of valuable information and technologies to address changing climate related issues of farming, bringing convergence between technologies, and demonstrating capabilities of technology packages in 151 most vulnerable villages of the country. The results of most case studies have shown possibilities of resources conservation, sustainable production, and livelihood security of farmers. Some of the resilient NICRA experiences are discussed here.

**Natural resource management:** In a given land use condition, enhancing the availability of water is one of the important means for efficient use of available resources and bring

resilience to farming. And, it could be achieved through means of adopting in situ water conservation measures and creating of ex-situ surface and sub surface storage structures. Thus at NICRA villages, farmers adopted multipronged approaches renovating creating community tanks, check dams, individual farm ponds besides in-situ conservation of rainfall through agronomic modification.

Renovation of traditional water reservoir 'Aahar' and conveyance channel 'Pyne' helped farmers of Nawada district (Bihar) to harvest additional 20,000 m<sup>3</sup> water for protective irrigation through drip irrigation in 24 ha area during kharif; enhance productivity by 20.7%, raised groundwater table by 20 cum; and improved availability of water for livestock. Similarly, renovation of irrigation channels (Mentepudi channel and VWS channel) in West Godavari district not only improved the water availability at tail end but also helped in safe disposal of excess rain water to avoid flooding and submergence of crops. Even during Neelam Cyclone, a flooding of just 42 cm against average 122 cm submergence (untreated areas) was observed, avoiding the yield loss up to 4.1 t/ha in paddy. Similarly, ex-situ rainwater harvesting and its efficient use brought perceptible change in kharif production at Nacharam Village (Khammam). Supplementary life-saving irrigation at critical crop growth stages gave mean additional yield of cotton (250 kg/ha), Chillies (150 and fodder (4.0 t/ha) and enhanced the income of farmers up to Rs.10900/ha.

Further, the rain water harvesting also proved boon to farmers of hilly regions. Even constructing a small community water storage tank of 200 m<sup>3</sup> at Chhoel-gadouri village (Kullu) is providing supplemental 5 irrigations to tomato crops in 2.2 ha area and improving the B:C ratio to 3.8. Likewise, availability of supplemental water through creation of small *Jal Kund* (capacity 30 m<sup>3</sup>) and adoption of pressurised irrigation practices made vegetable production profitable and doubled the cropping intensity at adopted villages in NEH Regions.

In addition, adoption of in situ soil moisture conservation through improved planting methods and conservation agriculture practices proved beneficial to withstand the vagaries of climate. In situ rainwater management practices viz. ridge and furrow (R & F) method, broad bed furrow (BBF) method, and contour farming helped in conserving rainwater at field level and simultaneously draining excess water into community drain channels. These practices were found very effective in rainfed regions of Maharashtra, Madhya Pradesh, Uttar Pradesh, Andhra Pradesh, Telangana, Rajasthan, Odisha, West Bengal, Karnataka and Jharkhand. For example, adoption of R&F method improved average yield of cotton by 15%, while BBF or contour farming along with adoption of short duration variety (JS-93-05, 90 days) enhanced soybean productivity by 22%. Similarly, adoption of zero till technology supported reducing cost of cultivation, advancing sowing time by 10-15 days, escaping terminal drought stress, improving green water availability, increasing crop intensity, and thereby enhanc-

ing crop resilience. For example, adoption of zero-till practices made sowing of succeeding mustard crop feasible under rice-fallows in 80 ha land at Mizoram, and the practices gave additional mustard equivalent seed yield up to 1.24 t/ha.

**Crop production system:** Adoption of location specific better management practices (BMP) including crop varieties has shown tremendous potential to bring resilience in Indian agriculture. Some of the important BMPs promoted through NICRA villages include adoption of short duration drought/flood tolerant varieties, improved soil health management, intercropping and agroforestry, crop diversification, and contingent crop planning to address creeping on cropping and impulsive disasters in farming.

During 2014, adoption of drought tolerant short duration varieties in many NICRA villages proved effective in alleviating the impacts of delayed monsoon without any yield loss. For example, replacing local maize cultivars with short duration varieties/ crops enhanced the seed yields by 18.4% at Umarani village (Nandurbar). Similarly, flood tolerant rice var. RG-2537 and MTU-106 under low inundation condition at Sirusuwada village (Srikakulam district) and lodging resistant var. MTU-1061 and MTU-1064 under cyclone prone areas at Undi village (West Godavari) proved better than traditional rice cultivars.

Location specific intercropping systems are another important adaptation measures for variable rainfall situations. Under NICRA, a number of intercropping systems has been identified and demonstrated at adopted villages. For example, soybean + pigeon pea (4:2) and cotton + green gram intercropping were found superior to sole primary crops at Shetka village (Aurangabad). Further, diversification of traditional crops and cropping systems to more efficient and climate resilient crops/varieties proved advantageous in most NICRA village and served as an insurance against crop failures. For example, replacing vulnerable cotton with short duration for foxtail millet varieties (SIA -3085 and Suryanandi) ensured higher yields (up to 19.5 q/ha) and net returns (Rs.11820/ha) besides fodder at Yagantipalli village (Kurnool).

The NICRA studies further confirmed the opportunities to enhance resilience of Indian agriculture by adopting location specific soil health management practices. Rationalizing recommended fertilizer doses using soil test based nutrient application at Nalgonda, liming in acid soils at NEH region (Senapati, Manipur), integrated nutrient management at most centres, and introduction of summer moong in rice-wheat system of Punjab (Faridkot) are some of the NICRA experiences explaining optimization of resource use, improving soil health, enhancing system productivity and ensuring higher net returns to the farmers.

**Contingent crop planning:** Uncertainty of weather conditions is the most important factor causing instability in farming. Preparedness through contingent crop planning for weather aberrations could subjugate the yield losses and thereby enhance the resilience of Indian Agriculture. With this

view NICRA in association with SAUs and State Department of Agriculture took major initiative to develop crop contingent plan for delayed monsoon onset/ deficit rainfall conditions prevailing at each rural districts of the country. These contingent plans involve appropriate crop/verities, soil moisture, nutrient management measures and plant protection strategies to face the impact of contingent conditions effectively. Till date, contingent plans for 614 rural districts of the country has been prepared and uploaded to the website of the ICAR, CRIDA and DAC&FW.

These contingent plans were taken up in NICRA villages where delayed onset/ deficit rainfall conditions were experienced. For example, contingency crops of sesame (Madhuri) and sunflower (PKV 559) produced higher yields than regular soybean crop under delayed planting (August) in Maharashtra (Takali village, Amravati district). Further, under delayed onset conditions, adoption of short duration pigeon peavar. BRG-2 over traditional cultivars enhanced the yield by 23.5%, while aerobic rice var. MAS-26 resulted 14.4% higher yield than transplanted rice at Tumakuru district (Tamil Nadu). Many similar experiences at NICRA villages confirm the usefulness of dynamic contingent crop planning to enhance farmers' livelihood security.

**Management of weather variability:** Unseasonal rains/hailstorms causes unpredictable damage to standing crops. For example, widespread rains during March 2015 severely damaged wheat, mustard, chick pea, lentil and vegetable crops in many parts of the country. Effective management of such sudden aberration is difficult, but adoption of several pre- and post- event measures could minimize the damage and results into faster recovery. Several studies at NICRA villages have shown better feasibility to manage such weather extremes. During March 2015, zero-till wheat experienced less damage due to lodging and waterlogging than conventional crop in Punjab and Haryana. Similarly, yellow rust resistant varieties viz., WH-1105, HD-2967, HS-507, and HS-420 showed faster post event recovery and negligible disease infestation. Similarly, furrow irrigated raised bed (FIRB) planted wheat resulted 70% lesser damage than conventionally sown wheat due to hailstorms at Kota (Rajasthan). Further, early maturing gram variety JG-14 escaped the damaged due to unseasonal rain (90 mm) in MP (Balaghat district). Such experiences at NICRA villages exhibit possibilities of effective crop management options to better withstand unseasonal rains /and hailstorms.

## CONCLUSION

Impact of climate change on agriculture will be one of the major factors influencing future food security in coming decades. Adaptive responses are mainly related to technological interventions, management practices, sound governmental policy and political will to overcome the ill effects of climate change. The success of agronomic management interventions implemented under NICRA across vulnerable districts in In-

dia has demonstrated the ability of different low cost interventions at enhancing resilience to climate change for sustainable agriculture. These technologies have large potential for upscaling through supportive policies and programs. A convergence with developmental programmes operative at the village level could upscale and mainstream NICRA technologies to reduce the risk in farming under changing climate scenarios. The important Governmental schemes that need convergence with NICRA output includes Prime Minister Krishi Sinchai Yojana (PMKSY), National Mission for Sustainable Agriculture (NMSA), National Water Mission, Prime Minister Fasal Bima Yojana (PMFBY) and Mahatma Gandhi National Rural Employment Guarantee Act (MGNREGA). Such convergence will accelerate achieving India's Intended Nationally Determined Contribution (INDC) target for 2030 by reducing GHG emissions, enhancing resource use efficiency, and creating additional carbon sink in farming systems besides ensuring national food security.

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## Understanding crop physiological processes for climate resilience

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As everybody knows, the climate is changing and over the next decade will be putting an increasing strain on agriculture production. This paper aims at putting some focus on what can really be addressed (the change in temperature) from what really cannot be predicted and dealt with (rainfall). But even the effect of one factor like temperature triggers a complex myriad of effects and the paper structures what needs to be done in relation to temperature, and focuses on recently discovered mechanism to adapt to a change in temperature. The paper then briefly reviews its biological basis, the mean to phenotype for it at a high rate and precision, and how the use of crop simulation can help us predict the effect of this trait on yield.

### Future climate or how to deal with higher temperature

General circulation models (GCM) for climate consensually predict an increase in the temperature globally, only diverging on the extent of that increase, i.e. 2 to 4 °C. By contrast, none of the 20 or so models agree with regards to rainfall and whether these would increase or decrease, where and how much. Therefore, an increase in temperature is the only expected change. Before we get on analysing the kind of effects temperature can have on crop productivity, two things need to be kept in mind: (i) there will also be an increase in CO<sub>2</sub> concentration, which is currently on-going. With a current yearly increase over 2 ppm, a concentration around 700 ppm is expected toward the end of the century. High CO<sub>2</sub> leads to stomata closure and expectedly would increase water use efficiency and possibly yields under water limited situation, which would in part alleviate some of the negative effects of increased temperature; (ii) the changes in temperature are foreseen over a time scale of five to ten decades, whereas the time frame in breeding is in the order of one decade. In other words, one thing at a time: we first need to develop the cultivars of the next decade, because there is already enough temperature-related climate vagaries ‘today’ that need to be dealt with, using the same entry points described in the next paragraph. Then as climate changes the environmental context of the breeding program will change and impose a new selection environment in which breeding lines are tested that will likely

alter the outcome of breeding selection. Breeders will then need to have their attention focused on what effects temperature is expected to have and what traits are expected to be “promising responses” to these changing conditions.

In relation to temperature stress, yield reductions are caused by three different reasons: (i) higher temperature affects dramatically the reproductive biology and leads to a reduced seed set. This area of research currently receives most of the attention, for instance in rice, wheat, or chickpeas that are known to be indeed sensitive to higher temperature at the time of anthesis; (ii) higher temperature mechanically hastens the phenological development and leads to a shortening of the crop duration with expected negative effects on crop yield. A simple solution to this is about breeding cultivars with an extended crop cycle; (iii) higher temperature will also increase the evaporative demand and have an effect on the plant water balance. In other words, while we often look at drought as being a scarcity of water in the soil profile, the effect of water scarcity in the atmosphere is often overlooked. An increase in the evaporative demand could be seen as a kind of “atmospheric drought”. In this paper, we will expand on that topic, which has so far received little attention and on which major breakthroughs have been recently achieved in relation to how crop respond to this constraint, the range of genetic variations, how to phenotype for it and how to harness genomic regions involved in this trait.

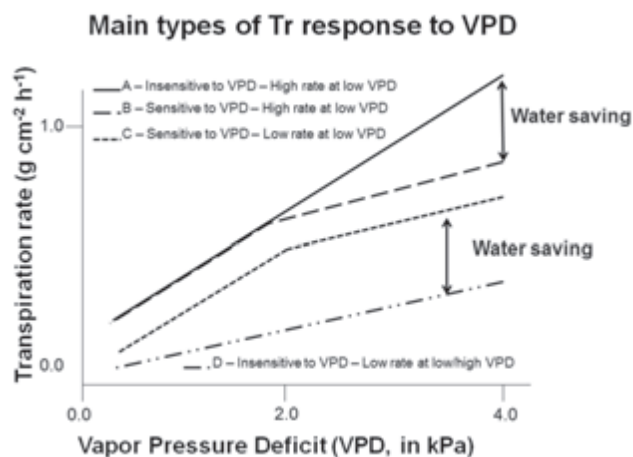
### Trait dissection

In the last few years, strong evidences have been acquired that small amounts of water during the reproductive and grain filling period are critical for enhancing grain yield under water limited conditions across dryland legume and cereal crops species. Water availability during grain filling is a consequence of a number of plant traits altering the plant water budget, and operating mostly in the absence of soil water stress. Our current thrust is to crack the plant water budget into simpler “building blocks”, more amenable to genetic analysis and breeding use. One such trait is the capacity of the crop canopy of certain genotypes to restrict transpiration under high vapour pressure deficit (VPD). This trait is highly

relevant for drought and climate change adaptation. Genotypic variation for this trait has been identified in soybean (Fletcher *et al.*, 2007), pearl millet (Kholova *et al.*, 2010) chickpea (Zaman-Allah *et al.*, 2011a), sorghum (Gholipour *et al.*, 2010; Kholova *et al.*, 2014), maize (Yang *et al.*, 2012), groundnut (Devi *et al.*, 2010). It has also been related to increases in grain yield under terminal stress conditions in chickpea (Zaman-Allah *et al.*, 2011b) or pearl millet (Vadez *et al.*, 2013a). A recent paper reviews the different traits that condition plant water use and in particular the transpiration response to increases in VPD (Vadez *et al.*, 2013b). Figure 1 below illustrates the different types of transpiration responses to increases in VPD which were found in different germplasm of different species over the last several years. Another paper then explains how this trait leads to increases in water use efficiency (Vadez *et al.*, 2014), basically by lowering the average daytime VPD at the leaf level, which mechanically increases TE according to the theory.

### High throughput phenotyping

For many crops, the genomics revolution has given hope that breeding would become easier and more efficient. Phenotyping is now a main bottleneck, especially for complex abiotic constraints, but phenotyping alone is not enough: Relevant phenotyping is needed and implies a thorough understanding of the biological mechanisms, and their interaction with the environment, conferring plant adaptation to abiotic constraints, and the “translation” of this knowledge into large scale and high throughput measurements. For assessing the transpiration response to increases in VPD at a scale that could be applicable to a breeding program, two essential elements were needed: (i) the capacity to assess the leaf area fast, precisely, and dynamically; (ii) the capacity to assess plant transpiration seamlessly and independently of time-con-



**Fig. 1.** Main types of transpiration (Tr) responses to increasing VPD conditions found in different germplasm of different species over the last few years. The differences in area between the different curves potentially represent different water savings (reproduced from Vadez *et al.*, 2013b)

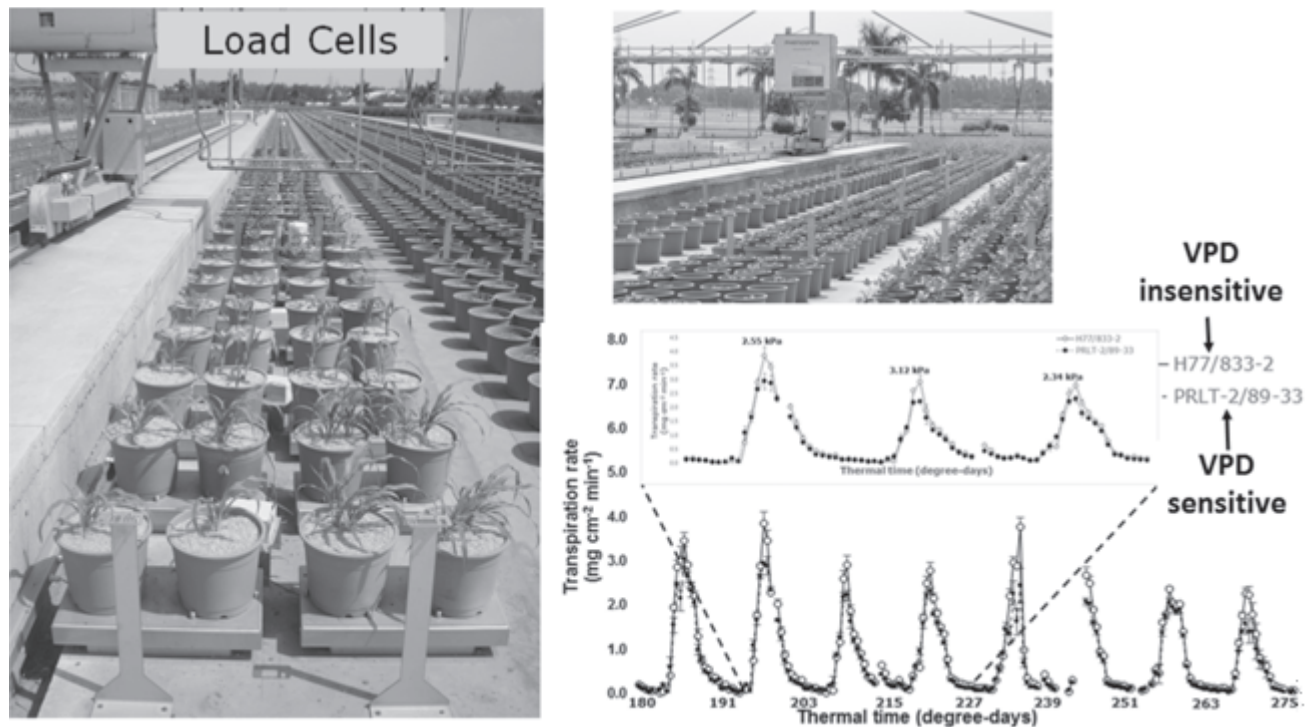
suming and labour intensive weighings. Toward that end, a large phenotyping platform, LeasyScan (Vadez *et al.*, 2015) has recently been developed. The imaging platform is based on a novel 3D scanning technique, a scanner-to-plant concept to increase imaging throughput, and analytical scales to combine gravimetric transpiration measurements. The scanning consists in the projection of a laser line at a 940 nm wavelength on top of the crop canopy and in the picturing of its full reflection by the canopy. The assembly of about 80 pictures s<sup>-1</sup> allows to generate a 3D point cloud from which several plant parameters are computed, including the plant leaf area. Analytical scales are also synchronised in the system and poll the weight of pots every few seconds and integrate the values over an hour, then providing a continuous assessment of the pot weights from which transpiration can be computed. Figure 2 below represents the load cell setup at the LeasyScan platform and gives an example of how transpiration is measured over several days under different maximum VPD conditions in lines of pearl millet known to contrast in their response to increased VPD. As can be seen, the transpiration rate of VPD-insensitive H77/833-2 peaks at the highest VPD in each day, whereas the transpiration rate of VPD-sensitive line PRLT-2/89-33 reaches a plateau in the circa 3 hours of highest VPD in each day. As such, this represents the first experimental evidence of the theory laid out earlier (Sinclair *et al.*, 2005).

### Modelling of trait effect

The difficulty of breeding for crop adaptation to water limitation is that these limitations are never the same and largely vary with time and geographical scales. Therefore, testing the effects of a given trait on crop yield across a range of environments that would represent the diversity of stress patterns is virtually impossible experimentally. In that context, crop simulation modelling has become a critical tool to be able to predict the effect of such traits / trait-by-management combinations on yield across time and geographical scale, and then to guide the choice of key breeding and agronomic management targets. In the case of the transpiration to increased VPD trait, it has shown that enormous yield benefits could be achieved in soybean across most environments in the US, and more so in dry years (Sinclair *et al.*, 2010). Similar results have been obtained for soybean in sub-Saharan Africa (Sinclair *et al.*, 2014). In sorghum, evidence has been acquired that the introgression of staygreen QTL elicit a VPD-sensitive phenotype and a modelling analysis has shown also major yield benefit across a large track of *rabi* sorghum in India (Kholova *et al.*, 2010).

### CONCLUSION

In this brief paper, we have shown that, besides an increase in CO<sub>2</sub>, most of the climate change effects that can be predicted would be around an increase in temperature. While the effects of temperature on reducing yield are several, here we



**Fig. 2.** Pictures of the load cell setup at the LeasyScan platform (left) and of the scanner supporting device (top right). The graph represents the transpiration evolution over several days in two pearl millet lines that were identified earlier as VPD-insensitive or VPD-sensitive (from Kholova *et al.*, 2010). The manifestation of this phenotype in the platform is in the plateauing of the transpiration rate in the middle part of the day in the VPD-sensitive line (closed symbols). (Reproduced from Vadez *et al.*, 2015)

have focused on the effect of temperature acting from the angle of plant water status via its effect on the vapour pressure deficit. We have shown that plants vary for their capacity to restrict transpiration under high VPD and that this trait confers water savings that are important under drought conditions. While this trait is typically a “climate change” trait, it has importance ‘today’ itself and is currently used toward breeding of cultivars adapted to high VPD conditions in the semi-arid tropics.

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**Symposium 2**  
**Organic Agriculture**





## Organic farming in 21<sup>st</sup> century

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Converting agriculture in to an organized business with the farmer, as an entrepreneur is the key to second green revolution and the essence of the much-desired evergreen revolution in India. The concept of *Ever Green Revolution* (EGR) relies on the need for improving productivity in perpetuity without associated ecological harm. The concept also emphasizes on basic policy shift from commodity-centered approach to a farming system centered approach in terms of technology development and dissemination. It is the pathway that involves the attention to Integrated Natural Resources Management through *Organic Agriculture* which in one hand precludes the use of synthetic chemical fertilizers, chemical pesticides, hormones and genetically modified crops and on the other hand adheres to the principles of integrated nutrient management (INM), integrated pest management (IPM), integrated weed management (IWM), improved water management through water use efficiency (WUE), use of appropriate local landraces of different crops, and also improved post-harvest technology.

### The world of organic agriculture

As per the statistics compiled by the IFOAM and FiBL (Anonymous 2016) world over 43.7 million ha land (1% of total agricultural land) is being managed organically by 2 million producers in 172 countries. Besides this there is another 37.6 million ha being certified for wild harvest collection. Global sales for organic products have reached 80 billion US\$ with US and Europe being the largest consumers.

As on March 2016, India has brought 57.0 lakh ha area under organic certification process, which includes 14.8 lakh ha cultivated agricultural land and 42.2 lakh ha of wild harvest



Fig. 1. Growth of area under organic certification over years

collection area in forests. Growth of cultivated farm area under organic farming during different years is presented in Fig. 1. Reduction in the area during the period from 2009-10 to 2012-13 was attributed to the loss of area under cotton due to introduction of BT cotton.

During 2015-16, India exported 2.64 lakh MT of organic products belonging to 135 commodities valuing at US\$ 285 million (approximately INR 1900 crore). The major share of exports was oilseeds, cereals and millets and processed foods with a combined share of around 91%. In the oilseeds category, soybean with exports of 1.26 lakh tons during 2015-16 had a share of about 95% among total oilseeds. In cereals and millets category, rice, maize, wheat and coarse millets are being exported. In the rice category the quantity of basmati rice exported was around 10300 tons. Domestic market is also growing at an annual growth rate of 15-25%. As per the survey conducted by ICCOA, Bangalore, domestic market during the year 2012-13 was worth INR 600 crore which has now grown to more than 1000 crore during 2014-15.

### Organic agriculture and productivity

Since the advent of organic farming in the recent years there had been concerns on the production potential of the system. But the results of long term experiments released during the last 10 years from world over have eliminated all fears. Under irrigated conditions organic farming may be yielding 5-12% less than their conventional counterparts but under rainfed and water deficit conditions organic system yields 7 to

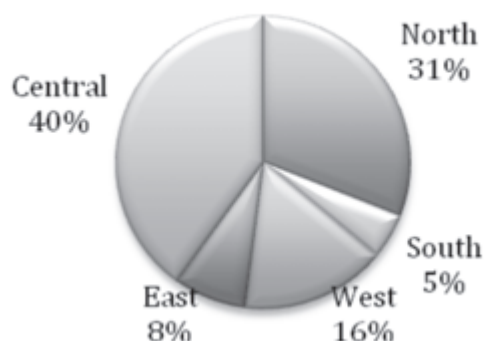


Fig. 2. Organic area under different zones

15% more. Six years experimenting, comparing two models of organic management with only chemical input and chemical + organic under 4 crop husbandry systems at ICRISAT (Rupela, 2006) revealed that organic systems were at par with integrated and higher than chemical fertilizers in all the years from second year onwards.

Reviewing 154 growing seasons' worth of data (Halwell, 2006) on various crops grown on rain-fed and irrigated land in the United States, it was found that organic corn yields were 94 percent of conventional yields, organic wheat yields were 97 percent, and organic soybean yields were 94 percent. Organic tomatoes showed no yield difference. More importantly, in the world's poorer nations where most of the world's hungry live, the yield gaps completely disappear.

A seven-year study from Maikaal-FiBL project in Khargone District in central India (Eyhorn *et al.*, 2005) involving 1,000 farmers, cultivating 3,200 hectares found that average yields for cotton, wheat, chili, and soybean were as much as 20 percent higher on the organic farms than on nearby conventionally managed ones. Another trial's result from Sustainable Agriculture Farming Systems project (SFAS) at University of California, Davis (Clark *et al.*, 1999) showed that organic and low-input systems had yields compa-

table to the conventional systems in all crops which were tested - tomato, safflower, corn and bean, and in some instances yielding higher than conventional systems. In similar study at South Dakota in Midwestern United States shows the higher average yields of soybeans (3.5%) and wheat (4.8%) in the organic compared to conventional farming system (Welsh, 1999). 21 year study compared plots of cropland grown according to both organic and conventional methods at Institute of Organic Agriculture and the Swiss Federal Research Station for Agroecology and Agriculture found that Organic yields were less by about 20% but Fertilizer, Energy and Pesticide use were less by 34%, 53% and 97% respectively as compared to conventional (Maeder *et al.*, 2002). Also organic soils housed a larger and more diverse community of organisms. The study at Iowa State University assessed (Delate and Cambardella, 2004) the agro ecosystem performance of farms which found that, initially the yield was slightly lower (Organic corn and soybean yield averaged 91.8% & 99.6% of conventional respectively) in organic plots but in fourth year organic yield exceeded conventional for both corn and soybean crops.

Research findings released from UAS, Dharwad, Karnataka under Network Project on Organic Farming (ICAR) reported that under rainfed systems organic management yields much higher productivity than conventional (UAS Dharwad, 2011) Some of the findings are given in Table 1, 2 and 3.

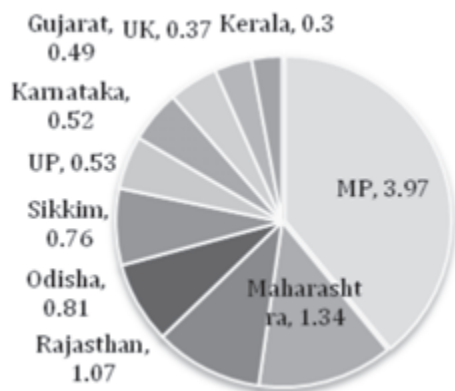


Fig 3. Area in lakh ha in some important states

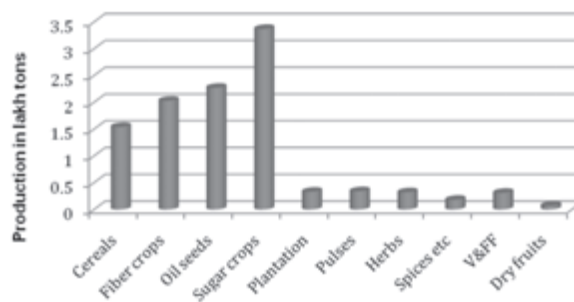


Fig 4. Production of important commodities (in lakh tons)

Table 1. Comparison of organic, chemical and integrated systems in three crop combinations (pooled data for six years)

Crop combination	Yield (kg/ha)	Yield (kg/ha)	Returns (₹/ha)
Groundnut-sorghum	Groundnut yield	Sorghum yield	Net returns
Organic	2975	1166	48345
Chemical	2604	1043	40790
INM	2842	1155	46090
Soybean-Wheat	Soybean yield	Wheat yield	
Organic	1769	1081	21120
Chemical	1521	933	16313
INM	1733	1062	19929
Chilli-Cotton	Chilli yield	Cotton yield	
Organic	447	662	19502
Chemical	427	559	14176
INM	445	681	19540

Recently, system comparison studies conducted by the FiBL, International Centre of Insect Physiology & Ecology, Kenya Agricultural & Livestock Research Organization, Kenyatta University, Kenya Organic Agriculture Network – KOAN and Kenya Institute of Organic Farming (Anonymous 2016) claimed that the organic systems start to deliver substantial economic advantage over conventional systems as soon as the initial conversion phase is over. Project coordinator Dr. Noah Adamtey says, “Our findings show that yields of maize – an important staple and cash crop – under organic production are similar to that under conventional production in high-input systems representing commercial scale farming”. “Furthermore, the profitability was similar in both systems from the third year in the absence of premium price, but when premium price was considered, organic farming was more profitable starting from the fifth year. At low input levels, maize yields were similar in both systems, especially under intercropping regimes and there were no differences for pest and disease incidence and damage”. These results also show that soil fertility improved significantly in calcium, magnesium, potassium and soil pH (acidity) levels under the organic approach.

### Organic agriculture and profitability

Recently a study was conducted in Maharashtra to study the impact of organic farming on economics of sugarcane cultivation in Maharashtra (Kshirsagar, 2007). The study was based on primary data collected from two districts covering 142 farmers, 72 growing Organic Sugarcane (OS) and 70 growing Inorganic Sugarcane (IS). The study finds that organic cultivation enhances human labour employment by

16.90 per cent and its cost of cultivation was lower by 14.24 per cent than conventional farming. Although the yield from organic was 6.79 per cent lower than the conventional crop, it was more than compensated by the lower cost and price premium received and yield stability observed on organic farms. The organic farming gives 15.63 per cent higher profits and profits were also more stable on organic farms than the conventional farms.

Tej Pratap and Vaidya (2009) in a nationwide survey of organic farmers suggest that “The cost-benefit analysis indicates favourable economics of organic farming in India. Farmers in 5 out of 7 states are better placed, so far as organic farming is concerned. The returns are higher in Himachal Pradesh, Uttaranchal, Karnataka, Maharashtra and Rajasthan. In Karnataka organic farmers had 4-35% higher returns than inorganic farmers. In Kerala the differentials ranged between 4-37% in favour of inorganic farmers. In Maharashtra the difference in net profit was more than 100% in case of organic soybean. Organic cotton farmers were enjoying comfortable profit margin. The profit differential in Rajasthan ranged from 12-59% in favour of organic farmers. In Tamil Nadu organic farmers were better placed with two crops, while inorganic farmers were at slight advantage in other two crops.

Comparative economic analysis with four cropping systems at UAS Dharwad also indicates the promising potential of organic farming systems (Table 7).

### Organic agriculture and soil health

Long term experiments comparing productivity and soil health parameters at ICRISAT have demonstrated that organic practices produced yields comparable to conventional plots,

**Table 2.** Yield of crops in four sequence cropping systems (2009-2012 pooled)

Farming systems	Groundnut	Sorghum	Soybean	Durum wheat	Maize	Chickpea
Organic	3789	1220	2602	1127	4611	1098
Integrated	3587	1194	2311	1038	4486	1013
RPP*	3545	1160	2376	1032	4509	1036
Inorganic	3018	1002	1804	857	3673	849
LSD (0.05)	303	92	269	71	306	101

(RPP - Recommended package of practices, *Source*: H. Babalad. 2016. National Seminar on Sustainable Agriculture, Gangtok, Sikkim, January 17-18, 2016)

**Table 3.** Yield (kg/ha) of rabi sorghum and chickpea under different management practices in zone-III

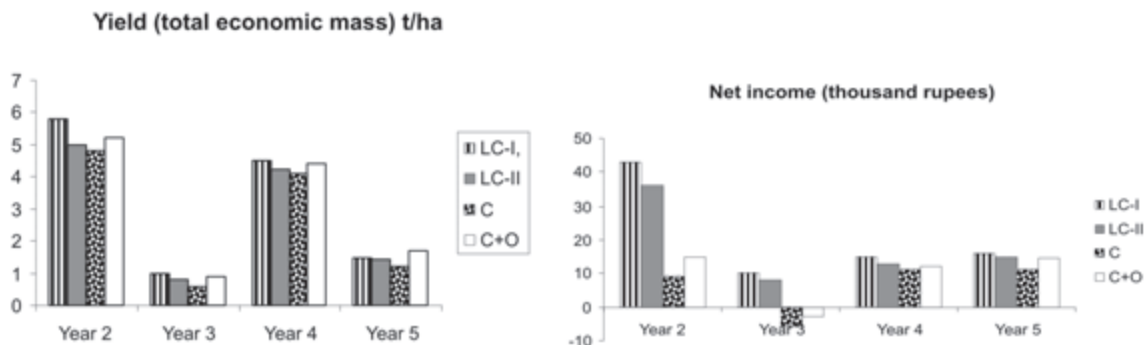
Treatments	Sorghum yield (kg/ha)	Net return (₹/ha)	Chickpea yield (kg/ha)	Net return (₹/ha)
Fully organic	1929	23359	1301	23661
Integrated (50% organic +50% inorganic)	1755	21639	1432	25730
In-organic (RDF)	1463	15635	1202	20879
RPP (RDF+ organic manure)	2017	25818	1370	24983
LSD(0.05)	254	2881	211	3510

(*Source*: H. Babalad. 2016. National Seminar on Sustainable Agriculture, Gangtok, Sikkim January 17-18, 2016)

**Table 7.** Comparative economic analysis of farming systems(2009-2012 pooled)

Management practices	Groundnut -Sorghum	Maize -Chickpea	Soybean -Durum Wheat	Cotton + peas
Organic	116555	58003	62047	72320
Integrated	111129	56171	54387	69981
RPP	114849	55714	58207	68905
Inorganic	96380	44078	44018	49061
LSD (0.05)	8637	4964	7133	7475

(Source: H. Babalad. 2016. National Seminar on Sustainable Agriculture, Gangtok, Sikkim January 17-18, 2016)



LC-I Organic model I (Long striped bar), LC-II organic model II (solid grey bar), Conventional where only chemical fertilizers were used (dotted bar), and Integrated application of chemical fertilizers+organic manures (plain bar)

without receiving any chemical fertilizer; they actually showed increase in the concentration of N and P compared with conventional. In years 3 and 4 of adopting organic management this increase was 11-34% in total N and 11-16% in total P over conventional plots. Among different soil biological properties, the soil respiration was more by 17-27% in organic plots than in conventional, microbial biomass carbon was 28-29% higher, microbial biomass nitrogen was 23-28% more and acid and alkaline phosphates were 5-13% higher in organic compared to conventional (Rupela *et al* 2005, 2006). In another similar study conducted under Network Project on Organic Farming of ICAR, (Gill and Prasad, 2009) appreciable improvements in yield levels under organic system were noted in the initial years with yields attaining comparable outputs by 4<sup>th</sup> and 5<sup>th</sup> years. Improvements of different magnitudes were also recorded in respect of soil organic carbon, available-P, available-K, bulk density, and microbial count under organic systems as compared to chemical farming.

In another study (Ramesh *et al.*, 2010) it has been reported that the bulk density of soil is less in organic farms which indicates better soil aggregation and soil physical conditions. Improvement in soil organic matter decreased the bulk density by dilution of the denser fraction of the soil. There was a slight increase in soil pH and electrical conductivity in organic farms compared to conventional farms. On an average, there was 29.7% increase in organic carbon of soil in organic farms (1.22%) compared to the conventional farms (0.94%). Dehy-

drogenase, alkaline phosphatase and microbial biomass carbon were higher in organic soils by 52.3%, 28.4% and 34.4% respectively compared to the conventional farms

## CONCLUSION

Organic farming as we see today is not the age-old traditional agriculture; it is a science based intensive cropping system, based on efficient management of resources, soil health, sun energy harvesting and judicious use of natural resources. Experiments world over has proved the productivity potential. Under irrigated and intensive cultivation conditions organic farming may be 5-12% less yielder but under rainfed, water stressed conditions and in marginal land areas it is 7-15% higher yielder. Organic farming in its modern version, equipped with local resources, strengthened with modern science and supported with mechanization is ready to take challenges in the field of environment preservation; resource optimization, comparable productivity and soil health build up. Besides, the adoption of organic farming in group and desire of the organic farmers to enter into direct trade as entrepreneurs is also contributing to social, physical and financial capital build up.

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## Organic agriculture technology and sustainability

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Agriculture, the leading economy of the nation, is taking part in a momentous responsibility in the overall socio-economic fabric of the country accounting for 17.9% of the GDP in 2015 and about 50% of the workforce [The World Factbook (GDP), 2015]. It must meet the challenges of feeding the growing population while simultaneously minimizing its environmental ill impacts. Energy intensive conventional agriculture boosts the productivity in terms of jeopardizing the natural resources *vis-à-vis* overall ecological balances. Hence, there is need to focus on more environment friendly and sustainable approach to increase the agricultural production. One such alternative approach is organic agriculture that uses bio-fertilizer, bio-pesticides, green manure, compost etc. which do not harm environment and provides sustainable yields. Thus, the major aim of organic agriculture is to augment ecological processes that foster plant nutrition yet conserve soil and water resources. Therefore, besides targeting the productivity of the crops alone, efficiency *vis-à-vis* resource input of different organic agriculture production systems and their comparative study with conventional farming systems and technology generation is the need at this hour.

The principles of organic agriculture are guides to tailor organic practices to each individual farming location as organic farming systems fall into similar categories as those of conventional agriculture i.e. mixed, livestock, stockless and horticulture. In many countries, organic agriculture has affected most areas of agriculture with food production often starting in niche markets such as ‘direct to customer’ or on-farm processing. This has resulted in a multitude of sustainable and profitable organic enterprises emerging around the world showing that organic agriculture can have a central role in ensuring sustainable agriculture (Thompson, 2002). However, issues remain as to whether the productivity of organic farms is restricted by the supply of available nitrogen or should the farm scale nutrient budget be the tool for management of soil fertility? Further, how microbiology of soils managed under organic and conventional regimes varies or is the

soil fertility under organic farming system fundamentally different are some of the key issues that need to be addressed for achieving sustainability of organic agriculture.

The growth of organic agriculture in India has three dimensions and is being adopted by farmers for different reasons. First category of organic farmers are following organic cultivation traditionally may be due to compulsion of the scarcity of resources needed in conventional farming. Second category of farmers is those who have adopted organic recently comprehending the ill-effect of conventional farming and the third category comprises of farmers and enterprises which have systematically adopted the commercial organic agriculture to capture emerging market opportunities and premium prices. While majority of farmers in first category are traditional (or by default) organic, they are not certified. Second category of farmers comprises of both certified and un-certified but majority of the third category farmers are certified. India has brought more than 5.55 million ha area under organic cultivation. Out of this, cultivated area accounts for 0.78 million ha only while remaining 4.77 million ha is wild forest harvest collection area (Organic Farming Statistics, 2011-12, NCOF, Govt. of India).

### Conventional vs organic farming: quality aspects

The demand for organically grown food is increasing worldwide and concept of organic farming is gaining ground. The nutritional value of food is essentially a function of its vitamin and mineral contents, particularly those related to important beneficial function in animals and humans. However, from scientific point of view, the question of whether organic plant-derived foods are more nutritious than conventional ones remain. Conventional farming usually relies on massive doses of readily soluble forms of minerals fertilizer (mainly N, P, K form), whilst, organic farming relies on the incorporation of organic material into the soil, normally though use of animal manures as fertilizer. The fundamental aim of organic farming is the provision of healthy, high quality

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plant and animal derived foods. The concept of food quality can be defined in many ways. Often, the quality is based on extrinsic and intrinsic quality. The extrinsic quality is based on visual characters such as shape, size and colour. However intrinsic quality is based on nutrients or functional properties due to elevated level of phytochemicals or containing fewer pesticides (Renaud *et al.*, 2014). So there is no defined concept of quality. It also depends upon end user. The choice between organic or conventional farming system primarily depends upon the socio-economic factors. When farmer grows a crop, the first question arises: How profitable would be its produce? The answer depends upon the choice of farmer makes about what crop to grow, where to grow and how to grow. It is important to study the variation in nutritional quality and safety of plant derived food produced under both organic and conventional farming methods. The quality of produce is deteriorating with excess use of chemical fertilizers. The quality of soil is also affected as the mineral contents of soil are depleting. Thus, the productivity and quality of produce is affected.

### Physiological aspect of organic farming

Physiology of crop is a key regulator of yield and productivity. Organic agriculture helps in maintaining soil organic matter and enhances cation exchange capacity, chelating ability of micronutrients and water holding capacity of soil. Physiology of plant integrates both external as well as internal environment of the cell for better growth and development. Photosynthesis which is the major reaction of the conversion of solar energy to chemical energy requires nutrients for its biochemical reactions. Plants do not discriminate the supply of nutrients through organic mode or inorganic mode. But they always absorb them in inorganic mode. The questions on physiology of crop to be answered through organic culture technology are:

- a) Whether slow release of nutrients is beneficial for chlorophyll biosynthesis and the adequate mineralization is required for photosystem II activity for proper electron transfer reactions for generation of ATP and NADPH as an assimilatory power?
- b) Whether the carboxylation efficiency of Rubisco i.e. ribulose 1,5 bis phosphate carboxylase/oxygenase will be higher during organic mode or in inorganic mode?

### Pest management in organic farming

The impact of pests, diseases and weeds on food supply is high that they reduce production by at least one-third despite using pesticides worth about \$38 billion. In the past 50 years, pesticides use has increased tenfold, while crop losses from pest damage have doubled. Detrimental upshot of indiscriminate use of agro-chemicals to manage pests is well evident in crop ecosystem. As a result of growing concerns about health and environmental problems associated with pesticides, there are accelerated efforts from scientists for organic production. The focus in crop production is now gradually shifting towards on food quality and environment safety. In organic production the insect pests and diseases can be managed by using biological *viz.*, plant extracts, micro-organisms or minerals and cultural pest control techniques like crop rotation, mixed cropping, ground covers, field fallowing and other vegetation, encouraging biodiversity to boost soil organic matter levels and to provide shelter and food for natural enemies of crop pests and diseases although approved organic pesticides may also be used when necessary. Their aim is to support the diversity and activity of natural enemies (Kristiansen, 2006).

Thus, not only the quality of produce that will come through organic mode, but also will be free from toxins and pollutants which can be supplemented with higher resource use efficiency of crops for sustainable agriculture.

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## Organic farming: The changing agricultural landscape in India

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Over a period of seven decades after independence, the policies and R&D priorities in agriculture & allied sector made an impressive impact and transformed a food deficit nation into a surplus producer and net exporter of many food items. The growth in Agri-GDP of over 4% during XI Plan compared to a meagre 0.3% during '50s amply signifies this achievement. While economic indicators are always drive the attention of the policy makers, the importance of the sector is beyond these economic boundaries as agriculture not only provides majority of the ingredients for two square meal over 1.25 billion people of the country and raw material to thousands of agro-based industries but also provides earning opportunity to nearly 50% of the workforce. The production of foodgrains has reached to all time high at 266 million tons in 2013-14 from 50.82 million tons in 1950-51. During the period, the wheat production increased over 12 times, rice over 4 times and oilseeds over three times. The production of pulses which has been stagnating at 14-15 million tons during last two decades increased to over 19 million tons in 2013-14 sending a strong positive signal that country is inching towards self-sufficiency in pulses. However, burgeoning population and changing economies both at national level and at household levels, have created a new constituency of food demand that is produced naturally and free from harmful chemicals. This renewed the pressure for enhancing the production with diversified farming practices more oriented towards use of natural sources and organic materials as a source of nutrients for the growing plants and its protection from diseases and pests. The policy implications are much wider on organic farming and farmers to infuse competitive commercialization and bring organic farming on the forefront for better returns. These needs to be understood with a critical analysis of policies, priorities, programmes, opportunities and impediments in the changing land scape of Indian agriculture towards organic production vis-à-vis food security both nationally and the level of a household.

Technology led development in agriculture initiated during mid-60s has made significant contribution to achieve national food security with some limitations at household level. The Nation is now a surplus producer and net agricultural exporter, albeit short of pulses and edible oils. The domestic

production could help offset the global food crisis in 2008. The foodgrains production along with nutrient rich and high value food items like milk, fisheries, meat, horticulture and vegetables have also increased substantially. While production of many food items increased by leaps and bounces, the intensive agriculture caused heavy dent on natural resources as well as the quality of the produce that are often cooked in the kitchen of a normal households for dietary intake. The residues in food materials are apparently much higher and beyond the accepted limit of human consumptions, the incidences of chronic diseases are becoming common due to unhygienic and unhealthy food materials consumed regularly. As a consequence, the demand and choice for organically produced food items started increasing. During last decade about 4.72 million ha area was brought organic certification process which includes 0.6 million ha of cultivated agricultural land and 4.12 million ha of wild harvest collection area in forests. The export of organic products touched 1.65 lakh tons of about 135 commodities during 2012-13 worth approximately Rs 3300 crores. The domestic market is also growing at an annual growth rate of 15-25%. The production is not limited to the edible sector but also produces organic cotton derivatives (yarn, textile and apparels) and value added processed foods and functional food products. The twin benefits of organic agriculture of providing safe and healthy food and conserving the natural resources, environment, soil fertility and health is now well established. It is also proving commercially viable to growers due to increased demand in domestic and international markets.

### Growing food demand and organic farming

The projections for food demand and supply are available for 2020-21 (Planning Commission, 2012), 2022 (Kumar *et al.*, 2009), 2026 (Mittal, 2008) and 2030 (Kumar and Joshi, 2016). Considering the actual past patterns of observed demand and the fact that cereals consumption per capita has declined since at least mid-1990s, the Planning Commission's working group on Crop Husbandry, Demand and Supply Projections, has made projections of 277 million tons of foodgrains, 71 millions of oilseeds, 124 million tons of fruits and 189 million tons of vegetables for 2020-21. Added to

these are the increased demand for milk at 139.7 million tons, meat at 11.4 million tons, eggs at 100 billion numbers and fish at 12.8 million tons. These projections suggest a substantial increase in the production of majority of the food commodities except the foodgrains which is very close to the likely demand by 2020-21. To achieve these levels of production of various crops and commodities, the growth rate of domestic output need to be accelerated to 3.5 to 4% p.a. from the existing level of 2.4%. It is also noteworthy that India has very high levels of malnutrition and, although there are many reasons for this, deficiencies in calorie intake remain one of the most important. The main reason behind no increase in calorie intake per capita even though the incomes have been rising is declining cereals consumption. Added to this is that not only the share of cereals in total food expenditure declining but also the share of income spent on foods is falling under both rural and urban space. This is a major disjunction between a basic element of human development and other demands. The other dimension of changing food habits and demand is likely spur in the organic foodgrains and also horticultural produce. Given the very limited scope for additional virgin land available for organic farming, a very critical issue of promotion and substitution of crops and areas for organic farming needs to be streamlined.

### Challenges and opportunities

The last decade witnessed a welcome turn-around in the performance of agriculture and allied sector especially the productivity which has turn from deceleration to acceleration. However, several policy imbalances do exist that can prove to be major handicaps. The projections amply suggest that the productivity in agriculture has to be increased substantially along with adding value to the produce to increase production of food items but also enhance the income of the farmers. The Prime Minister on 29<sup>th</sup> July, 2014 in his address to ICAR scientists stressed upon second green revolution for broad-based, more inclusive and sustainable approach of farming to produce more food and other commodities without depleting the natural resources. The important but closely related issue the ways and the means to produce adequate food to meet the likely demand of millions of the people. The diminishing and deteriorating natural resources, changing economies, increasing abiotic and biotic stresses and farm holdings getting unviable are the formidable challenge. While challenges are there, the production opportunities lies in the multiplicity of the seasons and agro-climatic regions that offer attractive opportunities in offsetting the adverse impact of weather and

also open a new window to produce the same or alternate commodity in the next season to build upon the food stock. There are also some very high potential regions in the country that are underutilized and could be transformed into an alternate food bowl especially organic foods with appropriate technology support and efficient and effective input delivery and support services. The eastern region and hill states of the country are one such strategic area. The twin benefits of organic agriculture of providing safe and healthy food and conserving the natural resources, environment, soil fertility and health is now established. It is also commercially competitive. An annual growth of 16% is projected in the global organic food market during the period 2015 to 2020. This growth can be attributed to growing health concerns and increasing awareness about the health benefits of organic food. Added to these are increasing income levels and initiatives of the Governments, etc. Future growth in organic farming will require clear policies for certification and input use to distinguish between traditional inputs such as seed, feed and organic manure and modern inputs such as chemical fertiliser, pesticides and farm power and make a proper balance of investment to infuse organic technology and inputs for reaping higher harvest. The compatibility of domestic organic protocols with globally accepted protocols, availability of quality organic inputs for new areas, marketing, processing and branding needs special consideration. The value addition and processing under organic protocols with growers as owners can ensure better empowerment of rural youth and increases new avenues for rural entrepreneurship. An attempt has been made in the present paper to analyse the technologies, policies and priorities on organic farming in the country and suggest way forward.

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## Sikkim's organic journey

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Organic agriculture movements emerged in the 1930's and 40's in the major industrial countries like Britain, Germany, Japan and the US as an alternative to increasing intensification of agriculture, particularly the use of synthetic nitrogen (N) fertilizers. Synthetic nitrogen (N) began to become available after World War I and it enabled a 20 fold reduction in the volume and weight of fertilizer relative to manures, drastically reducing fertilizer transport and application costs per unit of N. As a consequence, use of synthetic nitrogenous fertilizers became a soil fertility management practice for the next 50 years and more.

This form of agriculture which can also be called conventional industrial agriculture produces high yields per hectare by using external inputs such as fossil fuel, synthetic fertilizers and pesticides that result in higher levels of greenhouse gas emissions, land degradation and depletion of natural capital.

The scientific basis for crop soil management based on organic inputs was developed around the same period- 1920's and 30's and the first use of the term "organic farming" was in 1940 by Lord Northbourne in his book *Look to the Land*. Northbourne used the term not only in reference to the use of organic materials for soil fertility but also to the concept of designing and managing the farm as an organic or whole system, integrating soil, crops, animals and society. This systemic approach is at the core of organic agriculture today.

When externalities associated— such as soil erosion; reduced natural resistance of crops to pests; loss of human health and life (caused by pesticides and other chemicals); loss of biodiversity, ecosystems and ecosystem services; contamination of water; and costs associated with climate change — are accounted for, the cost inflicted by intensive industrial farming on a country and its population outweigh its benefits.

Having understood the detrimental environmental impacts of conventional agriculture and its potential to contribute quite substantially to the global food supply, there is a renewed interest globally in organic agriculture.

### What is organic agriculture?

Organic agriculture is defined by International Federation of Organic Agriculture Movements (IFOAM) as: "*a production system that sustains the health of soils, ecosystems and*

*people. It relies on ecological processes, biodiversity and cycles adapted to local conditions, rather than the use of inputs with adverse effects. Organic agriculture combines tradition, innovation and science to benefit the shared environment and promote fair relationships and a good quality of life for all involved.*"

### Defining Sikkim's organic agriculture

Organic farming is not new to Sikkim. Farmers have been practising organic agriculture for several decades, wherein different farming practices were largely in harmony with nature and the use of synthetic agro-chemicals was negligible. The farmers used animal compost and crop residue recycling as the principal soil fertility management strategies. To this end the farms in Sikkim could be defined as organic by default.

Elsewhere, today's conventional or industrial agriculture is considered unsustainable because it is eroding natural resources faster than the environment can regenerate them and because it depends heavily on resources that are non renewable. Given Sikkim's position as a repository of biodiversity (Sikkim is located in one of the 'biodiversity hotspots' of the world) and with increasing severity of climate change, there is a need to increase food production in a sustainable way so as halt the degradation of ecosystems, ecosystem functions and the loss of natural resources and biodiversity.

At a time when the desire for a sustainable agriculture gaining universality, yet agreement on how to progress towards it remaining elusive, a decision was taken by the Government in the year 2003 through a resolution in the State Legislative Assembly to create farming methods and models that enhance sustainability and also mitigate climate change.

This was the first policy initiative towards developing an organic farming state and with this; Sikkim became the first State in the country to enact such a far sighted and visionary policy for adoption of organic farming concepts.

### Standards for organic certification

Countries and groups of countries have developed their own specific regulatory systems for inspection and certification of "organic agriculture" and "organic products" in order to enable the distinction between organic and non—organic

products in the market place.

To provide a focussed and well directed development of organic agriculture and quality products, the Ministry of Commerce & Industry, Government of India has launched the National Programme on Organic Production (NPOP) and notified the same.

In case of Sikkim, the NPOP standards are being followed for organic certification. The NPOP provides for standards for organic production, systems, criteria and procedure for accreditation of certification bodies as well. The standards and procedures have been formulated in harmony with other International standards regulating import and export of organic products.

The certification programme in Sikkim has been carried out by engaging 6 certification bodies and 14 service provider agencies in accordance with the criteria for carrying out certification of conformity as laid down by NPOP.

### Initiatives of Government of Sikkim

Organic agriculture requires significant investments in capacity and skills development of farmers and the value chain. To promote organic farming, a number of initiatives were taken by the Government of Sikkim since 2003 and such activities are being pursued further with more intensity now, mainly looking at increasing prospects for exports of organic agricultural products. While doing so, the Government encountered a number of critical aspects for development and bottlenecks- such as production, marketing, supply chain, training, research etc which have been identified and worked upon.

Several notable initiatives were taken between the period 2003 and 2010 such as framing of action plan, discouraging use of chemical fertilizers, providing manure production infrastructure such as rural compost, vermicompost, establishment of biofertilizer production unit, soil testing facilities, organic seed production units etc. As a part of capacity building of farmers, numerous trainings have been imparted to farmers about organic farming and its advantages.

- **May, 2003-** A concept paper for Organic Farming in Sikkim was prepared with road map and action plan.
- **May, 2003-** Steps to discourage the use of chemical fertilizers initiated. The chemical fertilizer consumption was planned to be reduced in a phased manner by tapering off subsidy by 10% on fertilizers. The Government subsidy has been nil from the year 2007-08.
- **17<sup>th</sup> September, 2003-** "Sikkim State Organic Board" was constituted.
- **May, 2003-** Promotion of on farm production of organic manures initiated. The Department initiated action to supplement the nutrient requirements of the crop plants only through organic sources by adopting various technologies of recycling the farm wastes like rural composting, vermicomposting, EM composting,

biodynamics, etc., and making the State chemical-free.

- For capacity building the Government is training all the farmers to make appropriate changes in the package of practices and adoption of better technologies. Officers and field functionaries of the Departments are being trained on organic farming within the State as well as outside the State. The Extension Officers are being sent to various places to learn about organic farming.
  - Various infrastructures such as a facility for post-harvest technology, Seed Processing Centre, one each at Majhitar and Jorethang, have been established.
  - **2008-** Soil testing laboratories established. A fleet of two Mobile Soil Testing Vans included.
  - **2006-09-** Eight units of vermi-culture hatcheries had been established in five Government Farms and three KVKs of the State.
  - **2008- Centre of excellence for organic farming** at Nazitam and Mellidara farm were established by developing the infrastructure to produce organic manures using various technologies available in the country.
  - **2003-2009-** Adoption of bio-village programme- 396 villages were adopted as bio-village in collaboration with Maple Orgtech Pvt. Ltd. Kolkata.
  - **2008-09-** A Ginger processing unit was established at Birdang Farm, West District. It is being operated by SIMFED.
  - **2009-** Biofertilizer production unit was established in the State.
  - **2009-10-** Technology Development through research- A system comparison trials conducted at Bermiok farm with the consultancy service of ICCOA, Bangalore.
- Pilot projects on organic certification
- **2006-** A Gangtok based local NGO, M/S Mevedir, took up 1313.103 ha for third party group certification with their own resources. Two groups were registered and the number of registered farmers was 982. The Service Provider was M/S Mevedir and the certification agency was NOCA.
  - **2007-** The Department of Science and Technology, took up 2825.144 ha for third party group certification in two phases. The total registered groups were seven and the number of registered farmers was 2876. The Service Provider engaged was M/S Morarka Foundation, Jaipur and the Certification Agency was Onecert Asia.
  - **2008-** KrishiVigyan Kendra (KVK), FS & ADD, Government of Sikkim, took up 259.758 ha for third party group certification. One organic group was registered and the number of registered farmers was 170. The Service Provider was M/S Mevedir and the Certification Agency was SGS.
  - **2008-** The H&CCD Department, has took up 3758.731 ha for third party group certification in two phases. The total registered groups were eight and the number of

registered farmers was 3285. The Service Provider engaged were Mevedirand Morarka Foundation, Jaipur and the certification agencies were IMO control, and Onecert Asia.

### Sikkim Organic Mission (SOM)

The organic movement in the State was given a formal approach with the launch of the Sikkim Organic Mission on 15<sup>th</sup> August, 2010 during the Independence Day celebrations. Before its launch, a two day National Level Workshop on Organic Farming, “Vision for Holistic and Sustainable Organic Farming in Sikkim- The Future Thrust” was organised in March 2010 to create a road map.

A time frame was set to bring the entire agricultural land under organic management by the end of 2015. All these decisions have been made by the Government in the context of increased need to support sustainable development, enhance environmental reality, adopt to climate change effects, safe guard human health, preserve indigenous knowledge, plant varieties and animal breeds as well as promote socio cultural development.

Some notable initiatives under SOM

- **August 2010-** Three Livelihood Schools were established at Tadong, Bermiok and Daramdin. More than 800 educated and unemployed youth were trained and more than 700 engaged in ICS and Certification.
- **November 2010-** Capacity building of 12 Science graduates and post graduates arranged at GDC Morarka Foundation, Jaipur. Some of them are working as the Service Providers, others as project in-charge.
- 74,303 ha of agricultural land set as target for conversion
- 14 Service Providers and 6 Certifying Agencies engaged for ICS and certification
- **2010-11-** Automated Greenhouses were established for production of disease free quality planting material.
- **2010-11-** An Organic retail outlet at G.K. New Delhi, established.
- **2012-13-** A chapter on organic farming included in the school course curriculum.
- **2012-13-** In the trade licence, the “chemical inputs” substituted by “inputs of organic origin” thereby avoiding sales of chemical inputs.
- **2013-14-** State Organic Policy and perspective five years plan prepared.

Status of organic certification (2015)

Sl.No	Status	Area (Ha)	No of farmers
1	Certified area	74,190.871	64,726
2	In-conversion-II area	1,978.733	1,501
	<b>Total</b>	<b>76,169.604</b>	<b>66,227</b>

### Employment generation

More than 800 educated and unemployed youth who were trained under the livelihood schools for engaging for the certification programme and more than 700 of them were engaged in ICS and certification activities under the Mission. It is also worthwhile to mention here that a major portion of the certification fee paid to certification agencies and service providers is spent on the staffs that have been engaged by these agencies that mostly belong to Sikkim.

### Legislation

In order to regulate the import, sale, distribution and use of inorganic agricultural, horticultural inputs and livestock feed to prevent risk to human beings or animals and environment and to make the State of Sikkim an organic State, “The Sikkim agricultural, horticultural input and livestock feed regulatory Act, 2014” has been legislated and its rules have also been notified.

### Publication

Sikkim is the first and only state to bring out a publication titled, “Hand book of organic crop production in Sikkim” which has been prepared in a scientific manner based on field tested technology by the Sikkim Organic Mission under Department of Agriculture/Horticulture in collaboration with ICAR Research complex for NEH Region, Sikkim Centre, Gangtok, Sikkim. The handbook provides for complete package of practice on organic farming methods for more than 30 crops.

### Organic Certification Agency

Sikkim State Organic Certification Agency (SSOCA) was established by the State Government in 2015 and is awaiting accreditation for organic certification from APEDA. Once accredited, SSOCA will be one of the 26 certification bodies in the country and will be able to cater to the North Eastern States.

### Sikkim organic festival

Sikkim, by the end of the year 2015, was able to convert more than 76,000 ha of its cultivated area into organically certified cultivation including in conversion. And to mark this special occasion, the Sikkim Organic festival-2016 was organised in January, 2016 in which Hon’ble Prime Minister of India, Shri. Narendra Modi graced the occasion and declared to the world of Sikkim becoming the first completely organic farming State in the country.

### Marketing

Organic production and marketing is viewed as an opportunity to support Sikkim in its next stage of development. Through continued certification of the agricultural land, the Government of Sikkim is committed to creating opportunities for the next generation of family farmers.

This decision was made in the context of the increased need to support sustainable development, enhance environmental security, adapt to climate change effects, safeguard human health, preserve indigenous knowledge, plant varieties and animal breeds as well as promote socio-cultural development.

From the year 2016-17, the Government of Sikkim is implementing the Centrally Sponsored Scheme, "Mission Organic Value Chain Development for the North Eastern Region (MOVCD-NER)". The scheme aims at developing certified organic production in a value chain mode to link growers with consumers through an integrated and concentrated approach with end-to-end facilities for production, processing, storage and marketing.

Through this scheme it is expected to replace conventional farming/subsistence farming system into local resource based, self sustainable, high value commercial organic enterprise

#### **Difficulties faced and achievements**

The reality with the organic journey is that many of the

requirements have remained inadequate. Over the past decade, modest resources have been directed toward organic farming. The Government has pooled resources from the State Plan and various central schemes like, Horticulture Mission in North East (HMNE), Macro Management in Agriculture (MMA) and RashtriyaKrishiVikasYojna (RKVY).

However, the resources allocated to were still far disproportionate to the investment needed to realize the great potential of organic farming. Under these circumstances the transformation from conventional to organic has taken place. The entire agricultural land of more than 76,000 ha of land has been brought under organic management.

This is no ordinary achievement. This has been done in an era where organic crop production techniques are still under development and no standard protocols available. It was a small step but a giant leap. As on date, Sikkim, with only 0.2 % of the geographical area of the country, has accounted for more than 12% of the total organic area in the country (76,000 ha out of 6,20,000 ha).

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## Effect of Stimplex<sup>®</sup> on yield performance of tomato inorganic management system

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Organic agriculture has gained international recognition as a valid alternative to conventional food production both in developed and developing countries. The increasing consciousness about health hazards related to the contamination of farm produce due to excessive use of chemical fertilizers and pesticides has provided a thrust to this form of farming (Nandwani and Nwosisi, 2014). Stimplex is the seaweed (*Ascophyllum nodosum*) extract used as a bio-stimulant known to have synergistic effect on the yield, growth and development of the plants. As in organic farming there are very limited resources of fertilization are available. Bio-stimulants provide nutrition and the alternates for the inorganic-synthetic fertilizers and beneficial as they are produced from algae. Seaweeds is an essential part of marine coastal ecosystems, contains all plant nutrients, vitamins, auxin and antibiotics. Brown seaweeds are the most commonly used in agriculture and horticulture (Blunden *et al.*, 1986) and among them *Laminaria* and *Ascophyllum* seaweeds used for processing into dried seaweed and liquid extract. Recent studies have investigated a wide range of beneficial effects of seaweed extract applications on plants such as early seed germination and establishment, rich source of organic matter and bio-fertilizer, improved crop performance, resistance to insect pest and diseases, and enhances shelf life of perishable products. Stimplex<sup>®</sup> is a commercially used extract of seaweed (*Ascophyllum nodosum*) registered as plant bio-stimulants, contains trace amounts of all elements, vitamins, amino acids, auxins, cytokinins (Crouch *et al.*, 1992; Crouch and van Staden, 1993; Spann and Little, 2010). *A. nodosum* seaweed extract have been described to enhance fruit yield and quality of citrus (Fornes *et al.*, 2002). They have also been reported to increase drought stress tolerance of vegetables and flower seedlings (Neily *et al.*, 2010). Foliar applications of *A. nodosum* extract used as substitute to manage the number of thrips per leaf area unit in avocado transplants (Morales-Payan and Norrie, 2010).

Tomato (*Lycopersicon esculentum*) is one of the world's economically important, nutritious and widely grown vegetable in the world (Asgedom *et al.*, 2011). Lycopene is a bright red carotene which antioxidant properties two times

higher than  $\beta$ -carotene in destruction of free radicals (Liu *et al.*, 2004). According to Koyama *et al.* (2012), *A. nodosum* extracts can increase tomato plant growth and yield and many investigations reported that environmental friendly bio-stimulants effects on crop development, growth and yield and fits well with sustainable and ecological agriculture.

The objective of the present investigation was to compare the tomato fruit yield grown under organic management system and to observe the effect of Stimplex<sup>®</sup> (*Ascophyllum nodosum*) liquid seaweed extracts on fruit yield in four cultivars, i.e. Black Cherry, Brandywine, German Johnson, and Roma.

### MATERIALS AND METHODS

Organic seeds of four tomato cultivars, i.e. Black cherry, Brandywine, German Johnson, Roma were obtained from Johnny seed company, Maine. Seeds were sown in potting trays (72 cell) using organic potting mix, and kept in the greenhouse for 3-4 weeks. Transplants of four cultivars transferred in the field after 6 weeks of sowing. For each cultivar, 3 replications used, 12 plants/block, total 36 plants were transferred keeping a control or untreated and treated with stimplex. Stimplex<sup>®</sup> was procured from Acadian Company, Canada. Six plants in each row were treated and six untreated, total twelve plants/row/cultivar. The experiment was conducted using randomized block design (RBD) with three replications. Plants were spaced 3 ft. between rows and 2 ft. plant to plant distance within row. Drip irrigation system was used to irrigate plants. Nutri-rich (Organic Materials Review Institute-OMRI) 100% Natural Organic Fertilizer (4-3-2 Ca 7%) and Nature Safe (OMRI listed 8-5-5 Pelleted Grade) fertilizers were applied in the field on weekly basis in order to provide 5.23lb nitrogen, 10.46lb phosphorus and 10.46lb potash. During 3<sup>rd</sup> week of June, tomatoes were conditioned with weekly 2.5% Stimplex<sup>®</sup> crop bio-stimulant applications (i.e. 2.5ml Stimplex<sup>®</sup> in 1 gallon of deionized water). Seaweed extract treatment were applied at 2.5 ml/gallon as foliar spray once in 2 weeks and untreated plants served as control. At the end of 3<sup>rd</sup> application of Stimplex<sup>®</sup> treated plants received a total of 7.5 mL of Stimplex<sup>®</sup> prod-



uct. During the 6-week conditioning period all the plants were fully irrigated every 2-3 day as needed. Cultivation procedures (weeding, irrigation, fertilization, and plant protection against pest and diseases) were performed according to National Organic Program (NOP) rules and production practices for tomatoes.

At the end of the study, Fruits were harvested gradually as they turned red ripe fruit and achieved the physiological maturity. Data were collected from all 1-6 plants/replication, total 18 plants on maturity, number of fruits, total yield, marketable yield, fruit weight, fruit dimension for each cultivar. The percentage of fruits with infectious diseases, cracks and blossom end rot in total yield was separated as culls.

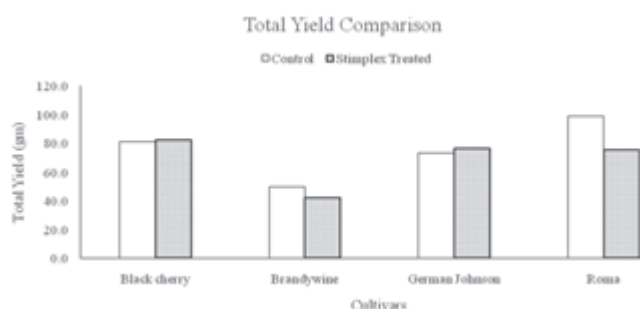
### Statistical analysis

All data were analyzed using Microsoft Excel and SAS Software. All data attributes were carried out in triplicates for each cultivar. Results were expressed as means  $\pm$  Standard error. Analysis of Variance (ANOVA) test (5% Confidence interval) was used to determine the significant differences between each cultivar.

## RESULT AND DISCUSSION

### Yield Performance

All four tomato cultivars showed different responses to the application of bio-stimulant (*Ascophyllum nodosum* seaweed extract) with respect to the yield performance. Stimplex treated plants of German Johnson and Black Cherry cultivars produced significantly higher yield than control. However, untreated Brandywine and Roma cultivars produced higher yield than stimplex treated plants (Fig. 1). Scientist Zodape *et al.* (2010) conducted an experiment and applied seaweed extract to tomatoes using different concentrations (i.e. 2.5, 5.0, 7.5, 10.0%) and reported that foliar application of seaweed bio-stimulants (*K. alvarezzi*) at 5.0% concentration recorded highest yield of tomatoes (38.09 tons/ha). However, In the current study foliar application of seaweed bio-stimulant (*A. nodosum*) at 2.5% concentration showed increment in yield for two cultivars German Johnson (20.05 tons/ha) and Black Cheery (22.65 tons/ha) and obtained less yield for Brandywine (11.71 tons/ha) and Roma (20.8 tons/ha) than



**Fig. 1.** Total yield performance of Stimplex treated and control tomato cultivars

untreated plants. There was non-significant increase of production was detected in stimplex treated tomato plants because of the low concentration (2.5%) of Stimplex have been used in the experiment. Yield data obtained from current study were in the agreement with the research conducted by Zodape *et al.* (2010) that concentration of SWE should be higher (5.0 %) to influence the production of tomato cultivars. Additionally, further research trials needed.

### Disease and insect Infestation

Foliar application of seaweed extract enhances the defense mechanism of plant to control diseases. Crouch and Van Staden (1993) reported that seaweed extract treated plant provides resistance to the plant from *Meloidogyne incognita*. There were some visual observations made for tomato plant in current study. During month of August, *Septoria* leaf spot and *Sclerotinia* stem root (soil borne) diseases was noticed in controlled tomato plants, which affected stem and leaves. Regalia (OMRI) fungicide applications (0.5%-1% v/v in 100 gallon of water/acre) suppressed the disease symptoms. Stimplex treatment led plants disease free, stronger stem, and growth of tomato plant, per previous studies (Crouch and Van Staden, 1993).

### Growth and Development

Stimplex contains micronutrients, amino acids and natural chelating agent to increase nutrient availability and usage. Amino acids biosynthesize gibberellins in plant tissue and directly influence the physiological activities of plant and development (Zewail, 2014). Additionally, El-Ghamry *et al.* (2009) reported that Amino acids increased plant height, number of leaves and branches of beans significantly. In current study, seaweed treated plants showed increase in plant height (Table 1) for each cultivar. Stimplex treated cultivar Brandywine recorded highest average plant height (100.1 inches) among all cultivars.

**Table 1.** Average Plant Height in different tomato cultivars

Treatment	Cultivar	Plant Height (inch)
Control	Black Cherry	44.7 $\pm$ 0.66
	Brandywine	95.1 $\pm$ 1.26
	German Johnson	86 $\pm$ 0.32
	Roma	48.5 $\pm$ 0.98
Stimplex Treated	Black Cherry	46.5 $\pm$ 0.92
	Brandywine	100.1 $\pm$ 0.081
	German Johnson	94.7 $\pm$ 0.43
	Roma	52.6 $\pm$ 0.37

## CONCLUSION

Seaweeds have received a greater acceptance in horticulture as plant biostimulants. Foliar application of stimplex

(*Ascophyllum nodosum*) seaweed extract increased plant yield for Black Cheery and German Johnson cultivars at 2.5% concentration. However, fruit yield is most likely to increase if concentration of extract is increased to 5.0%. Moreover, stimplex treated plants show increased plant growth and enhances defense mechanism to control diseases i.e. *septoria* leaf spot and *Sclerotinia* stem rot.

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# **Symposium 3**

## **Agriculture Diversification for Sustainable Resources**





## Agricultural diversity and ecosystem sustainability

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This paper will briefly discuss the ecosystem sustainability attributes of multispecies agricultural systems in comparison with sole crop systems, using the current state of knowledge on ecosystem services of agroforestry systems as a case in point.

### Agricultural diversity

The scope of the term “Agricultural Diversity” as used in this paper is narrower than that of the commonly used term “agricultural biodiversity” (also known as “agrobiodiversity”). Agricultural biodiversity encompasses the variety and variability of animals, plants, and microorganisms that are necessary to sustain key functions of the agroecosystem and includes the whole spectrum of domesticated crops and their wild relatives including woody perennials, domestic and wild animals, non-harvested species within and outside the production agroecosystem, and others. The term Agricultural diversity as used in this paper, however, is limited to the nature of plant species and their management in land-use systems, in sole stands of a preferred species (as in most agricultural or planted forestry systems) versus mixed stands of species of varying forms and growth habits (herbs, shrubs, and trees) in different temporal and spatial patterns but all on the same management unit.

### Sustainability

Coming to sustainability, the other major part of this paper, the word “sustainable” has been used in European languages since the early Middle-Ages. But it was with the publication of the United Nations’ WCED (World Commission on Environment and Development) report *Our Common Future* in 1987 that it was introduced into and became popular in the agricultural and developmental vocabulary. In spite of the numerous definitions and explanations that have been proposed, the WCED definition of sustainability still continues to be widely used: “meeting the needs of the present generation without compromising the ability of future generations to meet their own needs.” One of the oldest and most common meanings of the verb “to sustain” is to keep a person, a community, or the spirit from failing or giving way, to keep it at the proper level or standard; an equivalent of this verb is “to

last,” meaning to go on existing or to continue. Thus, the concept of sustainable development entails the balancing of preservation with economic advancement, acknowledging that economic advancement typically comes at a cost to the environment. These contradictions manifest themselves in the “ecology–economy divide” that is a major discussion point in the global development agenda today.

### Ecology – economy divide

From the ecologist’s perspective, the economy is a subset of the environment; all economic activity, indeed life, depends on the Earth’s ecosystem. This view recognizes that the resources (water, gases, nutrients, etc.) are finite, and the cycles thereof that keep us alive are bound by constraints. That means resource consumption beyond regenerative capabilities equate to future deficits. Upon these grounds, ecologists call for “intergenerational equity,” seeking to protect nature and natural resources for the benefit of future generations. Traditional economists, on the other hand, view the environment and its benefits as part of the economy, implying that benefits derived from the environment are considered infinite and substitutable. This translates into the belief that future generations are not affected the present-day undervaluation and/or degradation of natural resources, and fails to recognize externalities. The validity of this economic thinking, however, is questioned based on historical examples calamitous consequences of unscientific agricultural development.

### Historical examples of the ecological cost of agricultural development

Food shortages caused by environmental destruction undermined several ancient civilizations to the point of collapse. Most of such declines can be traced to one or two damaging environmental trends. The Sumerian civilization (that occupied a region in the lower valley of the Euphrates River in the Near East, fifth to third millennium BCE) collapsed due to crop failures caused by rising salt levels in soils because of a flaw in the irrigation practices. The Mayan Empire (Mexico, 2000 BCE to 600 CE) collapsed due to soil erosion and loss of soil fertility caused by forest clearing. Contemporary experience of the Green Revolution is that in spite of the “miracu-

lous” gains in cereal production, some of the GR methods have caused serious consequences: shrinking forests, eroding soils, deteriorating rangelands, expanding deserts, rising atmospheric carbon dioxide, and unpredictable water-table fluctuations.

### **Ecosystem services: the cornerstone of agricultural sustainability**

The above examples illustrate that the ineffectual balancing of economy and environment can have disastrous results. Sustainable agriculture, therefore, is not an option, but a must. Fundamental to maintenance of agricultural sustainability is the concept of ecosystem services. Simply stated, ecosystems refer to the organisms and the non-living environment with which they interact, and ecosystem services are the benefits people derive from ecosystems. These services include life-supporting functions of nutrient cycling, water-quality enhancement, and, in a self-perpetuating fashion, continued biological diversity. The United Nations Millennium Ecosystem Assessment has categorized these multifunctional ecosystem services as:

1. Provisioning services: providing food, energy, timber, fodder ...etc.
2. Regulatory services: carbon sequestration, microclimate modification, erosion control ...
3. Supporting services: biodiversity conservation, pest and crop disease management ...
4. Cultural services: cultural diversity, spiritual and religious values, social relations and cultural heritage values, recreation and ecotourism ...

### **Sustainability of sole-crop-vs. multi-species systems**

Compared with sole-crop (monoculture) stands of crops, the multi-strata, multi-species ecosystems provide a wider range of these ecosystem services. Prominent among these that have been widely recognized include provisioning services through production of fruits, nuts, vegetables, spices, and medicinal plants; and regulatory services such as improvements in soil organic matter status and water holding capacity resulting from better coverage of soil by foliage of multiple species leading to reduction of soil temperature and consequent reduction in soil organic matter oxidation, as well as reduced soil erosion. Compared with sole crop systems, mixed species systems also provide better supporting services such as enhanced biodiversity (by providing habitats for both animal and plant species), and cultural and recreational services. The underlying scientific foundation of such improved sustainability of multispecies systems is the “Niche Complementarity Hypothesis” that states that a larger array of species in a system leads to better and more efficient use and sharing of resources leading to a broader spectrum of resource utilization making the system more productive. The manifestations of these ecosystem services in land-use systems can be explained by considering them in the context of agroforestry

systems that are considered as the epitome of sustainability.

### **Agroforestry systems**

Agroforestry entails the purposeful growing of trees and crops, and sometimes animals, in interacting combinations for a variety of objectives, on the same unit of land. Over the past 35 years, agroforestry has been transformed from a vague concept into a robust, science-based, land-use discipline. Today, agroforestry is at the forefront of numerous development agendas, particularly in developing countries. The potential of agroforestry to sustain crop yields, diversify farm production, and provide ecosystem services has been well demonstrated in both the scientific literature and practical applications. The perceptions regarding the potential of AFSs to render ecosystem services at a higher level compared with single-species stands of croplands and grazing lands are based on solid scientific foundations.

The major, recognized ecosystem services of agroforestry systems (AFS) can be categorized into the primary scales at which they operate:

- Local: Soil-productivity improvement
- Landscape: Water-quality enhancement
- Regional: Biodiversity conservation
- Global: Climate-change mitigation.

### **Estimating ecosystem services of agroforestry systems**

The biophysical and ecological measurement of the sustainability of the systems will depend on how each of these ecosystem services can be measured and quantified at various spatial levels: plot/farm ! watershed ! regional ! global. Various analytical procedures can be used to measure the different parameters and entities of each of the ecosystem services discussed above. Numerous reports are available regarding the measurement and estimations of several of these parameters, the most common being carbon sequestration under AFSs. These studies, however, exhibit enormous variability in terms of their nature, degree of rigor, and extent of detail. Therefore, it becomes difficult to compare the various datasets based on uniform criteria and hence to draw widely applicable conclusions. Nevertheless, many aspects of the analyses of the carbon-sequestration (and climate-change-mitigation) potential of AFSs apply to other multispecies systems as well. Even if/when reliable quantitative estimates become available, the bigger question of the value that the society assigns to or is willing to accept for such services will be a major issue.

### **Sustainability science**

As the concluding section, the emergence of “sustainability science” as a cross-cutting sub-discipline also needs to be mentioned. Sustainability science arose from the realization that sustainable development is an aspiration to improve quality of life (development) in an enduring (sustainable) manner and that it can be accomplished only by acting across several

scales of time and space; it is a trans-disciplinary approach that integrates and synthesizes the theory and practice of the quantitative (natural) and qualitative (social) aspects. It is not confined to the borders of traditional disciplines, but draws from sociology, ecology, and economics, among other disciplines, allowing for a dynamic approach to meeting the “needs

of present and future generations while substantially reducing poverty and conserving the planet’s life support systems.” It does not seek a broadly applicable “correct” decision; it is about understanding the dynamics of evolving *social-ecological systems*. These tenets of sustainability science can be explained in terms of the attributes of multispecies systems.

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## Possibilities, pre-conditions and pathways for achieving crop diversification in South Asia

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Cropping diversification is often considered a foundation for sustainability, but transitions to diversified systems often occur in an unpredictable manner that may or may not be supported by agricultural development programming and government policies. The potential justifications for diversification are varied and include: enhancing profitability, increasing resilience, improving ecosystem services, pest suppression, and rationalizing resource use including fertilizer and irrigation water (Lin, 2011; Hazra, 2001). Broadly construed in the context of staple crop production, diversification at the field scale can take many forms including direct crop substitution (e.g. maize for wheat or rice) and opportunities for intensification by adding more crops to the annual rotation (e.g. development of winter fallows). At the farm enterprise scale, some opportunities also exist to bring new areas into cultivation with emerging production technologies.

At a global scale, the spread of 'planned' (i.e. evidence-based and policy supported) diversification has been slow, particularly considering the putative benefits associated with adoption (Lin, 2011). Prior to launching new agricultural development programming, it is useful to consider the achievable benefits, inherent risks, and enabling environment required to support the emergence of diversified systems. In this paper we present regional examples from South Asia that address these dimensions of diversification emerging from work supported by the Cereal Systems Initiative for South Asia ([www.csisa.org](http://www.csisa.org)).

### 1. Major opportunities for diversification

#### *Increasing incomes through triple crop systems*

In order to improve the overall productivity of the dominant cropping systems of the Eastern Indo Gangetic Plain (E-IGP), the productivity of a variety of cropping systems has been assessed in farmers' fields and also in controlled condi-

tions with Indian Agriculture Research Institute, Pusa. The highest-yielding systems were: maize followed by (fb) mustard (6.4 t/ha wheat equivalent yield), maize fb wheat (7.7 t/ha), rice fb mustard fb mung bean (9.0 t/ha), rice fb wheat (9.1 t/ha), and rice fb mustard fb maize (11.9 t/ha).

Profitability analyses indicate that the most profitable system is short duration rice fb mustard fb mung bean (US\$ 2,226/ha), with the next most profitable systems being: short-duration rice fb mustard fb maize (US\$ 1,880/ha), medium-duration hybrid rice fb long-duration wheat (US\$ 1,143/ha), and long-duration rice variety fb short-duration wheat (US\$ 988/ha). These results demonstrate that triple-cropping systems predicated on reducing the growth duration of rice can transform the profitability of staple crop production systems in the IGP.

#### *Foregoing winter fallows*

To meet future food needs, the potential to expand the agricultural frontier in South Asia is limited because arable land reserves are nearly exhausted. In Bangladesh, the situation is worse with rapid urbanization causing a shrinking of cropland from 91% to 81% of the country's total arable area in the last three decades. Fortunately, there is considerable scope to increase cropping intensity (e.g. number of sequential crops cultivated per unit area per year) in many of CSISA's working environments, especially in Southern Bangladesh and Odisha, where single monsoon rice cropping and subsequent fallowing is common. A recent IARI analysis suggests that Odisha has the highest dry season fallow area in all of Eastern India, with 4.7 m ha lying idle during the winter – additional 'upland' areas in the plateau are often left fallow during *khari*. In Bangladesh, policymakers have targeted fallows intensification through the use of surface water irrigation as a primary objective of the most recent country investment plan.

<sup>1</sup>Adopted from Krupnik *et al.* (*in press*) 'Sustainable crop intensification through surface water irrigation in Bangladesh? A geospatial assessment landscape-scale production potential.' *Land Use Policy*.



Drivers of change favoring fallows intensification are not only future-oriented. The emergence of large output markets in the form of feed mills represents a major new avenue for income generation and intensification in these areas. The average monthly income of Indian farmers is approximately Rs 6,500 (\$100), and even lower in the eastern states of UP, Bihar, and Odisha. Under the right circumstances, maize can be an extremely profitable crop with net returns exceeding \$1,000 ha<sup>-1</sup> even in the tribal-dominated areas of the Odisha plateau. This level of profitability, however, is wholly contingent on robust linkages to output markets.

In fallowed areas, two distinct intensification pathways are possible. The first prioritizes ‘higher yield – higher input’ cereals like wheat, rice, and maize, which require nutrient, weed, and irrigation management to achieve higher productivity. The second pathway relies on intensifying ‘extensive’, lower-input crops such as mung bean, which are normally grown in rainfed conditions without inputs, but which can yield 50% more with a single irrigation. Progress towards diversification must occur within a holistic framework that values quantification of farmer decision processes, market development efforts, and the sustainability dimensions of intensification.

*Coping with a weak and variable monsoon*

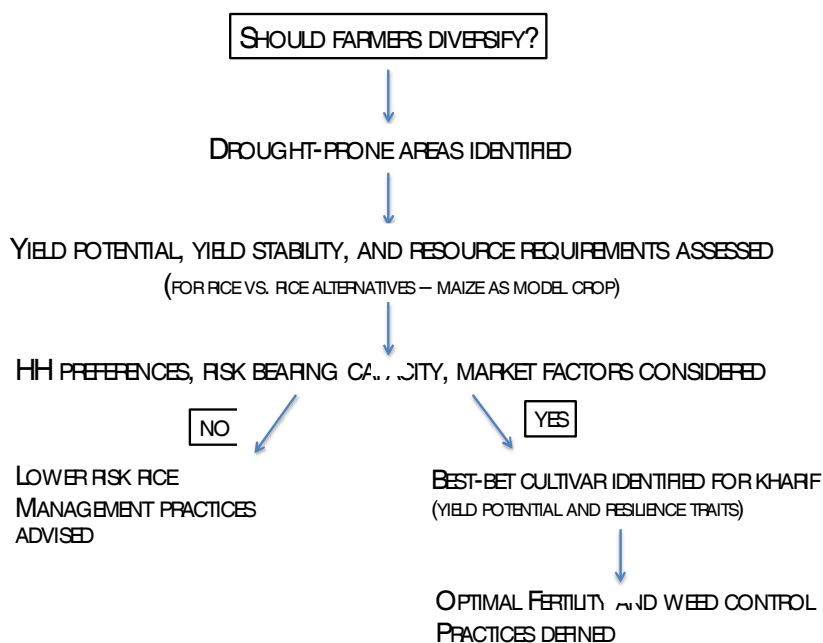
Farmers in CSISA’s target geographies in India and Nepal rely almost exclusively on rainfall to produce crops during the monsoon (*kharif*) season. In five of the last seven years, monsoon rains have been weak, with uneven distribution, resulting in yield reductions from late planting (or no planting) and in-season drought stress. The consequences of insufficient coping strategies for monsoon variability can be extreme: In 2009, aggregate production declined by 38%. Although the

drought experienced in 2014 was not as severe (all-India departure of 12.3% from mean rainfall), estimated losses in India were around US\$ 30 billion, with national GDP consequently decreasing by about 1.7%.

On average, approximately 440,000 ha of cropland that could be cultivated is left fallow every *kharif* season in Bihar and Eastern UP because of unfavorable weather. If these areas were cropped, we estimate an average profitability gain of US\$ 628 m per season in these two states. We roughly estimate that 136,000 ha of cultivatable land is similarly fallowed in Nepal. South Asia is a mosaic of production environments, with soil gradients that vary significantly as a function of sediment deposition processes from the river systems that cross the region. Where irrigation is absent or cost-prohibitive, especially on coarser-textured soils, farmers may gain yield and higher levels of production stability by diversifying into crops like maize or soybean as *kharif* season alternatives and away from rice. The transition may be most important for smallholders with lower risk-bearing capacity, although if the alternative crop is meant for market rather than home consumption, farm-gate price volatility may constrain adoption.

**2. Validating the benefits of diversification through long-term trials**

A holistic approach and long-term studies are needed to evaluate the benefits and trade-off associated with adoption of diversification, especially when coupled with innovative management practices such as ‘conservation agriculture’ (CA). To address knowledge gaps in the most intensified rice-wheat cropping systems in South Asia, a production-scale research platform was established at ICAR’s Central Soil Salinity Research Institute, Karnal, Haryana, India in 2009 with the intent of identifying a new generation of resource-efficient, high-



yielding cereal systems, that draw on the principles of CA, precision agriculture, and diversification. Overall objectives of this research platform were (1) assess the performance (short- to long-term) of different cereal-based cropping systems within key scenarios of agricultural change, using a wide range of indicators (e.g. yield; resource-use efficiency; crop, soil, and environmental health; economics; and energy).

As a *kharif* diversification option for rice, maize yields under CA increased over time with rice equivalent maize yields lower in year 1 (on average by 30%) but either similar or higher than rice in all subsequent years with maximum yield of 9.4 t ha<sup>-1</sup> in 2012-13. The cumulate impact of CA resulted in improved soil physical properties especially in infiltration rate. Just as importantly, results demonstrate that irrigation water application in maize was 86-89% lower than rice under different crop establishment methods. These results suggest that maize can be a viable diversification option in those areas where economic water scarcity due to declining groundwater tables are a policy priority and a looming threat to regional food security.

### 3. Defining the niche for diversification: ex ante technology targeting in Bangladesh<sup>1</sup>

In contrast to the NW IGP, staple crop production in the risk-prone Eastern Indo-Gangetic Plains is less intensive, especially during the drier winter months when large tracts of land are left fallow or are used to grow rainfed and low-yielding legumes. Seeing opportunity to boost staple crop production, national policy makers and external donors have reprioritized agricultural development investments in this impoverished region. Use of groundwater to support irrigation and intensified double-cropping, however, is not considered viable because of saline shallow groundwater and the prohibitively high installation and water extraction costs from deeper aquifers. Nevertheless, the region's network of largely underutilized rivers and canal resources could be tapped to provide less energetically and economically costly surface water irrigation (SWI), an approach now championed by the Government of Bangladesh. Initiatives to implement SWI are in the first stages of development, and have not been informed by a robust spatial and temporal assessment of freshwater resources and an identification of where these resources can be sustainably tapped to support intensified cropping.

To address these issues, remotely-sensed data was used to characterize agricultural land, freshwater resources, and crop production intensity across a 33,750 km<sup>2</sup> study area in south-western Bangladesh. Combining geo-referenced and temporally explicitly soil and water salinity information with relative elevation classifications, we examined the extent of winter fallows and low productivity rainfed cropland within land that could be that could be irrigated by decentralized small-scale pump sets. Applying observations of irrigated crop sowing dates and productivity from 510 wheat, 550 maize, and 553 rice farmers, we then modeled crop intensification potential

and estimate that at least 20,800 and 103,000 ha of fallow and rainfed cropland, respectively, could be brought into intensified double cropping using SWI. Scenario analysis indicates that if 25% to 75% of this fallow or low-intensity land were converted to irrigated maize, national aggregate production would increase by 10–14% or 29–42%, respectively, with the anticipated range depending on achieved crops yields. Conversion to wheat would similarly boost national production by 9–10% or 26–31% under the same scenarios. Our results suggest that the production and economic benefits of SWI-based cropping intensification are very significant but spatially heterogeneous, necessitating a targeted approach to guide public and private investment. Further studies are required to document and proactively manage the potential impact of increased water abstraction from SWI on basin hydrology and associated ecosystem services, including drinking water supplies.

### 4. The enabling environment for change: coalitions for achieving critical mass

Mungbean, a short-duration legume, is an ideal spring season complement to intensify the rice–wheat cropping system without displacing other crops. As a legume, may also support household nutritional outcomes and offer a low-cost pathway for income generation that does not require nitrogen fertilizer inputs.

Despite focused development efforts in Nepal, area expansion of mung had stagnated at a very low level. To support adoption, CSISA pursued a sequenced series of steps across the research to market continuum with a range of value chain partners. First, on-farm evaluations of mungbean were conducted in collaboration with the National Grain Legume Research Program to understand the geographic niche and productivity potential of mung in different cropping systems in 'real world' conditions. Building on successful field evaluations, CSISA developed a public-private partnership model linking private seed companies and millers with producers, and extension while playing a critical role in facilitating contractual arrangement between partners and providing technical backstopping for farmers. As a result, mungbean production is accelerating because there is buyback assurance and product aggregation from the millers, reducing market-based risks.

In the past, access to quality seed has also constrained adoption. Though a process of deliberate engagement with farmers and millers, private seed companies better understand the market opportunity and produced 10 metric tons (MT) of mungbean seed during the 2016 spring season – a ten-fold increase from 2015. Policy makers have also taken note, with the Department of Agriculture now promoting mung through its ongoing 'soil fertility enhancement' program across the Terai. To contribute to the further expansion of mungbean in Nepal, CSISA has developed a social-marketing video documenting the advantages associated with mungbean cultivation.

Efforts are underway to carry out community-level video campaigns in the strategic locations in collaboration with media outlets, millers, seed companies and state extension. In the niches with the highest potential, CSISA will focus on awareness raising among farmers on mungbean production technology, and continue to facilitate participatory market chain development to ensure that there is no gap between millers, traders, and producers.

### 5. A glimpse of the science ahead

In NW India (i.e. Haryana, Punjab), long-standing concerns for declining water tables and soil quality degradation have prompted renewed calls and new GOI investments in diversifying *kharif*-season staple crop production away from rice and into crops like maize. Despite the emphasis on diversification, there are several ‘unknowns’ about potential markets, higher economic risks for producers associated with crops that are not publically procured, as well as uncertainties about underlying hydrology processes and associated resource quality considerations – including the need to manage irrigation in ways that reduce the probability of secondary salinization in salt-affected soils. There are also significant feedback interactions between these factors that necessitate an integrative approach that unites socioeconomic, biophysical and policy dimensions in order to best estimate the implications of diversification at the household to regional scales.

In the comparatively warmer NE IGP (i.e. E. Uttar Pradesh, Bihar), there is a growing imperative to look for alternatives to *rabi*-season wheat as the thermal window for production, already sub-optimal, is expected to be further reduced and increasingly variable from year-to-year with progressive climate change. The most promising staple alternative in the NE is also maize which can be tremendously high-yielding in the winter months and is not as vulnerable to the threat of terminal heat during the spring grain filling period. Nevertheless, some of the same considerations on market dynamics must also be explored in the NE along with risks to individual producers from price perturbations caused by factors such as bird flu. Substituting maize for wheat in the NE IGP establishes a scenario where the relatively small and impoverished farmers would shift from a lower input ‘food security’ crop with higher biophysical risk of failure to a higher input commodity crop with significant market-based risks and investment requirements for fertilizer, irrigation, and energy. Understanding the risk-bearing and investment capacity of different groups of farmers is an essential consideration for shaping progressive policies that would facilitate diversification for meeting food and livelihoods objectives in the NE IGP with acceptable levels of risk.

Assessing the potential role of innovative technologies such as conservation agriculture is essential since risk, profitability, and environmental quality outcomes can be significantly conditioned not simply by crop choice, but also by the specific production practices employed by farmers. Quanti-

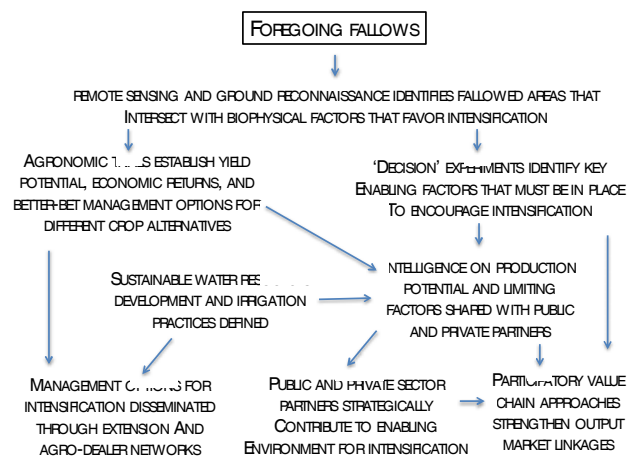
tative analysis is required to determine the value of these practices at nested spatial scales from the farm to the landscape.

It is important to note that climate and market-based risks are dynamic and, in the case of climate change, evolving with time. Determining the temporal aspects of diversification and addressing the issue of *when* it makes sense for policy makers, value chain actors such as feed mills, and individual farmers to invest are also salient concerns. Future research will build a linked simulation framework to quantitatively explore the prospects and implications of cereal systems diversification in the NE (maize for wheat) and NW (maize for rice) IGP in order to determine plausible impacts on food security, livelihoods, and environmental quality. This approach will be used for broadly establishing trajectories of change and multi-criteria outcomes under different policy investment, socioeconomic, and technological change scenarios.

In the context of winter fallows development, CSISA is placing a major research emphasis on identifying ‘precursor’ enabling factors that must first be in place to give farmers confidence to invest in diversification. FDGs have been initiated in Odisha and Southern Bangladesh to start to disentangle the story. Cognitive modeling, choice experiments, and game-based approaches will formalize insights into farmer decision processes and more clearly quantify first entry points that will lead towards an increase in fallows development.

### 6. Prioritizing partnerships and integrated, market-led approaches

Although farmers in CSISA’s intervention areas of Odisha’s plateau have begun to cultivate and broaden end-uses for maize, the best opportunity for growth, income generation, and therefore incentives for diversification are through grain sales to feed and food mills. That said, many women farmers and others involved with maize cultivation are typically not familiar with basic market concepts, and also not linked to end-users through aggregators and middlemen. As with CSISA’s work in the areas with *rabi* fallows in Bangladesh and coastal Odisha, we are working to provide market intelligence to food and feed mills on the maize pro-



duction potential through site visits, community engagement with local stakeholders, and review of participatory on-farm agronomic trials. The identification of local product aggregators and communication of product quality standards for different end-use markets is part of this engagement. Second, contract (or 'contact') farming arrangements will be pursued so that farmers have semi-assured markets once they've invested in maize. Third, basic training on financial literacy, pre-season production and market planning, and the functioning of markets is being provided through established self-help groups and their federations. Lastly, linkage events are held with agro-dealer shops so that maize farmers (including women) become comfortable purchasing inputs and, when necessary, negotiating prices. Together, these development efforts compose a comprehensive 'theory of change' that promises to take diversification beyond the pilot scale in the tribal belt of Odisha with relevance an example for other areas where the potential benefits of diversification are strong but social capital relatively weak.

## CONCLUSION

Diversification has a considerable role to play in the sustainable intensification of cereal-based cropping systems in South Asia, but the systems niche, potential benefits and requirement for bringing diversification to scale differ considerably across geographies. As a matter of public investment, the merits of specific types of diversification should be defined along with the scaling logic and partnerships required to drive adoption.

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## Agricultural biodiversity and agriculture sustainability

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Food and nutrition security, income growth, poverty alleviation, employment generation, judicious use of land, water and other resources, sustainable agricultural development, and environmental and ecological management /improvement have assumed high priority in the various countries of the Region. The benefits of agriculture have been immense. Before the dawn of agriculture, the hunter–gatherer lifestyle supported about 4 million people globally. Modern agriculture now feeds > 6,000 million people. Global cereal production has doubled in the past 40 years, mainly from the increased yields resulting from greater inputs of fertilizer, water and pesticides, new crop varieties, and other technologies of the ‘Green Revolution’. This has increased the global per capita food supply, reducing hunger, improving nutrition (and thus the ability of people to better reach their mental and physical potential) and sparing natural ecosystems from conversion to agriculture. By 2050, global population is projected to be 50 % larger than at present and global grain demand is projected to double. This doubling will result from a projected 2.4-fold increase in per capita real income and from dietary shifts towards a higher proportion of meat (much of it grain-fed) associated with higher income. Further increases in agricultural output are essential for global political and social stability and equity. Doubling food production again, and sustaining food production at this level, are major challenges.

A doubling in global food demand projected for the next 50 years poses huge challenges for the sustainability both of food production and of terrestrial and aquatic ecosystems and the services they provide to society. Agriculturalists are the principal managers of global useable lands and will shape, perhaps irreversibly, the surface of the Earth in the coming decades. New incentives and policies for ensuring the sustainability of agriculture and ecosystem services will be crucial if we are to meet the demands of improving yields without compromising environmental integrity or public health. Doing so in ways that do not compromise environmental integrity and public health is a greater challenge still.

### Agricultural biodiversity

Agricultural biodiversity is the variety and variability of living organisms (plants, animals, microorganisms) that are

involved in food and agriculture. It includes all those species (including crop wild relatives) and the crop varieties, animal breeds and races, and microorganism strains, that are used directly or indirectly for food and agriculture, both as human nutrition and as feed (including grazing) for domesticated and semi-domesticated animals, and the range of environments in which agriculture is practiced. It includes not just food as such but diets, food intake and nutritional considerations. Also covered are ingredients such as flavourings, colorants, preservatives, etc. that are used in food preparation, cooking, processing and storage. Agricultural biodiversity also includes habitats and species outside of farming systems that benefit agriculture and enhance ecosystem functions. In addition to the elements of agricultural biodiversity that are directly managed to supply the goods and services used by humans, other elements are vital because of their contributions to ecosystem services such as pollination, control of greenhouse gas emissions and soil dynamics. Production of at least one third of the world’s food, including 87 of the 113 leading food crops, depends on pollination carried out by insects, bats and birds. It is reported that ‘Pollinator diversity is mandatory for crop diversity’ and pollination services have been estimated to contribute to greater extent worldwide in 2005. Likewise, agricultural biodiversity includes elements that affect crops and food production negatively such as pests and diseases, weeds and alien invasive species. Agricultural biodiversity is by definition the result of the deliberate interaction between humans and natural ecosystems and the species that they contain, often leading to major modifications or transformations: the resultant agroecosystems are the product, therefore, of not just the physical elements of the environment and biological resources but vary according to the cultural and management systems to which they are subjected. Agricultural biodiversity, thus, includes a series of social, cultural, ethical and spiritual variables that are determined by farmers at the local community level. These factors played a key role in the process of selection and evolution of new cultivars or of local crops and in the ways in which they are grown and managed. It is important to recognize that ‘the relationship that people have with their environment is complex and locally specific. Consequently, environment and development problems may need to

be dealt with at the local scale so that remedies can be designed in ways that are culturally, socio-politically and environmentally suited to each local context’.

Agricultural biodiversity is the first link in the food chain, developed and safeguarded by indigenous people throughout the world, and it makes an essential contribution to feeding the world. The world’s agriculture and its ability to provide food for the ever-growing human population can be regarded as one of the great success stories of human civilization. It developed from our use of the natural capital of wild plant and animal biodiversity through a long period of natural and human selection and breeding of crops and the development of agronomic skills. The use of the diversity of wild species is at the very basis of human development. Across the world, our ancestors’ hunter-gatherer nutritional regime depended on local wild species of plants and animals for food while others, mainly plants, provided materials for shelter, fibre and fuel and medicine. The transition from hunting gathering to agriculture (*Neolithic* revolution) started some 12,500 years ago when the domestication of a small number of wild plant species in various parts of the world led to the first agricultural revolution that provided us with a relatively secure source of food. This in turn allowed human communities to grow and adopt a more sedentary way of life that paved the way for the development of villages, towns and cities that increasingly dominate our way of life and all the social and cultural changes that this involves. The diversity we have today in these crops and domesticated animals is the result of the interaction between countless generations of farmers and the plants and animals they domesticated, either through farming or aquaculture, and their environment. The connection between this diversity – agricultural biodiversity – and made and continue to make appreciable contributions to human diets, detailed evidence of their importance in terms of energy intake, micronutrient intake and dietary diversification is scarce and correlating agricultural biodiversity with human nutrition is generally difficult for a number of reasons including human diversity. Overall, the exploitation of agricultural biodiversity has provided enormous nutrition and health benefits despite the dramatic population growth of the human population during the past 150 years, more recently through agricultural intensification. Yet as we will see, this has incurred over-exploitation of some resources and extensive habitat loss as a result of land cleared for agriculture with considerable but largely undocumented loss of species and massive soil erosion. Some of these changes have also had negative impacts on dietary diversity, nutrition and health of some groups of society. Despite the success of the agricultural revolution in providing enough food to feed the world, today we are faced with issues of over and under nutrition both forms of malnutrition; more than a billion people today are chronically underfed thus making them more disease-prone while much of the developed world is at the same time facing a crisis of obesity caused by over nutrition aggravated by an unhealthy lifestyle, leading to

diet-related diseases, such as cardiovascular disease, hypertension, cancer, diabetes and non-alcoholic fatty-liver disease. This tendency is not confined to the developed world but is also spreading to countries undergoing rapid societal transition-so-called development-driven obesity. Worldwide 30 % more people are now obese than those who are underfed. The causes of these nutritional challenges are many and complex as are possible solutions. It is observed that healthy human nutrition is best achieved by an approach to agriculture that is bio-diverse, providing a varied food supply, and ecologically sustainable. Such a bio-diverse food-based approach should be seen as an element in an overall strategy that also includes continuing improvement of agricultural production, breeding cultivars that are more resistant to disease and stress, nutritional enhancement of crops, industrial fortification, vitamin supplementation and other nutrition–agriculture linkages. It is time to broaden our approach even further and explore the linkages between agriculture, food production, nutrition, ethno-biology and ethno-pharmacology and the resource base of wild and agricultural biodiversity in the context of accelerating global change. At an institutional level, both human nutrition and health is intrinsic, multifaceted and constantly changing. It is complex reflecting the many dimensions of nutrition, health and agricultural biodiversity and there is no necessary direct link between the amount or quality of agricultural biodiversity and provision of nutritional and health benefits. While it is incontestable that some elements of agricultural biodiversity such as crop diversity and wild-harvested plants and animals have globally and nationally, these issues are very loosely (or not at all) coordinated. Such a strategy for agricultural biodiversity and nutrition is proposed and it requires several different kinds of undertaking, including: an evidence-based approach to nutrition and health and sustainable, agriculture by small-scale farmers, the evaluation and use of local foods and their variety, traditional cuisines, culturally sensitive methods, nutrition education, research on novel and improved methods of food storage and processing and enhanced attention to marketing.

This paper will focus on components of agricultural biodiversity that impact most directly on nutrition and health and are directly managed to provide us with goods and services such as the diversity of wild and domesticated plant and animal species used in agriculture, including underutilized and wild-gathered species; the ecosystems in which they grow and are grown; plant and animal genetic resources, including crop wild relatives (CWR) and domesticated animal wild relatives and the landraces, cultivars and breeds developed from these wild species.

### **The simplification of agriculture practices**

A remarkable feature of the agricultural revolution was the relatively small number of plant species that were successfully domesticated and of these, the even smaller number which were selected over time because of their relative ease of cul-

tivation, reliability and their ability to be grown in a range of habitats, as well as their nutritional value. On the other hand, over the past 12,000 years, farmers have developed a bewildering diversity of local varieties or landraces of these staples and of minor crops resulting from 'interactions with wild species, adaptations to changing farming conditions, and responses to the economic and cultural factors that shape farmers priorities'. Landraces or primitive cultivars are the products of breeding or selection carried out by farmers, either deliberately or not, over many generations and natural selection and are recognizable morphologically; farmers have names for them, and different landraces are understood to differ in adaptation to soil type, time of seeding, date of maturity, height, nutritive value, use and other properties'. The number of animal species that were fully domesticated was even smaller and today only some 40-plus livestock species contribute to agriculture and food production. Likewise, the number of breeds that were developed in these domesticates was very much smaller than in the case of plants – FAO's Global Databank for Animal Genetic Resources for Food and Agriculture contains information on a total of 7,616 livestock breeds from 180 countries. Furthermore, as The State of the World's Animal Genetic Resources for Food and Agriculture notes, 'With the exception of the wild boar (*Sus scrofa*) the ancestors and wild relatives of major livestock species are either extinct or highly endangered as a result of hunting, changes to their habitats, and in the case of the wild red jungle fowl, intensive cross-breeding with the domestic counterpart. In these species, domestic livestock are the only depositories of the now largely vanished diversity'. It has been estimated that 30 % of the world's animal breeds are at risk of extinction. Agriculture and sedentism gradually led to a significant reduction in our dietary diversity through our increased reliance on domesticated species and new and improved crops varieties (cultivars) which increased yields and led to intensification of agriculture. Eventually only a tiny number of crop species – the staples – came to dominate our nutritional and calorific intake, and globally the number of wild species that we depended upon directly was dramatically diminished. It is reported that 'while farmers concentrate on high carbohydrate crops like rice and potatoes, the mix of wild plants and animals in the diets of surviving hunter-gatherers provides more protein and a better balance of other nutrients'. While many would cavil this report that the adoption of agriculture was 'the worst mistake in the history of the human race', there is some evidence that initially it had an adverse effect on human health. For example, in their Paleopathology at the Origins of Agriculture, it is reported empirical studies of societies shifting their subsistence from foraging to primary food production which showed that there was evidence for deteriorating health due to an increase in infectious diseases and a rise in nutritional deficiencies that could be attributed to reliance on single crops deficient in essential minerals, amongst other factors. But on the whole, agricultural intensification has been

one of the main factors that has allowed much of the human population to enjoy unprecedented levels of health and reduced mortality.

This process of simplification of agriculture led eventually to today's model of food production in which we rely on only around 100 crop species for about 90 % of national per capita supplies of food from plants. Of these only 20 to 30 make up the bulk of human nutrition – the so-called staples, such as wheat, barley, maize, rice, millet, sorghum, rye, cassava, yams, potato and sweet potato. Modern intensive agriculture not only reduces agricultural biodiversity but, is predicated on such a reduction. The gradual substitution of locally adapted landraces or cultivars by more advanced high-yielding cultivars that were resistant to disease or other factors resulted in the erosion of this pool of diversity and represented a further simplification of agriculture. This genetic erosion of our crop species led to the development of the plant genetic resource movement by pioneer researchers as an attempt to conserve the remaining diversity in crops and their wild relatives. The scale of loss of landraces reported has been dramatic in some cases although it is not easy to verify due to lack of reliable baseline data and consistent standards of recording. In rice (*Oryza sativa*), for example, 40,000 to 50,000 landraces are estimated to exist but many reports have been published indicating extensive national or local loss of cultivar diversity in the crop. Genetic erosion was reported by about 60 countries in national reports for the Second Report on the State of the World's Plant Genetic Resources for Food and Agriculture although few concrete examples were given. On the other hand, a study of germplasm and genetic data in the IRRRI gene bank collected throughout South and Southeast Asia from 1962 to 1995 was unable to detect a significant reduction of available genetic diversity in the study material, contrary to popular opinion. Likewise, despite the massive loss of landraces reported for several crops, it is reported that as measured by richness, evenness and divergence of cultivars, considerable crop genetic diversity continues to be maintained on farm, in the form of traditional crop varieties for a finite number of crops in a small number of countries. Major staples had higher richness in terms of the number of different kinds of individuals regardless of their frequencies and evenness (measuring how similar the frequencies of the different variants are) than non-staples. And in a study of genetic erosion in maize within smallholder agriculture in southern Mexico, it was found that despite the dominance of commercial seed, the informal seed system of local farmers persisted. True landraces were, however, rare and most of the informal seed was derived from modern 'creolized' varieties-developed as a result of exposing improved varieties to local conditions and management and continually selecting seed for replanting and promoting their hybridization with landraces. They also showed that genetic erosion was moderated by the distinct features offered by modern varieties. While acknowledging the undoubted success of modern agriculture, it should be re-

membered that the great majority of farmers in the developing world are traditional or peasant farmers who rely in varying degrees on small-scale cultivation of staples and various forms of traditional agriculture, including raised fields, terraces, swidden fallows, agro-forestry poly-cultures (e.g. home gardens), semi-domesticated species and wild harvesting of fruits, fibres, medicinal and so on, and on the natural and semi-natural ecosystems that border or are adjacent to the cultivated fields. Globally, small-scale agriculture is the dominant form of food provision. It is estimated that about 60 % of the world's agriculture consists of traditional subsistence farming systems in which there is both a high diversity of crops and species grown and of ways in which they are grown, such as multi-cropping and intercropping, that leads to the maintenance of variation within the crops. Such traditional agricultural landscapes are estimated to provide as much as 20 % of the world's food supply. They are rich in agricultural biodiversity, especially in poly-cultures and agro-forestry systems, thus contrasting with modern intensive industrial agriculture, and are often the product of complex farming systems that have developed in response to the unique physical conditions of a given location, such as altitude, slopes, soils, climates and latitude, as well as cultural and social influences. Many of the species grown in such systems are local '*underutilized species*' and provide nutritional balance to the diet, complementing the staple crops that are grown and providing micronutrients and vitamins.

Another advantage of growing a diversity of crops and maintaining genetic diversity within local production systems is that it also favours the conservation of local knowledge. Home gardens (also known as homestead gardens, yard gardens, kitchen gardens, etc.) are a long-established tradition and offer great potential for improving household food security and alleviating micronutrient deficiencies. The home garden can be defined as a farming system which combines different physical, social and economic functions on the area of land around the family home. They occur in most parts of the world but especially in tropical and subtropical regions and it has been estimated that nearly 1 billion people in the tropics live from the produce of home gardens supported by subsistence agriculture. The essence of such systems is the diversity of species they contain-up to 100 or more species per garden-and their two-to four-layered structure that allows different ecological niches to be exploited by the species planted. Several organizations such as FAO and the Centre for Sustainable Development offer training courses or manuals on home gardens. Home gardens may also provide animal products such as chickens, eggs and livestock, as in the case of the homestead gardens promoted by Biodiversity. Although numerous reports on the role of home gardens in nutrition are found in the literature, there is little reliable evidence of their value. A systematic review of agricultural interventions, including many on home gardens, that aim to improve the nutritional status of children by improving the incomes and the diet of the

rural poor, based on a systematic search of the published and unpublished literature and concluded that the interventions were as expected successful in promoting consumption of specific foods – in the case of home gardens fruit and vegetables – but very little evidence was available on their effects on nutritional status.

#### *The importance of plant diversity for nutrition*

Adequate human nutrition involves regular intake of a wide range of nutrients, some of which must be consumed on a frequent basis, even if in small quantities. World has its disposal some 400,000 species of plants but, as it has seen, only a small number of these are the staples on which global nutrition depends. This is, however, only part of the picture. The number of cultivated crop species (excluding ornamentals) has been estimated at about 7,000, most of them grown locally and on a small scale. In addition there are many locally used species that are scarcely or only partially domesticated and many thousands more are gathered from the wild.

The nutritional importance of dietary diversity (DD) is now widely recognized. Growing a range of local crops supplemented by wild-harvested species helps to provide such diversity in the diet, especially of poor rural families, and complements the nutrition provided by staples such as maize, rice and cassava. Balanced nutrition in the human diet depends not just on growing a diversity of crops but on the diversity within the crops. The micronutrient superiority of some lesser-known cultivars and wild varieties over other, more extensively utilized cultivars, has been confirmed by recent research. For example, recent analyses have shown that *beta-carotene* content can differ by a factor of 60 between sweet potato cultivars and the pro-vitamin A carotenoid of banana cultivars can range between 1 µg and 8,500 µg/100 grams, 2010), while the protein content of rice varieties can range from 5 to 13 %. As they observe, 'Intake of one variety rather than another can be the difference between micronutrient deficiency and micronutrient adequacy'. Unfortunately, we lack detailed information about such diversity within most crops at the cultivar level and the role it plays in nutrition because of the general neglect by professionals and much of the evidence is anecdotal.

#### *Underutilized or orphan crops*

The term '*underutilized species*' refers to those species whose potential to improve people's livelihoods, as well as food security and sovereignty, is not being fully realized because of their limited competitiveness with commodity crops in mainstream agriculture. While their potential may not be fully realized at national level, they are of significant importance locally, being highly adapted to marginal, complex and difficult environments and contributing significantly to diversification and resilience of agro-ecosystems. This means they are also of considerable interest for future adaptation of agriculture to climate change. The importance of underutilized species is now receiving more recognition. For example, the



present day situation recognizes that investments in agricultural knowledge, science and technology ‘can increase the sustainable productivity of major subsistence foods including *orphan* and *underutilized crops*, which are often grown or consumed by poor people’. Likewise, the Ministerial Declaration ‘Action Plan on Food Price Volatility and Agriculture’, issued by the G20 Agriculture Ministers from their meeting in Paris on 22–23 June 2011 recognized the importance of making the best use of all available plant genetic resources for food and agriculture, including research on *underutilized crops*. Underutilized species also received qualified endorsement in the Commission on Sustainable Agriculture and Climate Change’s report *Achieving food security in the face of climate change*.

### Wild-gathered plant species

Despite the simplification of agriculture, wild species still represent a major resource today and form an important part of the diet of societies in both the developed and developing worlds, providing not only variety but also essential vitamins and micronutrients in the form of bush-meat, fruits, vegetables, herbs and spices, beverages and intoxicants, not to mention their use as fibres, fuel, ornament and medicines. These range from locally consumed species such as leaf greens and wild fruits to economically important non-timber forest products obtained by extractivism, such as palm hearts, Brazil nuts and rubber and the trade-most of it uncontrolled and much of it illegal in ornamentals including cycads, orchids, cacti and succulents and bulbs.

The use of wild plants in most societies forms part of indigenous knowledge systems and practices that have been developed over many generations and which play an important part in decision-making in local agriculture, food production, human and animal health and management of natural resources. Growing vegetables in home gardens and other plots is often supplemented in traditional rural and farming communities by wild harvesting of local greens, fruits, nuts and fungi. The term ‘*wild food*’, therefore, is used to describe all plant resources that are harvested or collected for human consumption outside agricultural areas in forests, savannah and other bush-land areas. The consumption of traditional leafy vegetables (‘wild or leafy greens’) as an important source of micronutrients is attracting a great deal of attention, notably in the tropics. Often they provide rural poor with most of their daily requirements of essential vitamins and minerals, particularly folate (Fe), and vitamins A, B complex, E and C and in many cases they also have medicinal properties and form part of local health care systems. They are especially important in small children’s diets to ensure normal growth and intellectual development. In the Mediterranean region, the habit of consuming wild food plants is still prevalent, especially for rural people, although it is ‘ageing’, with fewer traditional vegetables consumed than in previous decades. A circum-Mediterranean ethno-botanical field survey for wild

food plants as part of the EU-supported RUBIA project documented 294 wild food taxa. In particular, traditional leafy vegetables (‘wild or leafy greens’) are widely consumed in several Mediterranean countries such as France, Greece, Italy, Spain, Turkey and Asian countries. They are especially important in Greece (where they are known as *xorta*), especially Crete (where over 92 wild greens have been catalogued and several studies published) and other islands such as Cyprus, Sicily and Sardinia.

In recent years, work on economically valuable wild plant species in the Mediterranean region has increasingly focused on the nutritional and health aspects of wild foods. A recent ethno-botanical study showed that as many as 2,300 different plant and fungal taxa are gathered and consumed in the Mediterranean region where they play an important role in human nutrition and can supply most of the necessary daily requirements for vitamins A, B complex and C and provide minerals and trace elements. They may sometimes even be better nutritionally than introduced cultivated vegetables. The so-called Mediterranean diet or more properly diets that are rich in fruit, vegetables, legumes and olive oil, as well as fish and poultry, but low in meat and animal fats often include a range of local wild-gathered plants such as ‘wild greens’.

Forests can play an important part in human nutrition, particularly in developing countries and according to the Collaborative Partnership on Forests (CPF), the potential of forests and trees to improve food and nutritional security needs more attention from policymakers and development agencies. It is estimated that at least 410 million people derive much of their food and livelihoods from forests while some 1.6 billion people get some portion of their food and livelihood from forests around the world. Non-wood forest products include many types of food such as fruits, nuts, leafy vegetables and oils that are widely recognized as contributing to the livelihood of millions of people in many parts of the world, especially in the tropics and subtropics, and contribute to dietary diversity. A six-year global study has documented for the first time on a broad scale the role that forests play in poverty alleviation and the significant contribution they make to the livelihoods of millions of people in developing countries. The Poverty and Environment Network (PEN) study consists of data from more than 8,000 households from 40+ sites in 25 developing countries makes a strong argument for the sustainable management of natural ecosystems to provide health and nutritional benefits. Domestication programmes are being developed to bring many wild species, both trees and herbs, into cultivation and integrate them into agro-forestry systems. Examples of such species are *Adansonia digitata*, *Barringtonia procera*, *Canarium indicum*, *Gnetum africanum*, *Irvingia gabonensis*, *Sclerocarya birrea* and *Vitellaria paradoxa*. As well as providing ‘marketable timber and non-timber forest products that will enhance rural livelihoods by generating cash for resource-poor rural and peri-urban households’ and restoring productivity through soil fer-

tility improvement, these species can provide health and nutritional benefits.

### Crop wild relatives

While crop wild relatives (CWR) may not play a significant direct role in human nutrition – although there are notable exceptions such as wild yams in Madagascar—they are an essential source of genetic material for the development of new and better adapted crops. For example, a recent study using micro-satellite markers showed that a wild rice in Vietnam has much greater genetic variation than cultivated rice, with a single wild population showing greater genetic variation than that found in 222 local Vietnamese varieties. Moreover, it is now widely recognized that the wild relatives of crops will play a key role in future food security in the face of global change.

### Changing the paradigm

The present paradigm of intensive crop production cannot meet the challenges of the new millennium. What we desperately need is another revolution, one that deals with agricultural productivity for the smallholders. We need to answer these questions: Are we growing the right foods? Are we growing them in the most efficient way with respect to inputs, water and land? Are we growing them in the most suitable way? And what foods are consumers actually eating in terms of quality and quantity, nutrition and food safety? *Agricultural intensification continues to pose a serious threat to biodiversity in many parts of the world.* For example, a recent study of the impact of crop management and agricultural land use on the threat status of plants adapted to arable habitats in 29 European countries showed a positive relationship between national wheat yields and the numbers of rare, threatened or recently extinct arable plant species in each country. This current paradigm of intensive high input, high output intensification of agriculture is now being questioned because of (1) growing concerns about its present impacts on biodiversity; (2) the predicted impacts of global change on agriculture and wild biodiversity; (3) serious issues over energy and water security; and (4) changes in dietary patterns. It is observed that almost all of the approaches used to date in agricultural intensification strategies, for example the substitution and supplementation of ecosystem function by human labour and petrochemical products, contain the seeds of their own destruction in the form of increased release of greenhouse gases, depletion of water supplies and degraded soils. We need to build production systems that deliver intensification without simplification. *Sustainable intensification of agricultural production—‘producing more output from the same area of land while reducing the negative environmental impacts and at the same time increasing contributions to natural capital and the flow of environment’* is now widely advocated. Recent volatility in food prices together with extreme weather events and the projected impacts of climate change have intensified

the search for alternative ways of addressing the problem of achieving food security through employing more sustainable and intelligent management of production and consumption. It is considered that ‘the goal for the agricultural sector is no longer simply to maximize productivity, but to optimize across a far more complex landscape of production, rural development, environmental, social justice and food consumption outcomes’. For example, FAO has published a policymaker’s guide to what is termed ‘*sustainable intensification of smallholder crop production*’ in which more is produced from the same area of land while conserving resources, reducing negative impacts on the environment and enhancing natural capital and the flow of ecosystem services. This approach involves: building crop production intensification on farming systems that offer a range of productivity, socio-economic and environmental benefits to producers and to society at large; using a genetically diverse portfolio of improved crop varieties that are suited to a range of agro-ecosystems and farming practices, and resilient to climate change; rediscovering the importance of healthy soil, drawing on natural sources of plant nutrition, and using mineral fertilizer wisely; smarter, precision technologies for irrigation and farming practices that use ecosystem approaches to conserve water; achieving plant protection by integrated pest management and avoiding over-use of pesticides; bringing about fundamental changes in agricultural development policies and institutions so as to encourage smallholders to adopt sustainable crop production intensification. The need to maintain and manage ecosystems sustainably so that they continue to provide us with goods and services is critical: as it is observed that ‘healthy ecosystems provide a diverse range of food sources and support entire agricultural systems’. Although not new, there are increasing calls today for a more ecological approach to agriculture sometimes called ecological agriculture, eco-agriculture or regenerative agriculture and also to human nutrition. Such approaches look beyond a focus on production to sustainability, biodiversity protection and the complex dynamics of the agro-ecosystem in terms of plants, animals, insects, water and soil. A diversity of crops (and where appropriate livestock) is also a characteristic as is a focus on the role of indigenous communities. So far, calls to promote a more food-based approach to nutrition and health have met with resistance from policymakers and governments and as discussed below, the role of species diversity in nutrition and alleviation of poverty has been largely disregarded by mainstream agricultural policy although it is now a subject of considerable discussion.

Assessing the role of biodiversity in alleviating hunger and malnutrition, a wider deployment of agricultural biodiversity is an essential component in the sustainable delivery of a more secure food supply. Although the link between biodiversity and alleviating poverty, including food poverty and malnutrition, has been pointed out by many authors in recent years and has been eloquently argued by distinguished figures such as

M.S. Swaminathan, the Father of the Green Revolution in India and world food prize winner, it is much more difficult to convince governments and policymakers and provide clear scientific evidence of a direct link between protecting the natural environment and promoting the interests of poor communities and more specifically between biodiversity and poverty and it is well documented that biodiversity and poverty are closely related.

As a recent editorial in Science and Development Network notes, 'without solid evidence that biodiversity conservation can alleviate poverty, politicians simply won't buy into the idea of protecting biodiversity, or will take action that however well meaning, ends up unfocused and ineffective'. One of the commonest criticisms of advocating a greater use of local agricultural biodiversity in the form of traditional crops, underutilized species and wild-harvested species to address under- or malnutrition is precisely that it is local and it is assumed therefore will have little impact on the global picture. Yet, at least 20 % of the world food supply comes from traditional multiple cropping systems, most of them small farm units often of 2 ha or less. There is ample evidence on the ground that local biodiversity and ecosystem services play an essential role in the lives of communities throughout the developing world, by providing a social safety net for food, medicine, fibre, fuel wood etc. that can act as route out of poverty and a source of income generation, prevent people falling further into poverty or in extreme cases as an emergency lifeline through the provision of 'famine food'. It can also play a major part in addressing some issues of malnutrition. The main reasons for the lack of attention given to underutilized or wild gathered species include: a lack of information and reliable methods for measuring their contribution to farm households and the rural economy; low productivity compared with staples; the lack of guaranteed markets, except for a small number of products the irregularity of supply of wild plant products; the lack of quality standards; lack of standardization of the product; the lack of storage and processing technology for many of the products; the availability of substitutes; the bias in favour of large-scale agriculture.

### **Agricultural biodiversity, nutrition and global change**

Agricultural biodiversity will also be absolutely essential to cope with the predicted impacts of climate change, not simply as a source of traits but as the under-pinning of more resilient farm ecosystems. The future impacts of the various components of global change-demographic, climatic, land use-on agricultural biodiversity and nutrition will be enormously complex and correspondingly difficult to decipher and predict. The growing human population will inevitably lead to further over-exploitation of resources and increase the pressure to convert further land for agriculture. What is much less clear is how the shifts in the climatic components of global change such as temperature, rainfall and greenhouse gases (carbon dioxide, methane, ozone and nitrous oxide) will inter-

act with agricultural production. Global warming is predicted to pose significant threats to agricultural production and trade and to the ability of ecosystems and agro-ecosystems and their component species to adapt to these changes.

The impacts of climate change will vary from region to region. and is reported that crop yields will decline, production will be affected, crop and meat prices will increase, and consumption of cereals will fall, leading to reduced calorie intake and increased child malnutrition'. It is also reported that higher temperatures eventually reduce yields of desirable crops while encouraging weed and pest proliferation; changes in precipitation patterns increase the likelihood of short-run crop failures and long-run production declines; although there will be gains in some crops in some regions of the world, the overall impacts of climate change on agriculture are expected to be negative, threatening global food security. As regards human nutrition, calorie availability in 2050 will be lower throughout the developing world; by 2050, the decline in calorie availability will increase child malnutrition by 20 % relative to a world with no climate change. Climate change will eliminate much of the improvement in child malnourishment levels that would occur with no climate change. The expected degradation of ecosystems is also likely to increase the vulnerability of populations to the consequences of natural disasters and climate change impacts. Food and nutrition insecurity; and climate change, the two major global challenges facing humanity, are inextricably linked. 'Strengthening the livelihoods of rural populations is intrinsically linked to poverty reduction efforts and is a key area to focus climate change adaptation strategies in the agriculture sector.'

The role of agricultural biodiversity and its interaction with human nutrition in facing up to the challenges of global change will be vital. Some of the key factors are: Increased diversification of crops and livestock will not only enhance nutritional possibilities but will allow farmers to have a greater number of options to face the uncertain weather conditions associated with the increased climate variability. Underdeveloped species are another source of potentially valuable food resources that can be developed for use in a wider range of farming systems and as a source of bio-fuels. The major crops contain many thousands of cultivars with wide variation in their capacity to adapt to a range of climatic conditions. Breeders and agronomists will have to make considerable efforts to identify and develop cultivars that will help provide the productivity increases needed for food production. In addition, the changing climates will require a massive effort in breeding cultivars that show better adaptation to the new eco-climatic conditions (including drought) that are predicted and crop wild relatives will be an important source of the genetic variation needed. Extension workers will have to assist farmers to evaluate these new cultivars and facilitate their supply and cultivation. Major efforts will be needed to assess the adaptive capacity of local crops and wild species that play a significant role in human nutrition to changing cli-

mates. The support of international and regional aid and development agencies and national governments will be needed to support the efforts of local communities in developing adaptation strategies that help them strengthen their capacity to improve their agronomic and land-management skills, and to diversify their livelihoods through maintaining diversified cropping systems and increasing the productivity of local crops. A considerable investment in both *ex situ* and *in situ* conservation of crop wild relatives will be needed.

### **Agriculture sustainability improvement**

#### *Sustainability and net benefits*

Agricultural practices determine the level of food production and, to a great extent, the state of the global environment. Agriculturalists are the chief managers of terrestrial 'useable' lands, which we broadly define as all land that is not desert, tundra, rock or boreal. About half of global usable land is already in pastoral or intensive agriculture. In addition to causing the loss of natural ecosystems, agriculture adds globally significant and environmentally detrimental amounts of nitrogen and phosphorus to terrestrial ecosystems, at rates that may triple if past practices are used to achieve another doubling in food production. The detrimental environmental impacts of agricultural practices are costs that are typically unmeasured and often do not influence farmer or societal choices about production methods.

Such costs raise questions about the sustainability of current practices. We define sustainable agriculture as practices that meet current and future societal needs for food and fibre, for ecosystem services, and for healthy lives, and that do so by maximizing the net benefit to society when all costs and benefits of the practices are considered. If society is to maximize the net benefits of agriculture, there must be a fuller accounting of both the costs and the benefits of alternative agricultural practices, and such an accounting must become the basis of policy, ethics and action. Additionally, the development of sustainable agriculture must accompany advances in the sustainability of energy use, manufacturing, transportation and other economic sectors that also have significant environmental impacts.

#### *Ecosystem services*

Society receives many benefits, called ecosystem services, from natural and managed ecosystems. Ecosystems provide food, fibre, fuel and materials for shelter; additionally they provide a range of benefits that are difficult to quantify and have rarely been priced. Intact forests can minimize flooding by slowing snowmelt and water discharge, moderate regional climate, and remove and store atmospheric carbon dioxide, a greenhouse gas. Forest and grassland ecosystems can create or regenerate fertile soils, degrade plant litter and animal wastes, and purify water, and this regenerative process is essential for subsistence slash-and-burn farming systems. The recharge of streams and aquifers by intact ecosystems pro-

vides potable water for little more expense than the cost of its extraction.

Agricultural practices can reduce the ability of ecosystems to provide goods and services. For example, high applications of fertilizers and pesticides can increase nutrients and toxins in groundwater and surface waters, incurring health and water purification costs, and decreasing fishery and recreational values. Agricultural practices that degrade soil quality contribute to eutrophication of aquatic habitats and may necessitate the expense of increased fertilization, irrigation and energy to maintain productivity on degraded soils. Practices that change species composition or reduce biodiversity in non-agricultural systems may also diminish goods and services, because the ability of ecosystems to provide some services depends both on the number and type of species in an ecosystem.

#### *Global land management*

The supply of agricultural products and ecosystem services are both essential to human existence and quality of life. However, recent agricultural practices that have greatly increased global food supply have had inadvertent, detrimental impacts on the environment and on ecosystem services, highlighting the need for more sustainable agricultural methods. Fundamental shifts in institutions, policies and incentives will be required in the search for, and broad adoption of, sustainable agricultural practices and this search must be an on-going and adaptive process.

#### *Food production and environmental costs*

There is a general consensus that agriculture has the capability to meet the food needs of 8–10 billion people while substantially decreasing the proportion of the population who go hungry, but there is little consensus on how this can be achieved by sustainable means. Sustainability implies both high yields that can be maintained, even in the face of major shocks, and agricultural practices that have acceptable environmental impacts. The main environmental impacts of agriculture come from the conversion of natural ecosystems to agriculture, from agricultural nutrients that pollute aquatic and terrestrial habitats and groundwater, and from pesticides, especially bio-accumulating or persistent organic agricultural pollutants. Agricultural nutrients enter other ecosystems through leaching, volatilization and the waste streams of livestock and humans. Pesticides can also harm human health, as can pathogens, including antibiotic-resistant pathogens associated with certain animal production practices.

How can such costs be minimized at the same time that food production is increased? In one sense the answer is simple: crop and livestock production must increase without an increase in the negative environmental impacts associated with agriculture, which means large increases in the efficiency of nitrogen, phosphorus and water use, and integrated pest management that minimizes the need for toxic pesticides. In reality, achieving such a scenario represents one of the great-

est scientific challenges facing humankind because of the trade-offs among competing economic and environmental goals, and inadequate knowledge of the key biological, biogeochemical and ecological processes.

#### *Increasing yields*

Raising yields on existing farmland is essential for 'saving land for nature', but the prospects for yield increases comparable to those of the past 40 years are unclear. Most of the best quality farmland is already used for agriculture, which means that further area expansion would occur on marginal land that is unlikely to sustain high yields and is vulnerable to degradation. Water, already limiting in many areas, may be diverted to uses that compete with irrigation. In some of the major grain production areas of east and South-east Asia, the rate of increase in rice yields is declining as actual crop yields approach a ceiling for maximal yield potential. Finally, continuous cereal production systems, including systems with two or three crops per year, may become progressively susceptible to diseases and insect pests because of insufficient diversity in the crop rotation.

Yields have been stagnant for 15 to 20 years in those rice producing regions of Japan, Korea and China where farmers were early adopters of green-revolution technologies; average yields are currently about 80 % of the climate-adjusted genetic yield potential ceiling. Lack of a larger exploitable 'yield gap' highlights the need for efforts to steadily increase the yield potential ceiling. The large yield gap for rice in many parts of south and South-east Asia, and for maize in developed and developing countries, indicates that these regions could have significant yield increases with use of appropriate technologies. Although breeders have been successful in increasing the yield potential of wheat, that of inbred rice has not increased since the release of IR-8 in 1966, and that of maize has barely increased in 35 years.

Stagnant yield potential is one of the chief impediments to sustainable agriculture and concerted efforts are needed to increase the yield potential of the major staple food crops.

#### *Increasing nutrient-use efficiency*

Intensive high-yield agriculture is dependent on addition of fertilizers, especially industrially produced  $\text{NH}_4$  and  $\text{NO}_3$ . In some regions of the world, crop production is still constrained by too little application of fertilizers. Without the use of synthetic fertilizers, world food production could not have increased at the rate it did and more natural ecosystems would have been converted to agriculture. Between 1960 and 1995, global use of nitrogen fertilizer increased sevenfold, and phosphorus use increased 3.5-fold; both are expected to increase another three-fold by 2050 unless there is a substantial increase in fertilizer efficiency. Fertilizer use and legume crops have almost doubled total annual nitrogen inputs to global terrestrial ecosystems. Similarly, phosphorus fertilizers have contributed to a doubling of annual terrestrial phospho-

rus mobilization globally.

Further increases in nitrogen and phosphorus application are unlikely to be as effective at increasing yields because of diminishing returns. All else being equal, the highest efficiency of nitrogen fertilizer is achieved with the first increments of added nitrogen; efficiency declines at higher levels of addition. Today, only 30 to 50 % of applied nitrogen fertilizer and about 45 % of phosphorus fertilizer is taken up by crops. A significant amount of the applied nitrogen and a smaller portion of the applied phosphorus are lost from agricultural fields. Such non-point nutrient losses harm off-site ecosystems, water quality and aquatic ecosystems, and contribute to changes in atmospheric composition. Nitrogen loading to estuaries and coastal waters and phosphorus loading to lakes, rivers and streams are responsible for over-enrichment, eutrophication and low-oxygen conditions that endanger fisheries.

Nitrogen fertilization can increase emission of gases that have critical roles in tropospheric and stratospheric chemistry and air pollution. Nitrogen oxides ( $\text{NO}_x$ ), emitted from agricultural soils and through combustion, increase tropospheric ozone, a component of smog that impacts human health, agricultural crops and natural ecosystems. As much as 35 % of cereal crops worldwide are exposed to damaging levels of ozone.  $\text{NO}_x$  from agro-ecosystems can be transported atmospherically over long distances and deposited in terrestrial and aquatic ecosystems. This inadvertent fertilization can cause eutrophication, loss of diversity, dominance by weedy species and increased nitrate leaching or  $\text{NO}_x$  fluxes. Finally, nitrogen inputs to agricultural systems contribute to emissions of the greenhouse gas nitrous oxide. Rice/paddy agriculture and livestock production are the most important anthropogenic sources of the greenhouse gas methane.

Solutions to these problems will require significant increases in nutrient-use efficiency, that is, in cereal production per unit of added nitrogen, phosphorus and water. There are a variety of practices and improvements that could each contribute to increased efficiency. For example, nitrogen-fertilizer efficiency of maize in the United States has increased by 36 % in the past 21 years as a result of large investments in public sector research and extension education, and investments by farmers in soil testing and improved timing of fertilizer application. The development and preferential planting of crops and crop strains that have higher nutrient-use efficiency are clearly essential. Cover crops or reduced tillage can reduce leaching, volatilization and erosion losses of nutrients and increase nutrient-use efficiency. Closing the nitrogen and phosphorus cycles, such as by appropriately applying livestock and human wastes, increases cereal production per unit of synthetic fertilizer applied.

Reliance on organic nutrient sources is a central feature of organic agriculture, but it is unclear whether the 'slow release' of nutrients from organic compost or green manures can be adequately controlled to match crop demand with nutrient

supply to increase nitrogen-use efficiency in intensive cereal production systems, thereby decreasing losses to leaching and volatilization. More research on improving efficiency and minimizing losses from both inorganic and organic nutrient sources is needed to determine costs, benefits and optimal practices.

Nutrient-use efficiency is increased by better matching temporal and spatial nutrient supply with plant demand. Applying fertilizers during periods of greatest crop demand, at or near the plant roots, and in smaller and more frequent applications all have the potential to reduce losses while maintaining or improving yields and quality. Such '*precision agriculture*' has typically been used in large-scale intensive farming, but is possible at any scale and under any conditions given the use of appropriate diagnostic tools. Strategies that synchronize nutrient release from organic sources with plant demand are also needed.

Multiple cropping systems using crop rotations (legume-cereals/cereal-legume) or intercropping (two or more crops grown simultaneously-legume and non-legume) may improve pest control and increase nutrient- and water-use efficiency. Agroforestry, in which trees are included in a cropping system, may improve nutrient availability and efficiency of use and may reduce erosion, provide firewood and store carbon.

Landscape-scale management holds significant potential for reducing off-site consequences of agriculture. Individual farms, watersheds and regional planning can take advantage of services provided by adjacent natural, semi-natural or restored ecosystems. Trees and shrubs planted in buffer strips surrounding cultivated fields decrease soil erosion and can take up nutrients that otherwise would enter surface or ground waters. Buffer zones along streams, rivers and lakeshores can decrease nutrient and silt loading from cultivated fields or pastures.

Crop pollination can be provided by insects and other animals living in nearby habitats or buffer strips, whereas other organisms from these habitats, such as parasitoids, can provide effective control of many agricultural pests. Buffer strips can also be managed to reduce inputs of weeds and other agricultural pests. The procurement of such ecosystem services will require landscape-level management.

#### *Increasing water-use efficiency*

Forty per cent of crop production comes from the 16 % of agricultural land that is irrigated. Irrigated lands account for a substantial portion of increased yields obtained during the *Green Revolution*. Unless water-use efficiency is increased, greater agricultural production will require increased irrigation. However, the global rate of increase in irrigated area is declining, per capita irrigated area has declined by 5 % since 1978, and new dam construction may allow only a 10 % increase in water for irrigation over the next 30 years. Moreover, water is regionally scarce. Many countries in a band

from China through India and Pakistan, and the Middle East to North Africa either currently or will soon fail to have adequate water to maintain per capita food production from irrigated land. Roughly 20 % of the irrigated area of the United States is supplied by ground water pumped in excess of recharge, and over-pumping is also a serious concern in China, India and Bangladesh. Urban water use, restoration of streams for recreational, freshwater fisheries, and protection of natural ecosystems are all providing competition for water resources previously dedicated to agriculture. Finally, irrigation return-flows typically carry more salt, nutrients, minerals and pesticides into surface and ground waters than in source water, impacting downstream agricultural, natural systems and drinking water.

Technologies such as drip and pivot irrigation can improve water-use efficiency and decrease salinization while maintaining or increasing yields. They have been used in industrialized nations on high-value horticultural crops, but their expanded use currently is not economically viable for staple food crops. In developing countries, 15 million ha have experienced reduced yields owing to salt accumulation and water logging. The water holding capacity of soil can be increased by adding manure or reducing tillage and by other approaches that maintain or increase soil organic matter. Cultivation of crops with high water use efficiency, and the development through the use of biotechnology or conventional breeding of crops with greater drought tolerance can also contribute to yield increases in water-limited production environments. Investment in such water-efficient technologies, however, is best facilitated when water is valued and priced appropriately.

#### *Maintaining and restoring soil fertility*

Fertile soils with good physical properties to support root growth are essential for sustainable agriculture, but, since 1945, approximately 17 % of vegetated land has undergone human-induced soil degradation and loss of productivity, often from poor fertilizer and water management, soil erosion and shortened fallow periods. Continuous cropping and inadequate replacement of nutrients removed in harvested materials or lost through erosion, leaching or gaseous emissions deplete fertility and cause soil organic matter levels to decline, often to half or less of original levels. Soil tillage speeds decomposition of soil organic matter and the release of mineral nutrients. Erosion can be severe on steep slopes where windbreaks have been cleared, vegetative cover is absent during the rainy season, and where heavy machinery is involved in land preparation. The effects of land degradation on productivity can sometimes be compensated for by increased fertilization, irrigation, and disease control, which increase production costs.

Crop rotation, reduced tillage, cover crops, fallows periods, manuring and balanced fertilizer application can help maintain and restore soil fertility.

### *Insect pests and disease control*

Improvements in the control of weedy competitors of crops, crop diseases and pathogens, and herbivores could significantly increase yields. Three cereals - wheat, rice and corn provide 60 % of human food. These crops, derived from once-rare weedy species, have become the three most abundant plants on Earth. A central conclusion of epidemiology is that both the number of diseases and the disease incidence should increase proportional to host abundance, and this disconcerting possibility illustrates the potential instability of a global strategy of food production in which just three crops account for so high a proportion of production. The relative scarcity of outbreaks of diseases on these crops is a testament to plant breeding and cultivation practices. For all three cereals, breeders have been successful at improving resistances to abiotic stresses, pathogens and diseases, and at deploying these defenses in space and time so as to maintain yield stability despite low crop diversity in continuous cereal systems. However, it is unclear if such conventional breeding approaches can work indefinitely. Both integrated pest management and biotechnology that identifies durable resistance through multiple gene sources should play increasingly important roles.

Nonetheless, the evolutionary interactions among crops and their pathogens mean that any improvement in crop resistance to a pathogen is likely to be transitory. Each defense sows the evolutionary seeds of its own demise. Maize hybrids in the United States now have a useful lifetime of about 4 years, half of what it was 30 years ago. Similarly, agrochemicals, such as herbicides, insecticides, fungicides and antibiotics, are also major selective agents. Within about one or two decades of the introduction of each of seven major herbicides, herbicide-resistant weeds were observed. Insects often evolve resistance to insecticides within a decade. Resistant strains of bacterial pathogens appear within 1 to 3 years of the release of many antibiotics. But the need to breed for new disease resistance and to discover new pesticides can be reduced by crop rotation and the use of spatial or temporal crop diversity. Recently, an important and costly pathogen of rice was controlled in a large region of China by planting alternating rows of two rice varieties. This tactic increased profitability and reduced the use of a potent pesticide. The intermingled planting of crop genotypes that have different disease-resistance profiles called a multiline can also decrease or even effectively eliminate a pathogen.

### *Implementing sustainable practices*

Farmer incentives are a central issue facing sustainable agriculture. Farmers grow crops or raise livestock to feed their families or to sell and earn a living in a market economy that is becoming increasingly global and competitive. Although some ecosystem services, such as pollination or control of agricultural pests, are of direct benefit to a farmer, other ecosystem services may benefit the public as a whole but be of

little or no direct benefit to the farmer.

Current incentives favour increased agricultural production at the expense of ecosystem services. Interestingly, many studies indicate that fertilizer-use efficiency could be greatly increased by better matching nutrient inputs to crop demand in time and space, but essential investments in on-farm nutrient-management research and in extension activities that promote such practices have not yet occurred. Similar opportunities for a significant increase in fertilizer efficiency exist for small-scale intensive rice cropping systems in the developing countries of Asia.

How, then, can society accomplish the dual objectives of improving yield levels and food stability and of preserving the quality and quantity of ecosystem services provided by the Earth's land and water resources? Clearly, appropriate incentives are needed. In addition to the practices described in the preceding sections, farmers will need to rely on a rapidly expanding base of biological and agronomic knowledge that is often specific to certain agro-ecosystems, regions, soil types and slopes. Making the right decisions at the farm level in terms of input-use efficiency, human health and resource protection is becoming an increasingly knowledge-intensive task.

Several policy initiatives have tried to level the playing field between agricultural production and production of ecosystem services. A number of countries, including Australia, Canada, European Union (EU) countries, Japan, Norway, Switzerland and the United States, have instituted various forms of 'green payments', that is, payments to farmers who adopt sustainable or environmentally benign farming practices. Norway and Switzerland provide substantial payments for 'landscape maintenance'. The United States' Conservation Reserve Program pays farmers to take land out of production for a specified period, and some countries have also instituted 'environmental cross-compliance' conditions as a prerequisite for farmers to receive agricultural support payments. Other policy options include taxes, removal of subsidies, and implementation of new regulations. A tax on fertilizers or pesticides, or removal of subsidies for these inputs, would discourage excessive use. International policies are needed when actions in one country cause environmental damage in another country, such as for polluted rivers that cross national boundaries, or for emissions of greenhouse gasses. But as the negotiations over the Kyoto Protocol on greenhouse gas emissions demonstrate, both the attainment and enforcement of such policies are major challenges.

Consumer incentives are also possible. A broad look at trends in agricultural production shows that many of the elevated environmental impacts projected for the coming 50 years are tied to increased consumption of livestock products and concomitant elevated demand for grains fed to livestock. Pricing and labeling each type of livestock product to reflect the true total costs of its production could provide consumers with important information and with incentives for choosing alternative food products.

Providing the right incentives should help to maximize the total return to society of the net benefits of agricultural production. However, many environmental problems and ecosystem services are difficult to monitor and quantify. For nitrogen or pesticide runoff or carbon sequestration, it may be costly to assess environmental performance of individual farms. Rather than basing incentive payments on environmental performance itself, proxies for performance, such as the adoption of certain auditable practices, may be as close as policy can get. The achievement of such objectives will require coordination among federal agencies or ministries for agriculture and for environment, which often have different objectives. Sustainable agriculture requires addressing the concerns of both groups.

The pursuit of sustainable agriculture will also require substantial increases in knowledge-intensive technologies that enhance scientifically sound decision making at the field level. This can be embedded in physical technology (for example, equipment and crop varieties) or in humans (for example, integrated pest management), but both are essential. However, the challenges of disseminating information on new technologies or on efficient input use and management are enormous, especially in cases where extension programmes are ineffective or completely lacking. The earlier paradigm of science being developed at the international or perhaps national level and then disseminated to farmers should be replaced by an active exchange of information among scientists and farmers. Scientists in developing countries who understand the ecosystems, human culture and demands on local agricultural systems must be actively trained, promoted and brought into the international scientific community.

Substantially greater public and private investments in technology and human resources are needed internationally, especially in low-income nations, to make agricultural systems more sustainable. Global research expenditures are less than 2 % of agricultural gross domestic product (GDP) worldwide, being roughly 5.5 % of agricultural GDP in developed countries, but less than 1 % in developing countries (where most of the increased food demand will occur during the next 50 years). At present, there are few incentives for the private sector to increase investments in lower-income developing countries. Furthermore, unless reward structures also reflect the value of ecosystem services, there will be little incentive for the private sector to invest in sustainable agricultural methods. Without adequate investments, yield gains and environmental protection may be insufficient for a transition to sustainable agriculture.

## Implications

The coming 50 years are likely to be the final period of rapidly expanding, global human environmental impacts. Future agricultural practices will shape, perhaps irreversibly, the surface of the Earth, including its species, biogeochemistry and utility to society. Technological advances and current economic forces, including large agricultural subsidies in the United States, EU and Japan, have both increased food availability and decreased the real costs of agricultural commodities during the past 50 years. But the resulting agricultural practices have incurred costs related to environmental degradation, loss of biodiversity, loss of ecosystem services, emergence of pathogens, and the long-term stability of agricultural production.

The goal of sustainable agriculture is to maximize the net benefits that society receives from agricultural production of food and fibre and from ecosystem services. This will require increased crop yields, increased efficiency of nitrogen, phosphorus and water use, ecologically based management practices, judicious use of pesticides and antibiotics, and major changes in some livestock production practices. Advances in the fundamental understanding of agroecology, biogeochemistry and biotechnology that are linked directly to breeding programmes can contribute greatly to sustainability.

Agriculturalists particularly agronomists are the *de facto* managers of the most productive lands on Earth. Sustainable agriculture will require that society appropriately rewards ranchers, farmers and other agriculturalists for the production of both food and ecosystem services. One major step would be achieved were agricultural subsidies in the United States, EU, Japan and other countries redirected to reward sustainable practices. Ultimately, sustainable agriculture must be a broadly based effort that helps assure equitable, secure, sufficient and stable flows of both food and ecosystem services for the 9,000 million or so people likely to inhabit the Earth.

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## Ecological services and economic benefits of aromatic crops

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Growing population with increasing demand for food coupled with growing concerns of climate change and its impact on agricultural systems of the world is a growing challenge which needs attention of scientists, farmers and policymakers. Diversification of agricultural crops to include ecologically and economically viable systems is not just an option but a necessity. Such diversification systems have to address both economics and environment.

Aromatic plants have a potential as diversification crops in agriculture (Prakasa Rao, 2009). Aromatic plants synthesize secondary metabolites, mainly terpenes which have several ecological and economic functions. Aromatic plants yield essential oils on steam distillation which are widely used in avours and fragrances, perfumery, pharmaceuticals and in alternate systems of medicine such as aromatherapy.

The roles of aromatic plants for ecological services and economic benefits have been discussed in this paper.

### Ecological services

Aromatic plants provide several ecological services which can be harnessed to restore agro-ecosystems. Some of such ecological services are discussed.

1. Soil restoration: Aromatic plants such as rosemary, lavender (Bienes *et al.*, 2010), vetiver (Donjadee and Chinnarasri, 2013) reduce soil erosion. Long-term cultivation of aromatic crops such as *Eucalyptus citriodora* improved soil pH, cation exchange capacity, soil organic matter and soil bulk density (Prakasa Rao *et al.*, 1999). In Egypt anise, caraway, coriander and cumin have been used to restore newly reclaimed soils (Hassanein, 2009). Palmarosa, vetiver and chamomile restore salt affected soils (Patra *et al.*, 1999). Aromatic plants arrest soil degradation processes in marginal lands (Prakasa Rao, 2012a).
2. Phyto-remediation: Aromatic plants help in removal of toxic substances from soils and water thereby helping environment. Coriander, sage, dill, hyssop, lemon balm, chamomile have been found suitable in areas where Zn-Cu smelters are located in Bulgaria (Zheljazkov *et al.*, 2008). Vetiver has been found suitable for phyto-

remediation of soils with toxic wastes (Truong, 2011). Oregano and rosemary were found suitable commercial crops in soils irrigated with secondary-treated municipal effluents rich in Na<sup>+</sup>, Cl<sup>-</sup>, HCO<sub>3</sub><sup>-</sup>, P, K, NH<sub>4</sub><sup>+</sup>, NO<sub>3</sub><sup>-</sup>, Ca+Mg, B, Mn, and Fe (Bernstein *et al.*, 2009).

3. Carbon sequestration: Growing need to curb CO<sub>2</sub> emissions and capture excess CO<sub>2</sub> in the atmosphere to mitigate climate change effects has been felt across the world and terrestrial C-sequestration through plant biomass has gained importance. Recent research involving perennial aromatic grasses, vetiver, lemongrass and palmarosa has shown their potential to sequester C; vetiver has sequestered more than 15t C/ha/year (Singh *et al.*, 2014).
4. River bank and water ways restoration: In many parts of the world, vetiver grass has been widely used for restoration of river banks (Truong, 2011). This will greatly help in restoration of water ways and flood control in vulnerable areas such as Brahmaputra river course (Bhattacharyya, 2011).
5. Pest and disease control: Essential oils from aromatic plants have a wide variety of secondary metabolites such as thymol, carvacrol, terpinen-4-ol, cinnamaldehyde,  $\alpha$ -pinene, anethol and eugenol which have been shown to control insect pests, plant pathogens and weeds (Prakasa Rao, 2015). Essential oils act against cockroaches, mosquitos, stored beetles (Adorjan and Buchbauer, 2010) and food spoiling fungi (Kurita *et al.*, 1981).
6. Aesthetics and agro-tourism: Essential oils are volatile in nature and in eco-systems where they are grown, the aesthetic value could be enhanced. As agro-tourism is gaining attention in order to improve quality of life and also enhance economic returns to farmers, aromatic plants could play important role in providing such benefits as health and aesthetics to the visitors.

### Economic benefits

While planning for diversification of crops, it is important to consider economic benefits of such crops relative to exist-

ing crops. Incorporation of several aromatic crops in traditional cropping system have been found to significantly improve economic returns while providing several ecological benefits (Prakasa Rao, 2012b). Aromatic plants have been shown to provide economic advantages when incorporated in plantation crops (Sujata *et al.*, 2011), horticultural crops (Rawal and Loko, 2009), agro-forestry systems (Thakur *et al.*, 2007) and in the traditional food cropping systems in Indo-Gangetic plains (Sushil Kumar *et al.*, 2001).

Thus, aromatic plants offer an important option to derive economic benefits and at the same time provide ecological services.

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## Sustainable intensification and diversification: means for maintaining soil health

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The decline in yield and fatigue in productivity have been noted under long-term experiments in various cropping systems of different agro-eco-regions of the country. Continuous cultivation of rice–wheat cropping system (major contributor to Indian food security) in the Indo-Gangetic plains is under threat with decline in soil organic carbon (SOC), total factor productivity and overall sustainability (Ghosh *et al.*, 2012). India is also facing a dual challenge of reducing CO<sub>2</sub> emission and enhancing the gross domestic product (GDP) by 20-25% by 2020 compared with the 2005 baseline. The concern about soils health degradation and agriculture sustainability has kindled renewed interest in the sustainable intensification and diversification of agro-ecosystems.

Soil health can be maintained through crop diversification and adoption of appropriate soil and crop management practice that either increases organic matter input to the soil, decrease the mineralization rate of soil organic matter, or both. Crop diversification through inclusion of pulses, forages, oilseeds, MPTs along with balanced application of plant nutrients, organic amendments and /or crop residue and tillage management can enhance and sustain SOC stock. Diversified cropping systems and management practices that ensure greater amounts of crop residue returned to the soil are expected to cause a net build-up of the soil organic carbon (SOC) stock. Identifying such systems or practices is a prior-

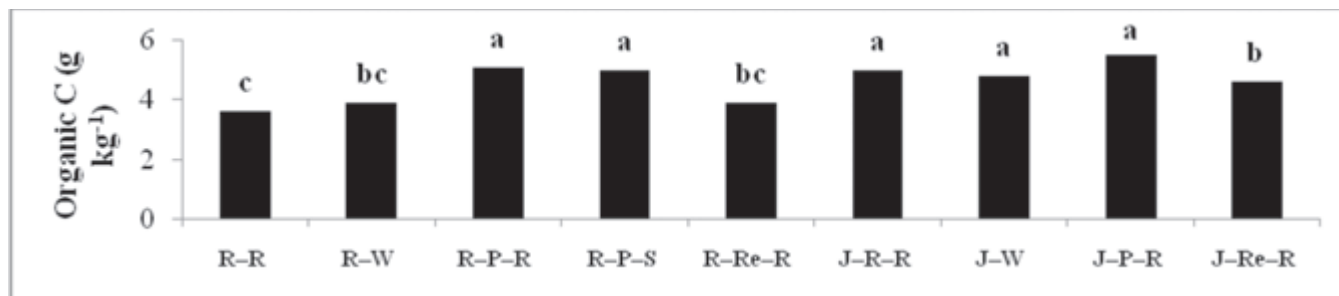
ity for sustaining crop productivity. The Amount of C input is required (kg ha<sup>-1</sup> y<sup>-1</sup>) to maintained SOC in different cropping systems is given in Table 1.

Pulses, an important component of crop diversification, are known to improve soil quality through their unique ability of biological N<sub>2</sub> fixation, leaf litter fall, soil covering nature, deep root system, greater below-ground biomass, easy to accommodate under diverse agro-ecosystems and more importantly complementary with cereals. The rice–wheat–mungbean system resulted in 6% increase in SOC and 85% increase in soil microbial biomass carbon as compared with the conventional rice–wheat system in a long-term fertility experiments in an Inceptisol of the Indo-Gangetic plain of India (Ghosh *et al.*, 2012). Similarly, in another study, maize–wheat–mungbean and pigeonpea–wheat systems resulted in significant increases of 11 and 10%, respectively in total soil organic carbon, and 10 and 15% in soil microbial biomass carbon, respectively, as compared with conventional maize–wheat system in Indo-Gangetic plains.

Alternate crops like oilseeds can also be grown without hampering the profitability of the rice-wheat system. The prominent oilseed crops for diversification are soybean, sunflower, groundnut and mustard. At least 5-6 lakh hectares of rice area in Punjab could be shifted to soybean. The area which goes to late season wheat due to late harvest of basmati

**Table 1.** Change in SOC storage equilibrium ( $dC_s/dt = aX - b \text{ SOC}$ ) in relation to total input require to maintain SOC in different cropping systems

Cropping system	Equation	Amount of C input required to maintained SOC (kg/ha/y)
Soybean-wheat IISS, Bhoal	Y= 0.1806X-160.34	888
Rice-wheat-jute (Barrackpore)	Y= 0.0536X-298.08	5562
Sorghum-wheat (Akola)	Y= 0.0217X-53.4	613
Groundnut (Junagarh)	Y= 0.2635X-1854.4	7600
Fallow based (Junagarh)	Y= 0.1931X-834.8	4300
Rice based	Y=0.064X-3.60	2920
Groundnut mono cropping (Anant pur)	Y=0.25X-5.57	1120
Sorghum-wheat	-	1078.8
Soybean - wheat	-	735.2
Soybean+sorghum - wheat	-	842.3



**Fig. 1.** Effect of different cropping sequences on organic carbon content of the soil (R, rice; W, wheat; P, potato; S, sesame; Re, rapeseed; J, jute). Within each column, means followed by the same letter do not significantly differ ( $P < 0.05$ ).

rice can be shifted to sunflower cropping. Course rice-potato-sunflower recorded higher returns (70262/ha) compared to course rice-wheat system (35881/ha). Ghosh *et al.* (2006) tested two rainy season crops (groundnut or fallow) and five post-rainy season crops (wheat, mustard, chickpea, sunflower or summer groundnut) and observed that the total system productivity was 130% higher in the groundnut-based than in the fallow-based system. However, C loss was more in groundnut based systems than fallow based. The amount of residue or organic matter needed per ha per year to compensate for loss of soil organic carbon was estimated to be 4.3 t in the fallow-based and 7.6 t in the groundnut-based cropping system. The groundnut-wheat system contributed more C, particularly root biomass C, than other systems, improved the restoration of soil organic carbon and maintained total system productivity.

Perennial grass based land use system had high SOC stock in comparison to seasonal crops. The TOC content (10.34 g kg<sup>-1</sup>), SOC stock (24.4 Mg ha<sup>-1</sup>) and SOC build up rate (1.95 Mg ha<sup>-1</sup> yr<sup>-1</sup>) were highest in Guinea grass + (cowpea-berseem). Interestingly, guinea grass based cropping system and FYM application contributed more in active C pools. Introduction of legumes and nitrogen fertilizer application caused 1.29 times increase in TOC of the grassland. *Macroptilium lathyroides* was the most suitable range legume producing highest dry forage yield (4.9 Mg ha<sup>-1</sup>), TOC (11.05g kg<sup>-1</sup>) and TOC build up rate (1.83 g kg<sup>-1</sup> yr<sup>-1</sup>). In the watersheds, development of Silviculture on wasteland enhanced the SOC stock from 9.47 mg ha<sup>-1</sup> to 30.81 Mg ha<sup>-1</sup> with annual build up of 5.33 mg ha<sup>-1</sup>. Amongst the Silviculture systems, SOC stock (mg ha<sup>-1</sup>) in surface soil was in the order of *Leucaena leucocephala* (36.6) > *Albizia lebbek* (32.7) > *Acacia*

*nilotica* (31.3) > *Hardwickia binata* (29.2) > pasture (28.8).

In India, average sequestration potential in agroforestry has been estimated to be 25tC per ha over 96 million ha but there is substantial variation in different regions depending upon the biomass production. The role of trees outside forests in carbon balance has been considered only recently, indicating that trees outside forests in India store about 934 Tg C or 4 Mg C/ha, in addition, to the forests. The net annual carbon sequestration rates for fast growing but short rotation agroforestry crops such as poplar and Eucalyptus have been reported to be 8 Mg C/ha/year and 6 Mg C/ha/year respectively. In terms of potential, currently area under agroforestry worldwide is 1,023 million ha and areas that could be brought under agroforestry have been estimated to be 630 M ha of unproductive croplands and grasslands that could be converted to agroforestry worldwide, with the potential to sequester 586 Gg C/year by 2040.

Therefore, intensification and diversification especially with pulses, oilseeds, forages and agroforestry can maintain soil health reducing the carbon footprint of the entire agriculture production system.

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**Symposium 4**  
**Integrated Farming Systems for**  
**Smallholder Farmers**





## Future farming systems and farm design

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Farming systems are in constant evolution and, considering the great challenges ahead related to climate and other drivers of change (e.g. population pressure, resource scarcity, market development), need to constantly adapt. Alternative technologies and policies have been (and are being) developed to support the adaptive and productive capacity of farming systems to future conditions. For example, conservation agriculture practices have showed important advantages in terms of resource use efficiency and yield stability to climate change and variability in a wide range of agro-ecologies (Jat *et al.*, 2014). This is one of the reasons they have been called Climate Smart Agricultural practices (CSAp) (Jat *et al.*, 2016). Also, beyond agronomy, alternatives related information services/decision support systems and novel insurances and credit schemes, are innovations being developed to improve adaptation and resilience in farming systems.

The household, its resources, and the resource flows and interactions at the individual farm level are referred to as a farm system (Dixon, 2001). Smallholder farm systems are complex because they commonly have several components (e.g. crop and livestock production and mixed off/on/non-farm income and labor investments) tightly interlinked which are geared together towards the satisfaction of a multiplicity of goals (e.g. food self-sufficiency and income generation, risk management). Technological and institutional options need to be tailored to fit the characteristics and objectives of farm systems in specific contexts.

Quantitative farming systems research (QFSR) can provide useful tools to better fit options to diverse farming systems and assess, *ex-post* and *ex-ante*, the contribution of such options to their sustainability. In this contribution, we show some examples on the use of QFSR to understand the diversity of farming systems and to assess the plausible impacts of alternatives on their sustainability.

### Understanding diversity of farming systems

Capturing the diversity of farming systems in a given context is an indispensable step toward the development of ap-

propriate alternatives that best match resource endowment and allocation, and livelihood objectives. Any agronomist knows that farming systems are different, in fact all unique, in terms of their agro-ecologies, their culture and traditions, their resources, their agricultural activities and techniques, their interaction with markets in terms of inputs, products and labor, their objectives for agricultural production, etc. Such diversity implies that silver bullet solutions at technological and policy level are rarely best fits across different types of farming systems and individual farms.

Farmsystems typologies have been commonly used to understand the diversity of farming systems and the potential pathways to strengthen their sustainability. Typologies can be developed through, among other, expert knowledge (Berre *et al.*, 2016), participatory processes (Lopez-Ridaura *et al.*, 2015) and multivariate statistical methods (Lopez-Ridaura *et al.*, 2016), the latter being the most commonly used (see Alvarez, 2014). Each method have its strengths and weaknesses, expert based methods are quick and easy to develop but might be limited by the aspects the “expert” believe are important, participatory typologies capture diversity of farming systems as the local actors perceive them but might be biased depending on participating farmers and group composition and dynamics. Statistical typologies allow combining several variables to develop distinctive types but require good quality quantitative data and the choice of those variables will strongly affect the resulting types.

Typologies have normally been developed for specific technologies (or entry points in term of interventions). For example, if a research project is implementing alternatives related to soil fertility, a typology on different fertility techniques and management is developed (e.g. Tittonell *et al.*, 2005). Although very important for the purpose of the development projects and the targeting of specific techniques, such typologies may represent a narrow view on the diversity of farming systems and their livelihood strategies which is necessary to understand for the design of alternative farming systems able to adapt to future conditions.

<sup>1</sup> [www.csisa.org](http://www.csisa.org)

<sup>2</sup> <http://www.cimmyt.org/project-profile/buena-milpa/>

Taking in to account the complexity of farming systems (i.e. multifunctional systems -- see before) a systems approach is suggested to capture the diversity of farmsystems in a given region by describing the main elements of a system: i) its boundaries (eg. farm resources), ii) the system’s inputs and outputs (e.g. labor or agricultural products to markets), iii) its components (e.g. livestock and food or cash crop production) and iv) the interactions among the components (e.g. product destiny, labor allocation, crop residue and manure management).

For example, Fig. 1 shows three distinctive farm types, out of five, delineated using the baseline survey from the *Cereal Systems Initiative for South Asia (CSISA)*<sup>1</sup> to understand the diversity of farming systems in Bihar. Main difference between the farm types relate to the available resources in terms of land and hard size, the crops and diversity of crops grown, the main destination of farm products and the income generated within and outside the farm.

Such farm systems types can be spatially explicit with the use of GIS providing key information on the spatial nature of such diversity (e.g. agroecologies or access to infrastructure and markets). Fig. 2 shows the spatial distribution of different types of farm systems identified in the municipality of Todos Santos in the western highlands of Guatemala in the context of the *BuenaMilpa* project<sup>2</sup>. Figure shows that, in the western lower lands of the municipality, farmers with diversified in-

come sources are more common than elsewhere while in the center of the municipality (with moderate climate, irrigation facilities and close to the largest town) the young full time farmers concentrate (Reyna-Ramirez, 2016).

Looking at the temporal dimension, typologies can be developed in relation to how the systems have changed in the past (Falconnier *et al.*, 2015; Bathfield *et al.*, 2016). Historical datasets might be especially relevant to better understand the trajectories of farming systems and accompany them in their pathway towards more sustainable systems adapted to future climatic and socioeconomic conditions.

**Assessing alternative farming systems**

Assessing the plausible combined impact of change and innovations on the sustainability of farming systems is necessary to increase preparedness for future conditions. Changes can be climatic or socioeconomic but also technological. “What if” questions rise when thinking on the adaptive capacity of farming systems such as: what could the benefit of a specific technology on the multiple objectives of a specific farm type? Are there important tradeoffs between conflicting objectives or synergies? What could be the plausible impact of climate change for the specific goals of a farm types in a specific region? Several tools and methods have been developed for QFSR to tackle these questions at the farm or farm household level, from participatory methods engaging in a co-

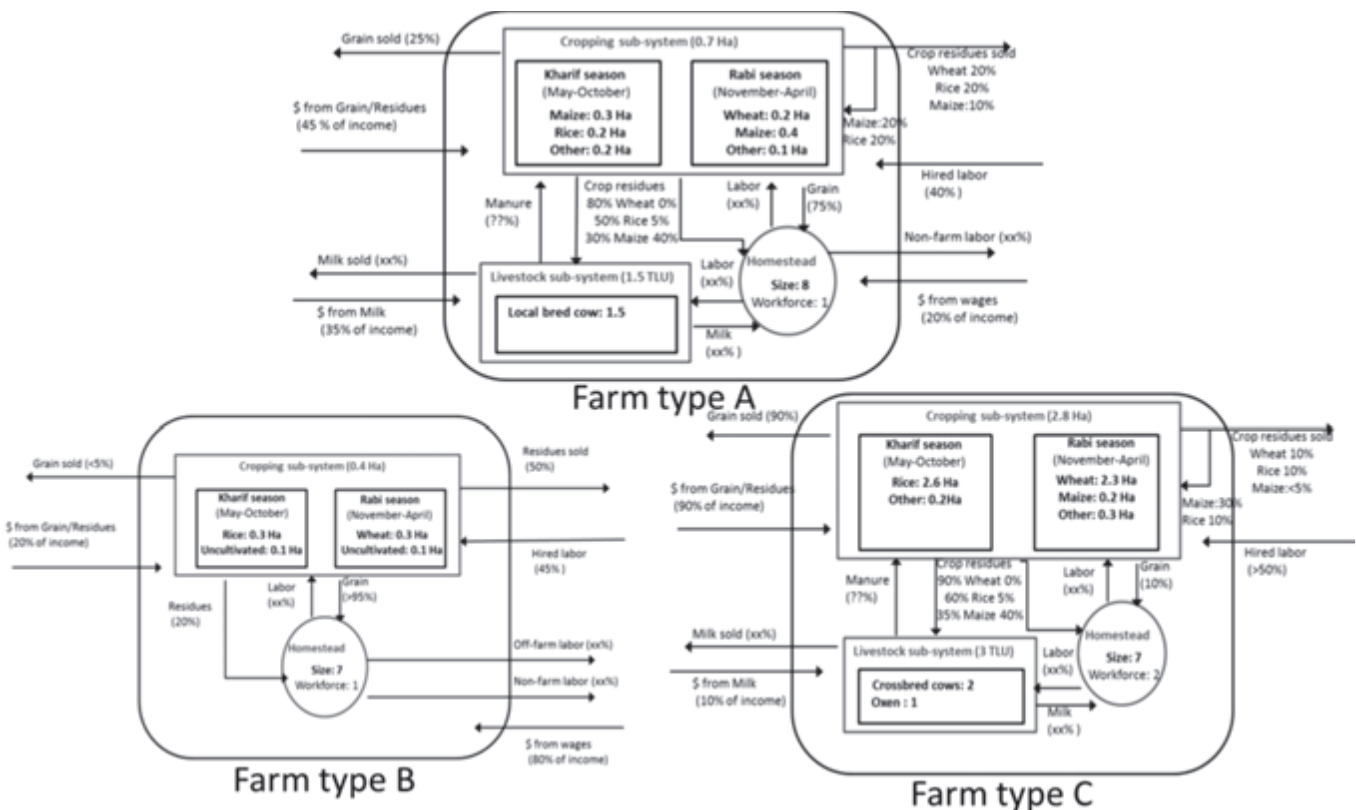


Fig. 1. Farm systems types from Bihar (based on Lopez-Ridaura *et al.*, 2016)



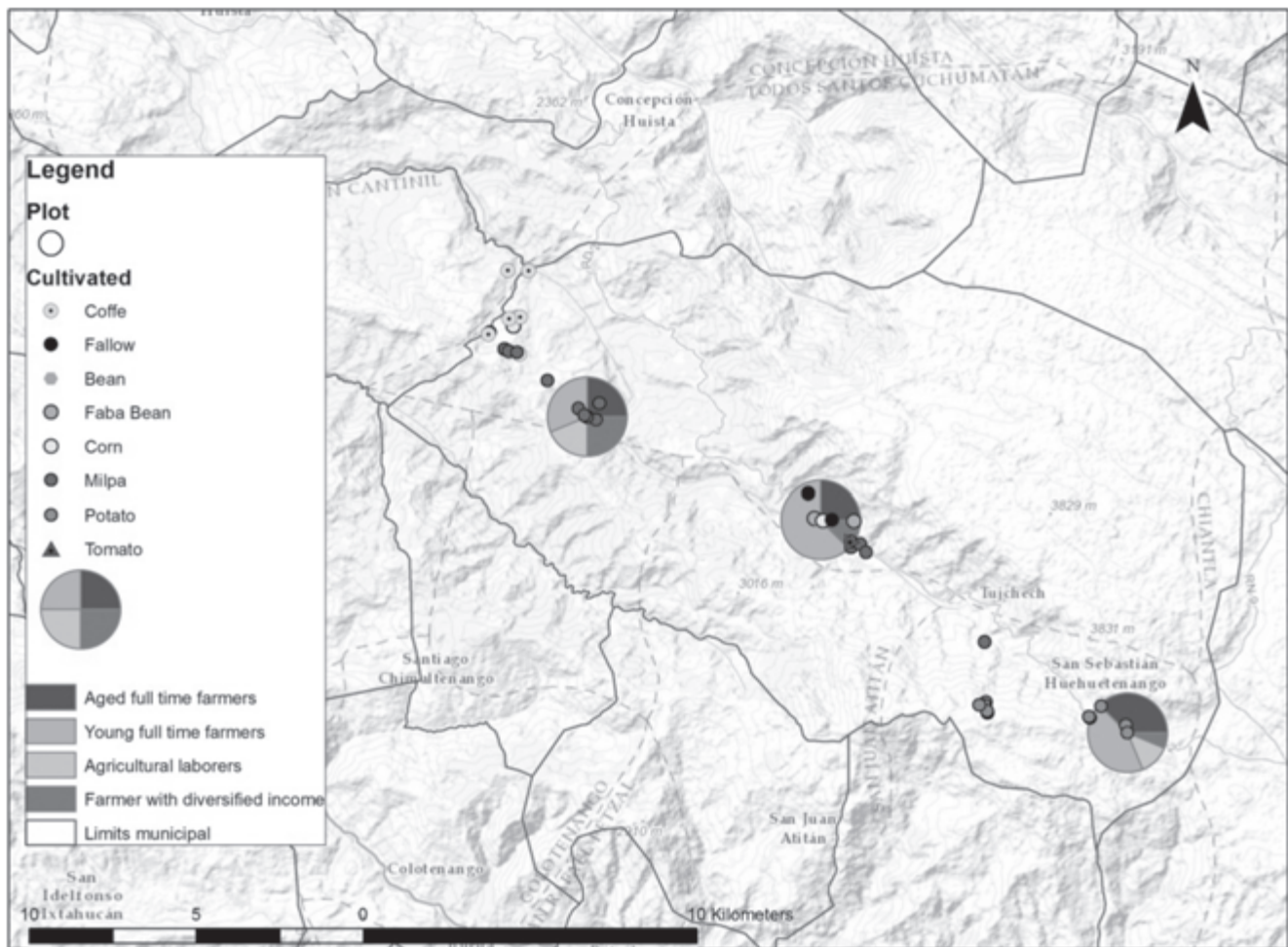


Fig. 2. Spatial distribution of farming systems in the Todos Santos, Western Highlands of Guatemala (Reyna-Ramirez, 2016)

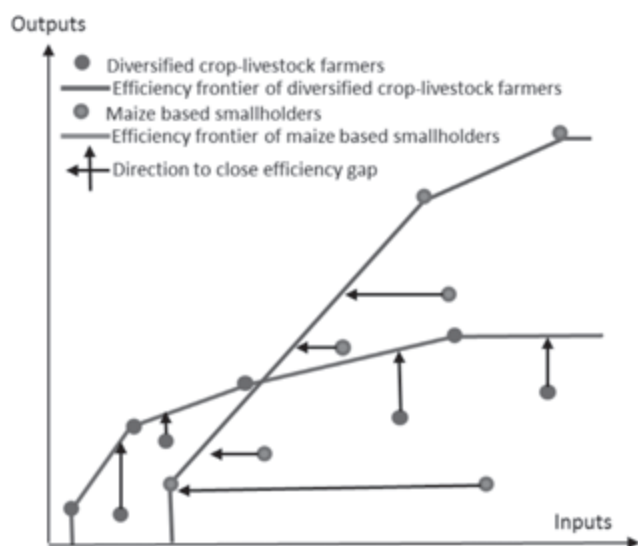
innovation process to ex ante modeling approaches (Dogliotti *et al.*, 2014; Lopez-Ridaura *et al.*, 2016).

Fig. 2 showed the different farm types in the Western highlands of Guatemala, the dots in the figure locate different participatory trials set up with farmers, after an individual diagnostic exercise, to engage in a process of co-innovation. Participatory trials range from maize and potato variety testing or planting densities, to irrigation systems, to rotations with fodder crops; always considering the main characteristics of the farm systems.

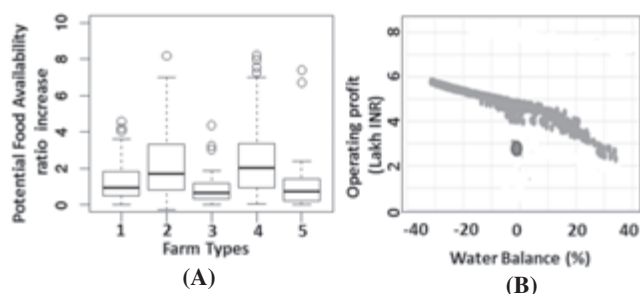
Modeling approaches to assess the sustainability of farming systems and their adaptive capacity have been developed and applied worldwide (e.g. Berre *et al.*, 2016; Lopez-Ridaura *et al.*, 2016). For example, in Malawi a multiple dimension frontier efficiency model was developed to identify the most appropriate pathways to increase efficiency, at farm scale, for two distinctive farm types. It was found that “diversified crop-livestock farmers” may gain efficiency by increasing the level of output with the level of inputs they are using while for “maize-based small holder” efficiency gaps can be closed by reducing the input level while maintaining same

outputs (Fig. 3) (Berre *et al.*, 2016).

In Bihar, India, two different approaches are being applied for farming systems ex-ante assessment. Taking in to account the typology developed with the CSISA dataset, a food security model was parametrized and scenarios related to the intensification of farming systems assessed. Fig. 4a, shows the differentiated impacts, in terms of the potential food availability, of sustainable intensification alternatives related to the production of wheat and rice showing that types 2 and 4 (Wealthy farmers and medium-scale cereal crop farmers, respectively) are the most benefited farm household types from the sustainable intensification of cereal based cropping systems (Lopez-Ridaura *et al.*, 2016). Fig. 4b shows the example of a preliminary result of the Farm Design model (Groot *et al.*, 2012) that has been parametrized for the different farm types identified in Bihar. The figure shows results for farm type 1 (part time farmers) revealing that, although a clear trade-off exists between operating profit and water balance (as calculated from current water balance and expressed in %), there is room for improvement in both indicators in relation to current values (Kalawantawanit, 2016).



**Fig. 3.** Efficiency frontier approach at the farm level to identify main directions to close the efficiency gap (adapted from Berre *et al.*, 2016)



**Fig. 4a.** Results of the FSA model (Lopez-Ridaura *et al.*, 2016);  
**Fig. 4b.** Results from Farm Design model (adapted from Kalawantawanit, 2016) for Bihar

## CONCLUSIONS

Farming systems are complex and diverse and, to develop appropriate adaptation strategies, such diversity needs to be captured. System's approaches provide the necessary theoretical basis and operational tools to understand the diversity of farming systems through formalizing their boundaries, the main inputs and outputs, their components or subsystems and the main interactions among these components. Such an approach is especially relevant for small scale farming systems where multiple coordinated activities are performed to contribute to the satisfaction of multiple, often conflicting, goals.

Farming systems approaches allow to assess the contribution of different technological or institutional change, or the effect of mayor drivers of change, on the sustainability of the farm system as a whole. Through modeling, farming systems analysis allows to explore and assess future plausible scenarios in terms the multiple objectives pursued by farm households (as well as other ecosystem services demanded by soci-

ety) and the trade-offs and synergies associated to those scenarios.

Stressing the fact that quick fixes or silver bullets are no longer conceived as an option for rural development and farming system's future required adaptation, farming systems approaches and the assessment of future scenarios provide the basis for, and need to be embedded on, the decision-making process of key actors for the development and implementation of agricultural technology and for guiding policy.

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## Diversified farming systems for sustainable livelihood security of small farmers in salt-affected areas of Indo-Gangetic plains

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Threats to global food security in the most of agricultural regions of world are increasing with depleting natural resource base and due to changing climate (IPCC, 2007). In the context of such growing threats, the effectiveness of diversified farming systems at mitigating the risk of crop failure bears significant relevance. Smallholders practice diverse crop–livestock farming systems in many parts of the tropics, particularly Asia and Africa, which integrate different enterprises on the farm; crops provide food for consumption and feed to livestock, and in turn livestock provide milk for improved nutrition and manure to fertilize the soil. The synergies between highly diversified cropping and livestock systems offer real opportunities for raising productivity and increasing resource use efficiency (Herrero *et al.*, 2010). Out of total 129.22 million land holders in the country, 64.8% are marginal holders who own less than 1 ha and 18.5 % families are small farmers owing between 1–2 hectares of land. The Indo-Gangetic Plains (IGP) of South Asia is characterized by lowest per capita availability of land, inequitable agrarian structure and resource poor farmers (Singh *et al.*, 2011). Continuity of rice-wheat system in IGP of India has raised serious concerns on degradation of soil health and shrinking fresh water resources. Integration of various farm enterprises in the form of diversified farming system may offer sustainable solutions to these problems, especially for the increasing number of small holders in the region.

To improve the agricultural productivity and profitability per unit area, a study on diversified farming system was carried out at ICAR-Central Soil Salinity Research Institute (CSSRI) Karnal, India in reclaimed sodic soils. Subsequently, a land reclamation model based on the concept of land modifications (physical land reclamation) and pond based integrated farming system was evaluated at the farmer's field at Kashrawan near Sharda Sahayak Canal in Raibareli district of Uttar Pradesh, by CSSRI, Regional Research Station (RRS) Lucknow and at CSSRI, Regional Research Station (RRS), Canning town (West Bengal) for integrated cultivation of

crops and fish to use available fresh and brackish water in the coastal area. These pilot studies explored the synergies of integration of different possible components of farming systems and evaluated their role to enhance the availability of and access to food, and increase household incomes and employment of smallholders in salt affected areas.

### METHODOLOGY

At CSSRI Karnal, out of the total 2.0-hectare study area (average land holding in the region); 1.0 hectare was allocated to grain crops and 0.2 hectare to each of fodder, vegetables, horticulture, fish pond and livestock+ poultry with biogas plant and compost pits. The allocations of different crops/agricultural enterprises adopted in the integrated farming system at Karnal are described in Table 1. Fruit trees like guava, banana, papaya, crane berry (karaunda), and Indian gooseberry (aonla) were planted on pond dykes and understory interspaces between these plants were used for raising seasonal vegetables around the year.

The total 1.0 ha area at Kashrawan (Raibareli, U.P.) comprised of fish pond, field crops, fruit crops, forages and vegetables components on 0.40, 0.25, 0.15 and 0.10 and 0.10 ha area, respectively. Fish were grown in the pond after initial pond treatment of soil sodicity. The flat beds of pond embankment and raised beds in remaining area were utilized for raising field crops and horticultural plantations. While the slopes of embankment and raised beds were utilized for eucalyptus plantation, which served the purpose of bio-shield and bio-drainage in the system. At CSSRI, RRS, Canning town, an area of 2.3 ha was reshaped into five different models viz: Paddy cum Fish (PCF) in 0.51 ha, 0.51 ha under PCF for brackish water (PCF-B), 0.36 ha under farm pond (FP), 0.22 ha in deep ridge and furrow (DF), 0.21 ha under shallow furrow and medium ridge (SF) with 0.51 ha area under original land (C) to create the scope of multi-cropping on mono-cropped land. Various rotations of field crops, vegetables, fruits along with paddy cum fish and fresh water fish in pond

were taken as against single crop of rice (*khariif*) in control. Each component was evaluated at the field and farm level for its profitability, sustainability and resource use efficiency in comparison to prevalent rice-wheat or rice-rice at (Canning town) system for respective years of studies.

## RESULTS AND DISCUSSION

At CSSRI, Karnal, the productivity in different components of diversified cropping system was worked out based on marketable produce from 2007-08 to 2013-14. It represents the yields of individual components in terms of grain, green fodder, green vegetable and fresh fruit in the case of grain crops, fodder crops, vegetables and fruits, respectively (Table 2). In food-grain production, the highest system productivity in terms of rice equivalent yield (REY) was recorded with rice-wheat-moongbean cropping system (12.2 t ha<sup>-1</sup>) followed by rice-wheat (11.1 t ha<sup>-1</sup>) and maize-wheat-moongbean (7.0 t ha<sup>-1</sup>). However, the lowest rice equivalent yield (3.7 t ha<sup>-1</sup>) was recorded in winter maize-soybean cropping system with low net returns of 9815/- because of foggy weather conditions which resulted in frequent attack of diseases (mildew, blights and rusts) during flowering to ripening of soybean. Under grain production components, rice-wheat and maize-wheat-moongbean cropping systems were comparable with each

other in terms of production and profitability.

The average net income from crop and subsidiary components together was ₹348,595/-, out of which ₹72,020/- came from crop (including fodder), ₹35,880/- from vegetables and fruits and ₹195,650/- from subsidiary components from an area of 2.0 ha, which was substantially higher than conventional rice-wheat cropping system (₹302,250/-). Among all the systems, fruits and fisheries production were found more remunerative with a B:C ratio of more than 4, whereas, vegetable production system generated lowest B:C ratio (1.9) due to involvement of higher input cost and labor in this system.

The economy of the integrated farming system at Kashrawan (Raibareli, U.P.) was evaluated in terms of cost benefit analysis of the individual cropping systems. The B:C ratio of the various components under study varied from 1.70 in fruit based system to 2.63 fish farming system (Table 3). The whole system B:C ratio comes to 2.21, despite of the fact that guava and Indian gooseberry have not come to fruiting at this stage. The initial investment of approximately 250000 on account of digging the fish pond is not included in the B:C ratio estimation.

Economics of various land shaping models at CSSRI, RRS, Canning town (W.B) were calculated and farm pond model emerged as the most profitable with highest B:C ratio

**Table 1.** Different crop/agricultural enterprise rotations followed within each production system

Crop components Grain production (1.0 )	Horticulture			Subsidiary components	
	Fodder Area in hectare (0.2)	Vegetables (0.2 )	Fruit trees (0.2 )	Livestock /Poultry (0.2)	Fisheries (0.2 )
Rice-wheat- 0.2	Sorghum-	Cabbage-tomato-	Guava + papaya +	3 buffaloes+2	Catla
Rice-wheat-moongbean-0.2	berseem	khira-0.1	banana	cows+120 birds	Rohu
Maize-wheat-moongbean-0.2		Bottlegourd-			Mirgal
Winter maize-soybean-0.2		cauliflower/potato-			Common carp
Pigeonpea-mustard-fodder maize-0.2		onion-okra-0.1			Grass carp

**Table 2.** Average Rice Equivalent Yields (REY) and income generated by various components from their respective area during 2007–08 to 2013–14 at CSSRI, Karnal

Component	Area (ha)	Rice equivalent yield (t/ha)	Gross income (₹)	Expenditure (₹)	Net Income (₹)	B:C ratio
Rice-wheat	0.2	11.1	49,075	18,850	30,225	2.6
Rice-wheat-moongbean	0.2	12.2	54,145	19,630	34,515	2.8
Maize-wheat-moongbean	0.2	7.0	31,135	11,700	19,435	2.7
Winter maize-soybean	0.2	3.7	16,250	6,435	9,815	2.5
Pigeonpea-mustard-maize	0.2	4.3	19,175	8,710	10,465	2.2
Fodder	0.2	4.4	19,305	6,695	12,610	2.9
Vegetables	0.2	6.4	28,210	14,625	13,585	1.9
Fruit trees	0.2	6.6	29,315	7,020	22,295	4.2
Livestock	0.2	67.7	299,130	134,550	164,580	2.2
Fisheries	0.2	9.3	41,015	9,945	31,070	4.1
Enterprise mix diversification	2	13.3	586,755	238,160	348,595	2.5

**Table 3.** Income generated by various components from their respective area during 2007-08 at Kashrawan ( Raibareli), U.P.

Component	Area (ha)	Gross income (₹)	Expenditure (₹)	Net income (₹)	B:C ratio
Rice-wheat	0.25	10,103	5,235	4,868	1.93
Forage	0.10	2,228	1,198	1,030	1.85
Vegetable	0.10	7,472	2,989	4,483	2.50
Fruit	0.15	2,100	3,600	—	1.70
Fish	0.40	42,840	16,254	26,586	2.63
Total	1.00	64,743	29,276	36,967	2.21

**Table 4.** Economics of land shaping based diversified farming system at CSSRI, RRS Canning Town West Bengal

Land shaping model	Operational cost and return ( <i>kharif + rabi</i> ) (₹)				
	Area (ha)	Gross income (₹)	Expenditure (₹)	Net Income (₹)	B:C ratio
Control	0.51	22,510	18,292	4,218	1.23
PCF	0.51	129,804	60,798	69,006	2.14
PCF-B	0.51	407,888	206,383	201,505	1.98
FP	0.36	144,676	60,112	84,564	2.41
DF	0.22	150,771	64,665	86,106	2.33
SF	0.21	141,326	72,550	68,776	1.95

of 2.41 followed by deep furrow (DF) and paddy cum fish (PCF). All the land shaping models have been generating higher net returns over the control plot (Table 4).

The higher net return from diversified multi-enterprise agriculture system comes from synergistic effect among various enterprises resulting in reduced overall costs of production. These observations are consistent with the findings of earlier studies (Chan *et al.*, 1998). The reduced net returns variability and income was due to extended trade-offs among various agricultural enterprises.

### CONCLUSION

The diversified farming system can be an efficient and remunerative alternative to rice-wheat/rice-rice cropping system for small holders of salt affected areas in IGP. This diversification of system may help to gain confidence of small and marginal farmers in agriculture by increasing productivity,

profitability and sustainability and ultimately their livelihood security.

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**Symposium 5**  
**Abiotic and Biotic (Weeds)**  
**Stress Management**







## The role of conservation agriculture in rainfed environments

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Conventional farming practices, particularly tillage and crop residue burning, have substantially degraded the soil resource base (Montgomery, 2007; Farooq *et al.*, 2011a), with a concomitant reduction in crop production capacity (World Resources Institute, 2000). Under conventional farming practices, continued loss of soil is expected to become critical for global agricultural production (Farooq *et al.*, 2011a).

Conservation agriculture (CA) is a set of technologies, including minimum soil disturbance, permanent soil cover, diversified crop rotations and integrated weed management (Fig. 1; Reicosky and Saxton, 2007; Hobbs *et al.*, 2008; Friedrich *et al.*, 2012), aimed at reducing and/or reverting many negative effects of conventional farming practices such as soil erosion (Putte *et al.*, 2010), soil organic matter (SOM) decline, water loss, soil physical degradation and fuel use (Baker *et al.*, 2002; FAO, 2008). For instance, soil erosion, water losses from runoff, and soil physical degradation may be minimized by reducing soil disturbance and maintaining soil cover (Serraj and Siddique, 2012). Using organic materials as soil cover and including legumes in rotations may help to address the decline in SOM and fertility (Marongwe *et al.*,

2011). With less soil disturbance comes less fuel use, resulting in lower carbon dioxide emissions, one of the gases responsible for global warming (Kern and Johnson, 1993; West and Marland, 2002; Hobbs and Gupta, 2004; Holland, 2004; Govaerts *et al.*, 2009). CA helps to improve biodiversity in the natural and agro-ecosystems (Friedrich *et al.*, 2012). Complemented by other good agricultural practices, including the use of quality seeds and integrated pest, nutrient and water management, CA provides a base for sustainable agricultural production intensification (Friedrich *et al.*, 2012). Moreover, yield levels in CA systems are comparable and even higher than traditional intensive tillage systems (Farooq *et al.*, 2011a; Friedrich *et al.*, 2012) with substantially less production costs.

CA is increasingly promoted as “a concept of crop production to a high and sustained production level to achieve acceptable profit, while saving the resources along with conserving the environment” (FAO 2006). In CA, modern and scientific agricultural technologies are applied to improve crop production by mitigating reductions in soil fertility, topsoil erosion and runoff, and improving moisture conservation and environmental footprints (Dumanski *et al.*, 2006). CA improves soil water use efficiency, enhances water infiltration and increases insurance against drought (Colmenero *et al.*, 2013). CA is thus an eco-friendly and sustainable management system for crop production (Hobbs *et al.*, 2008; Govaerts *et al.*, 2009) with potential for all agro-ecological systems and farm sizes.

### Permanent or semi-permanent organic soil cover

In CA, crop residues—the principal element of permanent soil cover—must not be removed from the soil surface or burned. The residue is left on the soil surface to protect the topsoil enriched with organic matter from erosion. At the same time, fresh residues must be added to the soil when existing residues decompose. Burning not only increases mineralization rates which rapidly depletes nutrients and organic matter from the soil, but also causes air pollution (Magdoff and Harold, 2000). In CA, plants are either left in the field or killed, with their residues left in the field to decompose *in situ*. This practice is primarily aimed at protecting the enriched topsoil against chemical and physical weathering. Plant resi-

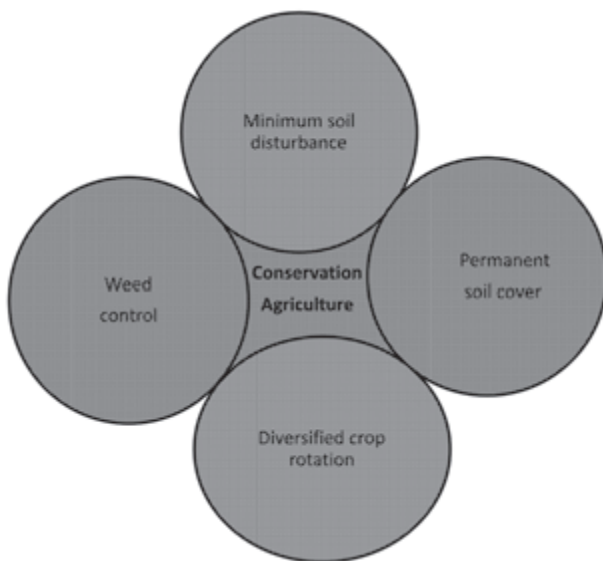


Fig. 1. Elements of conservation agriculture

dues slow down the speed of falling raindrops, provide a barrier against strong winds and temperature, decrease surface evaporation and improve water infiltration (Thierfelder and Wall, 2009).

Cover crops/green manure crops are grown to increase or maintain soil fertility and productivity. They increase SOM content either by adding fresh plant residues to the soil or by reducing soil erosion. Legume cover crops can fix nitrogen from the atmosphere into the soil increasing N availability to crop plants. Cover crops are mowed or killed before or during soil preparation for the next economic crop. A gap of one or two weeks before planting the next crop is needed to allow some decomposition and reduction in allelopathic effects of the residues, and to minimize nitrogen immobilization (Miguel *et al.*, 2011; Farooq and Nawaz, 2014).

CA improves soil biodiversity, soil biological activity, water quality and soil aggregation, and increases soil carbon sequestration through maintenance of crop residues. By keeping residues on the surface and using cover crops, permanent soil cover is maintained during fallow periods as well as during crop growth phases. Giller *et al.* (2009) opined that the benefits of each principle need to be properly evaluated as tradeoffs exist and some farmers have not adopted all of CA components. Retaining crop residues has positive and negative effects; researchers should develop strategies to enhance the positive effects (Kumar and Goh, 2000).

### Minimal soil disturbance

CA promotes minimal soil disturbance through no or reduced tillage, careful management of residues and organic wastes, and a balanced use of chemical inputs; all aimed at decreasing soil erosion, water pollution and long-term dependence on external inputs, improving water quality and water use efficiency, and minimizing greenhouse gas emissions by reducing the use of fossil fuels (Kumar and Goh, 2000). Zero tillage systems need minimal mechanical soil disturbance and permanent soil cover to achieve sufficient living and/or residual biomass to control soil erosion which ultimately improves water and soil conservation. CA emphasizes the importance of soil as a living body, particularly the most active zone in the top 0–20 cm, to sustain the quality of life on this planet; yet this zone is most vulnerable to degradation and erosion. Most environmental functions and services—essential to support terrestrial life on this planet—are concentrated in the macro, micro and meso flora and fauna, which live and interact in this zone. Human activities with regard to land management have the most immediate and potentially maximum impact in this zone (Hobbs *et al.*, 2008). By protecting this fragile zone, the vitality, health and sustainability of life on this planet may be ensured.

A recent modeling analysis, for three sites with fine-textured soils and different crop rotations in North America (Conant *et al.*, 2007), simulated zero tillage until equilibrium was reached and ran experimental models for 220 years there-

after. The model demonstrated a substantial decrease (~27%) in soil C content due to a shift to conventional tillage from zero tillage (Conant *et al.*, 2007).

### Diversified crop rotations

Crop rotations play a critical role in determining the success of crop production enterprises, but are most important in determining the success of crop production systems using conservation tillage. CA addresses the problem of insect, pests and diseases by integrating crop rotations, which help break the cycle that perpetuates crop diseases such as wheat rust and pest infestations (Witmer *et al.*, 2003), resulting in higher yield. A well-planned systematic crop rotation helps farmers to avoid many problems linked with conservation tillage, such as increased soil compaction, plant diseases, perennial weeds and slow early season growth (Tarkalson *et al.*, 2006).

Continuous maize planting in a no-till system may cause several problems such as perennial weeds, leaf diseases, inoculum buildup in residues, and wetter and cooler soils at planting due to heavy maize residues (Fischer *et al.*, 2002). These residues interfere with seed placement resulting in uneven stand establishment; while allelopathic effects from decomposing maize residues on young plants may slow the growth of maize early in the season (Fischer *et al.*, 2002). In such situations, a maize–hay rotation—as an alternative to continuous maize—is gaining popularity on dairy farms in Pennsylvania. Many problems linked to continuous no-till maize may be eliminated in this rotation when the sod is killed in autumn. The residue level will be manageable, the flux of perennial weeds will be less, insect problems will be less, and the soil structure usually will be excellent resulting in higher yields. Inclusion of *Sesbania* in direct-seeded rice as a green manure intercrop and then knocking it down with broadleaf herbicide has been effective in suppressing weeds and improving soil fertility in rice–wheat cropping systems (Yadav, 2004; Hobbs *et al.*, 2008).

With systematic crop rotations, the benefits of CA can be achieved on soils or at locations where success is often difficult. Combining the timeliness and reduced-labor benefits of CA with advantages of higher yield and reduced inputs when associated with a better crop rotation significantly increased profit levels (Linden *et al.*, 2000).

### Weed control

Weed control is considered a serious problem in CA systems and its success largely depends on effective weed control. Multiple tillage operations are required to control perennial weeds by reducing the energy reserves in different storage organs or roots of weeds (Todd and Derksen, 1986; Fawcett, 1987). Weed control in CA depends upon agronomic practices, herbicides and level of tillage used (Lafond *et al.*, 2009). In CA systems, small-seeded weed species are favored (Chauhan *et al.*, 2006a; Farooq and Nawaz 2014), while dormant weed seeds present in the soil do not move to the soil

surface (Cardina *et al.*, 1991). In CA, crop residues are maintained on the soil surface that keeps the soil moist and cool, which increases the survival of germinated small weed seeds compared with conventional agriculture. In conventional tillage systems, weed seeds are buried in the soil, while in CA more weed seeds are left on the soil surface (Chauhan *et al.*, 2006b), which are generally more susceptible to decay (Gallandt *et al.*, 2004).

Chemical weed control is the most effective weed management option in CA; however its effectiveness depends upon several factors including application of appropriate herbicides, time of application (post-emergence vs. pre-emergence) and the amount of crop residue present on the soil surface. Crop residues directly affect weed germination and the bioavailability of herbicides such as trifluralin (Chauhan *et al.*, 2006c). Residue retention strongly impacts weed emergence; several factors determine the extent of this influence including type and quantity of residue, nature of the residue, soil type, weather conditions and prevailing weed flora (Buhler, 1995; Chauhan *et al.*, 2006d). Phenolics in the surface residue may reduce the weed infestation (Farooq *et al.*, 2011b) in CA system. Nonetheless, the presence of plant residues may reduce the persistence and efficacy of soil-applied herbicides, which do not require incorporation into the soil and also intercept and bind the chemical before it reaches the soil surface (Potter *et al.*, 2008).

The availability of transgenic crops with resistance to non-selective herbicides, such as glyphosate and glufosinate, can effectively control weed species while decreasing labor demands and repeated applications of herbicides (Cerqueira and Duke, 2006). By using transgenic crops in CA, growers have boosted profitability by reducing labor expenses. The introduction of herbicide-tolerant transgenic crop varieties in CA systems provided effective weed control with substantial yield increases (Duke and Powles 2008). A new challenge to develop herbicide-resistant weed biotypes is threatening the use of herbicide-tolerant transgenic crops in CA systems (Farooq *et al.*, 2011a; Heap, 2014). Several weeds have developed resistance against herbicides. The first case was reported in 1970 in common groundsel (*Senecio vulgaris* L.), which developed triazine resistance (Ryan, 1970). Worldwide, the number of herbicide-resistant weed biotypes has reached 432, which demands continued research to control the resistance and avoid the future spread of resistant weeds (Appleby, 2005; Heap, 2014).

Kirkegaard *et al.* (2014) opined that herbicide rotation, green/brown manures, and harvesting and destruction of weed seeds may help in weed management under CA systems. They further proposed to include strategic tillage as a component of integrated weed management approach where applicable and safe (with respect to erosion risk) (Kirkegaard *et al.*, 2014). This may help to reduce the incidences of development of herbicide-resistant weed biotypes.

## The role of policy and institutional support

CA is a multi-dimensional approach ensuring the sustainability of resource use and food security. Principally, CA offers resistance to the irrational use of natural reserves through good management practices such as minimal soil disturbance using optimized tillage operations, check on soil exposure to environmental calamities, and biodiversity maintenance through diversified crop rotations. With the ever-increasing global population and urbanization reducing the amount of land under agriculture, food security has become a conundrum (Hobbs *et al.*, 2008); the sustainable use of available resources is a key element of CA systems.

Adoption of CA is a paradigm shift requiring huge efforts and tradeoffs at individual and institutional levels. In the long run, CA should be the ultimate solution to agricultural problems in small landholding farming communities (Derpsch, 2003; Giller *et al.*, 2009). CA research has progressed but adoption at the farmer level is a serious concern. Many factors hinder the uptake of CA by farmers and authorities: lack of proper information, poor knowledge dissemination, lack of demonstration, the need for long-term hard work, temporary decline in economic returns, hesitation, vague policies, lack of institutional support and natural disasters. Institutional support, innovative policy making, organizational collaboration, motivated think tanks and government supervision are critical to develop a strong system for proliferation of CA (Kassam *et al.*, 2012).

Policy making involves the realization of the available resources and serious approach to rethink the issue and options. Ecological, social and political activism on the issue of natural resource depletion and sustainability has been ignited for 20–30 years at a global level. Understanding this problem provides the foundation for structural development and promotion of sustainable approaches along with an awareness campaign (Kassam *et al.*, 2012). One important policy is ‘Save and Grow’ coined by the Food and Agriculture Organization. It covers the idea of a two-way process of sustainable production and economical usage, which has simplified and clarified the theme of CA. Policy formation strengthens the expression, adoption and promotion of this approach (FAO 2011b). Effective policies offer pragmatic solutions to several challenges (Kienzler *et al.*, 2012) such as:

- Useful practices to improve food production under limited inputs and thus sustainable promotion of food production and the supply chain
- Lowering the intensity of environmental damage through eco-friendly approaches
- Economizing the production chain via improved cultural practices, judicious input use and reduced exploitation of on-farm resources
- Preserving ecological hierarchy by maintaining biodiversity and natural habitats
- Offering a wide range of adjustments, adaptations and

rehabilitation after frequent natural and secondary disasters.

Institutions are the main hubs for information gathering, knowledge sharing and technology transfer. The role of institutional development in agriculture is significant. Linkage between research organizations, educational institutes and extension wings must be very strong to launch any technology. Considerable work is being undertaken on the adoption of CA on national and international fronts. Governments are sensing the vitality of the system and reinforcing the approach through multi-actions. In developed countries, the scientific community is leading the task by innovating and modifying the steps for sustainability. Strict implication of the rules and regulations has confirmed the success of CA in different cases.

### CONCLUSION

CA is a complex suite of technologies, including wise soil manipulation, retention of crop residues as soil cover, planned and diversified crop sequences, and effective weed management, for eco-friendly sustainable crop production. CA has proved beneficial in terms of yield, income, sustainability of land use, ease of farming, and the timeliness of ecosystem services and cropping practices. CA systems are being increasingly adopted worldwide; however, in some countries, its adoption is either slow or non-existent. Sustained governmental policies and institutional support may play a key role in the promotion of CA through the provision of required services for farming communities and certain incentives. On-farm participatory research and demonstration trials may help accelerate the adoption of CA.

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## Research needs to improve weed management in direct-seeded rice

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Rice, as a staple food, will remain the mainstay of the sustenance of Asia's population for years to come. During the past few decades, Asian rice production has been increased many folds because of advancement in research, formulations of agro-ecological based production and protection technologies, and efficient production input delivery systems. Continuous sustained rice production in Asia now faces many emerging challenges particularly in the wake of climate change and diminishing resource base, and the task of keeping pace with population growth is difficult. To address these challenges, rice research needs to be reoriented especially with emerging problems of looming water crisis and increasing labour scarcity. Therefore, smart rice research and development programmes are needed for sustained rice productivity and profitability and to conserve natural resources, especially water. To feed the future generation without degrading the resource base, rice production systems must become economically and ecologically sustainable. In this direction, direct-seeded rice (DSR) is becoming an emerging production system in entire Asia (Chauhan, 2012). Research and extension efforts are being made to popularize this production system on a large scale in Asia. However, weeds are the main constraints for obtaining similar yields in DSR (Mahajan *et al.*, 2009) to those in puddled transplanted rice. All types of weeds (grasses, broadleaves, and sedges) emerge simultaneously at high densities with crop emergence in DSR, because of absence of flooding during early stages. The transition to DSR can therefore only be successful if accompanied by effective weed management practices, which need best management practices, a right choice of herbicides, and effectiveness of herbicides relative to dominant weed flora, soil moisture at the time of herbicide application, and the effect of weather on weeds and herbicide efficacy (Mahajan *et al.*, 2013). Alone herbicide-based weed management technologies in DSR may pose environmental pollution and increase the chances of occurrence of herbicide-resistant weeds in DSR. The availability of cost-effective agro-ecologically based modern weed control technologies in DSR making it possible to avoid or minimize losses caused by weeds and they have now given confidence to Asian farmers adopt DSR (Chauhan

*et al.*, 2014).

Considering the diversity and complexity of weed problem, no single method of weed control whether cultural, manual, or chemical would be sufficient to provide season-long sustainable weed control under DSR. An integrated weed management (IWM) system as a part of an integrated crop management system would be an effective, economical, and eco-friendly approach for weed management in DSR. Weed management in DSR requires an understanding of weed ecology and biology, and due attention to an integrated approach that utilizes effective cultural (seed rates, competitive cultivars, planting patterns, and irrigation and nitrogen management), mechanical (tillage and stale seed bed), ecological, and chemical methods in a mutually supported manner (Chauhan, 2012a). The major thrust area in research and development that deserves focus in future for weed management in DSR are discussed in this article.

### Weed population dynamics and weed ecology

Weeds in DSR compete for the growth limiting factors such as nutrient, water, light, carbon-dioxide, etc. The empirical models developed for DSR provide an assessment of weed competition and impact on growth and yield of rice. Studies on population dynamics related to weed seed germination, establishment, and competition with DSR lead to an assessment of weed seed production potential in this system. Developing economic threshold levels for weeds in DSR would enable us in understanding the weed status, extent of yield losses, and suitable weed control measures. There is a need to assess such threshold levels and crop-weed interference models under Asian conditions for understanding the weed status and for the development of suitable weed control technologies. To develop viable weed management technologies in DSR, a better understanding of weed ecology, basis for competitiveness, phenology, physiology, and biochemistry of weeds and threshold populations is required, and towards this research programmes need to be reoriented.

Some weed species, such as *Leptochloa chinensis* (L.) Nees, *Eleusine indica* (L.) Gaertn., and *Eclipta prostrata* (L.) for example, may be encouraged by alternate wetting and dry-

ing in dry DSR. Sedges primarily compete for nutrients as their root systems are fibrous so, they must be controlled at early stages of the crop. *Echinochloa* species poses serious competition for light because of its height, whereas weeds with short stature [e.g., *Monochoria vaginalis* (Burm. f.) Kunth] offer little competition for light (Chauhan and Johnson, 2010). Management and environmental factors greatly influence weed distribution in DSR. Soil moisture content in the plough layer affects weed emergence patterns. All weeds in DSR do not emerge at one time but rather in several flushes. Seed dormancy and germination play a greater role in survival mechanisms of weeds. The seed bank in the soil is depleted through germination, predation, and decay while it builds up through seed production and dispersal. Seedling emergence and weed population dynamics are influenced by the differential vertical distribution of weed seed bank in the soil, the consequences of differences in availability of moisture, diurnal temperature, light exposure, and predator activities at different soil depths (Chauhan *et al.*, 2006; 2007). Therefore, the behaviour of weed species such as time of weed seed germination, period of fruit setting, emission of first vegetative organ, etc., varies with cultural and management practices followed in DSR, especially sowing methods. Understanding the behaviour of weeds under different management practices in DSR will be very critical in weed management. There is very limited information available on phenology (as influenced by moisture, crop competition, etc.) of key weed species in DSR.

#### *Weed seed germination stimulants*

Intensive research is needed to understand weed seed germination in DSR fields. If we could induce uniform germination in seeds of most weed species in one flush using germination stimulants, weed control practices could be significantly improved. The availability of weed seed germination stimulants could lead to the development of weed control systems for use at a stage when crop is not grown. This would impart added impetus to IWM in DSR.

#### *Crop management manipulations*

Successful weed management in DSR requires an intensive use of herbicides as pre- and post-emergence herbicides are needed in a sequential mode (Mahajan and Chauhan, 2013). Very few studies have been conducted on the influence of row spacing, seeding rate, and crop canopy in respect to crop-weed competition in DSR. There are several evidences that these factors can successfully be manipulated to provide a competitive advantage to DSR and can be a highly effective component of IWM in DSR with a little load of herbicides in agro-ecosystems (Mahajan *et al.*, 2014). For example, in the north-western part of India (Mahajan *et al.*, 2010) and in other parts of South and Southeast Asia (Chauhan *et al.*, 2011), it was observed that use of higher seed rates than the optimum seed rate caused significant reductions in weed dry matter and

resulted in an increase in yield of dry DSR. Some genotypes in DSR cover canopy earlier when planted in paired rows and provide a smothering effect on weeds; thus, resulted in increased yield (Mahajan and Chauhan, 2011). Greater weed competitive ability traits in some genotypes (early vigour and plant height, high leaf area index, high root-shoot ratio, drought tolerance ability, etc.) allow less use of herbicides in DSR (Mahajan *et al.*, 2014, 2015). Plasticity in some genotypes increased in response to water and nitrogen application that improved their ability to have rapid early growth and thus, smothered the weed flora at early stages in DSR (Mahajan and Timsina, 2011). Varietal improvement specifically dealing with characteristics that relate directly to increased weed tolerance and weed suppressive ability is almost non-existent. Even with this gap, weed scientists have observed differences among cultivars in their ability to compete with weeds. The genetic variability in specific crop cultivars, as a mean of enhancing the competitiveness of crops with the weed flora, has not been fully exploited in DSR (Mahajan *et al.* 2014). Intensive research in this area undoubtedly will provide a boost to the IWM concept in this rice establishment system.

#### *Crop and herbicide rotations*

The rotation of crops is an efficient system to minimize weed competition. As a component of IWM, rotations of crops will also facilitate herbicide rotations in the cropping system. Greater herbicide effectiveness may be achieved when crops as well as herbicides are rotated. For example, grasses and sedges in the rice-wheat cropping system can be controlled to a great extent by incorporating summer cowpea as a fodder crop or *Sesbania* as a green manure crop in the system, resulting in significantly lower weed populations (Singh *et al.*, 2008).

Crops with different management practices aid in disrupting the growth cycle of weeds (Chauhan, 2013; Chauhan and Mahajan, 2012). When there is a fallow period in any crop rotation, it can be exploited to stimulate the emergence of problem weeds. These weeds are then controlled by non-selective herbicides. In Southeast and South Asia, weedy rice is becoming a serious weed problem in DSR (Chauhan and Johnson, 2010a; Chauhan, 2013). In rice-based cropping systems, replacing one rice crop with an upland crop, such as maize, soybean, sesame, mungbean etc., in the dry season may significantly help in reducing the seed bank of weedy rice in the soil.

With crop rotation, growers can use new herbicides and this practice helps to control problematic weeds in DSR. Integrating sequential herbicide applications and herbicide mixtures with cultural, mechanical, and bio-control methods will reduce the chance of undesirable ecological shifts to tolerant weed species, minimize the chance of an accumulation of herbicide residue in the soil and cause reductions in weed seed population in the soil. To make this approach most effective,

preventive weed control must precede and accompany standard weed control practices.

### Long-term herbicide use and herbicide resistance

Environmental contamination, side effects not anticipated or fully comprehended including unsuspected metabolites or contaminants in herbicide formulations that may be detrimental to human being and animals, need be monitored. Improper use of herbicides in DSR may increase the risk of herbicide residue in rice grains and straw. To make the component of IWM in DSR eco-friendly, information that can provide the best assessment of actual as well as potential risks from the current use of herbicides in DSR needs to be generated. The DSR technology with intensive use of herbicides has gained wider acceptance in entire Asia including India; however, the problem of weeds resistance to herbicides over a period has start appearing to be a possibility. Already there are reports of herbicide-resistant weeds in South Asia and America, where DSR had been practised for a couple of decades. Mostly, ALS inhibitor herbicides are being used in DSR, that pose enough selection pressure on weeds and the genetic possibility cannot be ignored that a specific weed may develop resistance to a herbicide. However, it is also believed that herbicide resistance in weeds may not be a significant problem in DSR if farmers follow IWM programmes for DSR. However, there is a great concern regarding the ecological shift to weed population that are resistant to control by herbicides.

Weedy rice is becoming a threat in DSR fields and special attention is needed to restrict its spread (Chauhan, 2013). As weedy rice is very difficult to control through herbicides, more emphasis has been given to develop herbicide-tolerant (HT) rice. Continuous use of herbicides in DSR is essential that also demands HT rice. The main advantage of introducing HT rice are as follows: (1) it solves the problem of rice weeds, including weedy rice; (2) it will provide opportunities to use new herbicides with better environmental profiles and greater efficiency; (3) it provides the solution to herbicide-resistant weeds; and (4) it will strengthen resource conservation technologies by improving weed management techniques (Chauhan *et al.* 2012).

Three HT rice systems have been developed: imidazolinone-, glufosinate-, and glyphosate-tolerant cultivars (Gealy *et al.*, 2003). Glufosinate- and glyphosate-tolerant rice cultivars were developed through transgenic technologies. Imidazolinone-tolerant rice was developed through chemically induced seed mutagenesis and conventional breeding. Growing rice containing transgenes that impart resistance to post-emergence, non-selective herbicides such as glyphosate and glufosinate allows farmers to use no-till cultural practices, which may potentially reduce the total quantity of herbicides released in the environment while controlling nearly the entire spectrum of weed species (Duke, 1999). Therefore, HT rice offers a new way of conferring selectivity and enhancing crop safety and production (Chauhan *et al.*, 2012; James, 2011).

The use of non-transgenic HT rice cultivars developed by seed mutagenesis could be used as an effective weed management strategy in DSR systems. The use of non-transgenic HT rice cultivars (Clearfield rice) in DSR would be a classical, safe, and yet novel and effective means of weed management through the application of new-generation herbicides that are highly effective, non-toxic, and rapidly biodegradable (Mahajan and Chauhan, 2013).

HT rice can be used to control weeds that proliferate in conservation (minimum) tillage systems, such as *Cyperus* spp., parasitic *Orobancha* spp., and *Striga* spp. However, stewardship guidelines need to be followed while using HT rice. There is a risk that weedy rice may acquire resistance to herbicides following introgression of resistant gene(s) from the HT rice. Therefore, this issue needs to be addressed adequately by educating researchers, extension specialists, and farmers.

### Allelopathy

The role of allelopathic effects of weeds and crops and secondary chemicals in crops and weeds are not well understood in relation to their competitiveness including ecological shifts in weed population. Allelopathy can contribute to the competitive ability of crops against important weed species under DSR fields. Only a few studies, however, have been directed towards the specific use of allelopathy as a potential mean of controlling weeds. Olofsdotter (2001) reported that allelopathic rice can suppress both monocot and dicot weeds. The potential of some allelopathic rice cultivars to inhibit weed growth is up to 40% and this has been shown by planting *Echinochloa crus-galli* (L.) Beauv. together with various allelopathic rice varieties in a greenhouse (Mattice *et al.*, 1999). Quantitative trait loci, which are associated with rice allelochemicals against *E. crus-galli*, have been identified (Jensen *et al.*, 2001). This is an important step towards breeding allelopathic rice cultivars.

Recently, many studies suggested that farmers in rice growing countries would be benefited by success in breeding new rice cultivars with high weed-suppressing ability and this will play a vital role in sustaining DSR (Jamil *et al.*, 2011; Khanh *et al.*, 2007). The use of allelopathic plants, or substances isolated from them and produced transgenetically may become an important form of weed control in future.

### Biocontrol

Some of the outstanding examples of biocontrol of weeds are the use of plant pathogens to control *Aeschynomene virginica* L. in rice fields. This example of success must inspire rice researchers to take up further research in the area of biocontrol of weeds in DSR fields. Natural enemies for most weeds have been identified but whether these can provide the level of control, specificity, and environmental safety required by today's standard, remain open to question. The role of biocontrol in IWM in DSR and the extent to which it can help



in controlling numerous weeds remains to be seen in DSR. The use of the biocontrol aspect is species-specific and may be useful in DSR.

### Climate change

To tackle the problem of erratic rains during the emergence time of DSR, new genotypes with traits of anaerobic germination and having tolerance of early submergence are needed (Mahajan and Chauhan, 2013). These types of genotypes may provide uniform crop establishment, high and early seeding vigour with rapid leaf area development during the early vegetative stage of the crop under climate change scenario; therefore, they may be helpful in suppressing weeds. In the wake of climate change, climate resilient, water-efficient, and weed competitive genotypes are needed in DSR (Mahajan *et al.*, 2012). Genotypes with traits of droopy leaves at the seedling stage and erect canopy nature at later stages are needed to make DSR climate resilient. These traits may be incorporated through developing introgression lines with *Oryza glabberima*. Weedy rice may emerge as a problematic weed in DSR fields in future. Ziska *et al.* (2010) reported that weedy rice responds more strongly to increasing levels of CO<sub>2</sub> than does cultivated rice. In DSR fields, the rate of emergence of weed seedlings increased with increases in CO<sub>2</sub> concentrations (Ziska and Bunce, 1993). Under erratic rainfall conditions also, a similar change in weed flora can be expected because of climate change. Any type of environmental stress on a crop due to a sudden change in climate may increase its susceptibility to attacks by insects and pathogens; it thus becomes less competitive with weeds. These aberrant weather conditions not only increase weed competitiveness but also enhance weed seed germination in several flushes, making weed management more difficult. An increase in the CO<sub>2</sub> level in the atmosphere may increase tolerance of weeds for glyphosate (Ziska *et al.*, 1999); a pre-plant herbicide used to kill weeds before crop sowing. Such information suggests that glyphosate efficiency in the future may decrease with increase in CO<sub>2</sub>, thereby posing a threat in DSR fields where weeds are controlled using the stale seedbed technique (glyphosate application on emerged seedlings). The impact of climate change on weeds and rice-weed competition is yet to be understood. Efforts are needed to evolve and popularize climate resilient strategies by integrating herbicides and non-chemical approaches for effective, economical, and eco-efficient weed management in DSR.

### Decision making tools

Decisions for weed control in DSR must be made on the basis of type of weed flora, biology, and phenology of weeds (Chauhan, 2012). Herbicide use and application rates must be decided based on types, population size, and growth stages of weeds in the DSR field. For effective weed control in DSR, the choice of post-emergence herbicides clearly depends upon the type of weed flora existed in the field. For example, if a

field is infested with *Cyperus iria* L., *Cyperus rotundus* L., and *Echinichloa colona* (L.) Link, azimsulfuron is the best herbicide. If population of *C. rotundus* is less, bispyribac-sodium can be used as alternative. If a field is infested with *L. chinensis*, *Dactyloctenium aegyptium* (L.) Willd., and *Digitaria sanguinalis* (L.) Scop., fenoxaprop (with a safener) is the best herbicide. The application time of herbicides also varies with nature and extent of weed flora. If weed pressure is less at early stages in DSR, the application of post-emergence herbicides can be delayed for few days. If there is complex weed flora in the DSR field, then decision regarding the tank mixing of herbicide application is needed. Fertilizer and irrigation schedule also varies with nature of weed flora in DSR fields. According to the extent of weed flora, sometimes delaying fertilizer schedule provides a competitive advantage in the favour of the crop. Knowledge of weed history in the field may help in deciding the choice of a pre-emergence herbicide for effective weed control in DSR. The selection of agronomically, economically, and socially acceptable weed control systems requires an understanding of the technical, economic, and social realities of the area. Research is needed to develop effective decision-making tools for weed management in DSR.

### CONCLUSION

The biology of weeds must be understood and appropriate weed management strategies must be developed based on this knowledge. Elimination of weeds in DSR fields is possible through proper understanding of weed seed banks, proper manipulation of soil moisture, adjusting cultivation practices, altering planting patterns, and by maintaining desirable ecological conditions with the help of weed-competitive cultivars. IWM practices and herbicide resistance management programmes will need to be established if DSR is to retain the benefit of herbicides in long run. HT rice provides options to farmers for efficient and economic ways to cultivate DSR, but stewardship guidelines must be followed to avoid future problems. Herbicide companies must come forward for ready mix herbicide combinations to tackle complex weed flora in DSR. However, when ready mix combinations of herbicides are to be used in DSR, each product should be used at the specified labelled rate appropriate for the weed present. Exploitation of allelopathy by genetic manipulation of crops through classical breeding programmes or biotechnology can increase capability for weed control in DSR. The role of remote sensing, modelling, and robotics as an integral part of precision weed management in DSR must be explored. Understanding the impact of climate change on weeds, weed ecology, and their response to weed management practices including herbicides must be studied thoroughly for effective weed management in DSR.

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## Sustaining crop productivity during post reclamation phase following resource conservation technologies in reclaimed sodic soils

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Rice–wheat system is dominant cropping system in north-west Indo-Gangetic plains (IGP) grown over reclaimed sodic lands after introduction of green revolution in the country. The sustainability of this system is at risk past recently because of declining factor productivity and stagnating crop productivity. This mainly attributed to degradation of natural resource base (e.g. soil and water), shortage of labour, declining groundwater table, multi nutrient deficiencies including soil organic carbon, inappropriate residue management, inefficient use and mounting costs of inputs (e.g. fertilizer, labour, water, fuel and pesticides) leading to rise in cultivation costs and adverse changes in climate, and socioeconomic conditions of farmers. In some areas of northwest IGP, the water table is now being depleted at nearly 0.4 - 1.0 m yr<sup>-1</sup>. In 2009, 103 out of 138 in Punjab and 55 out of 108 administrative blocks in Haryana were overexploited (Humphreys *et al.*, 2010). Excessive pumping of fresh water aquifer is prone to salinity and sodicity problems lead to impaired physical and biological environment; the soil and plant growth is adversely affected. The steady increase in irrigated areas in India and cascade of environmental changes would lead to secondary salinization because of high evaporative demand in reclaimed salt affected soils in rainfed ecosystem and by replacing water exhaustive rice crop with less water intensive crop in irrigated system consequentially leading to estimated 11.25 and 20.00 m ha salt affected areas by 2025 and 2050 respectively compared to the current estimate of 6.73 m ha (Vision 2050, CSSRI-Karnal). As in Haryana and Punjab, the salinity of the groundwater increases with depth (Kamra *et al.*, 2002). The rate of salinization of the aquifer may be slowed down by diversifying rice-wheat system and by adopting resource management/conserving practices to minimize the amount of irrigation water applied to crops by reducing the evaporation through soil covering using crop residues.

In northwest IGP, with rising concerns related to degradation of natural resources and factor productivity with expected changing climate, there is a need to address the issues related of water, labour, nutrient, energy and residue management on

holistic approach basis for achieving the systems sustainability. Now-a-days, sustainable intensifications for higher productivity, resource efficiency, sustainability, and adaptability to expected changes in socioeconomic and environmental drivers is required to meet food security demand of future growing population using new crop rotations with resource conserving technologies (RCTs). In the recent past climate change induced variability forced to develop resilient system based on system approach rather than single-technology-centric approach following the principle of conservation agriculture (CA) (Balasubramanian *et al.*, 2012; Ladha *et al.*, 2009).

During last two decades in IGP, several CA-based component technologies have been developed and evaluated for resource conservation. These mainly includes laser land leveling (LLL), zero tillage (ZT), crop establishment (CE) methods, residue management, water and nutrient management which had a significant positive impact on crop productivity, profitability, and resource-use efficiency across IGP (Ladha *et al.*, 2009; Gathala *et al.*, 2013).

### Resource conserving technologies (RCTs)

Resource conservation based agriculture has emerged as a new paradigm to achieve goals of sustainable agricultural production (Sangar and Abrol, 2005). RCTs is a broad term that refers to any management approach or technology that increases factor productivity of available resources. RCTs include a wide range of practices related to management of water (LLL, micro-irrigation, direct seeded rice, bed planting, crop diversification), nutrient (ZT, residue management, legume integration, precision nutrient management) and energy (ZT, residue management, legume integration). RCTs are increasingly being adopted by farmers in the heartland of rice-wheat system because of advantages of saving on labour, water, fuel and cost along with timeliness in operations particularly early planting of wheat. Experimental evidence from various production environments suggests that CA based management can have both immediate, e.g. reduced produc-

tion costs, reduced erosion, stabilized crop yield, improved water productivity, adaptation to climatic variability (Hobbs, 2007; Bhushan *et al.*, 2008; Jat *et al.*, 2009; Malik *et al.*, 2014) and long-term benefits, e.g. higher soil organic matter contents and improved soil quality (Gathala *et al.*, 2013, Sharma *et al.*, 2015). It also offers an opportunity for arresting and reversing the downward spiral of resource degradation and thereby making agriculture more resource use efficient, competitive and sustainable. Integration of RCTs as per the universal principles of CA including permanent rational soil cover (through crop residues, cover crops etc.), minimum soil disturbance and crop rotations/intensification is now considered a way to achieve goals of higher productivity while protecting natural resources and environment. The main RCTs are as follows: -

### **Laser land levelling (LLL)**

It is a precursor to good agronomic, soil and crop management practices. Resource conserving technologies perform better on well levelled and laid-out fields. Effective land levelling saved irrigation water by 20-30%, improve crop establishment, increase cultivable area (by 3 to 5% approximately) and crop yield by 10-30% depending upon the type of soil and crop.

### **ZT/Residue management**

It is the main RCTs in rice-wheat system of northwest IGP. In northwest IGP, combine harvesting of rice and wheat is a common practices and leaving large amount (> 6 t) of crop residues in the fields. To vacate fields for the timely sowing of wheat (till 15 November), majority of the rice straw is burnt in situ by the farmers causing environmental pollution and loss of plant nutrients and organic matter. The main reasons for burning crop residues in field are timely unavailability of labour, higher wages during peak periods and use of combines. Burning of crop residues leads to loss of plant nutrients (all amount of C, 80% of N, 25% of P, 50% of S and 20% of K) and had adverse impacts on soil physico-chemical and biological properties.

### **Permanent Bed Planting (PBP)**

It provides opportunities to reduce the adverse impact of excess water on crop production or to irrigate crops in semi-arid and arid regions (Gathala *et al.*, 2011). Moreover, it controls machine traffic, limiting compaction to furrow bottoms, allows the use of lower seeding rates than with conventional planting systems and reduces crop lodging. Bed planting saves the irrigation water by more than 30 per cent over the flat system and also provides suitable micro-climatic conditions for microbes through better aeration and temperature moderation (1.5-2.3 °C) (Jat *et al.*, 2015).

### **Micro-irrigation system**

It is a technique in which narrow tubes delivers water di-

rectly to the base of the plant through emitters (drip irrigation) or spraying water in different directions through water jets (sprinklers) that saves costly inputs like water and fertilizers. Due to over-exploitation of groundwater in rice-wheat belt (Rodell *et al.*, 2010), there is immense pressure on the agricultural sector to reduce its water consumption. Researchers have been evaluating if cereals such as rice, wheat and maize based cropping systems can be grown with micro-irrigation systems (sprinkler, surface drip and sub-surface drip). Very recently demonstrations on direct seeded rice crop were grown with drip and sprinkler system in Haryana and Punjab. Compared to flood puddled transplanted rice, drip and sprinklers saved nearly 60% and 48% irrigation water, respectively.

### **Direct Seeded Rice (DSR)**

It is a smart method of seeding rice for resilient crop production with lesser irrigation water in any agro-ecosystem. In Indian IGP, increasing shortages of water, energy and labour forced the farmers to adopt CT/ZT-DSR. DSR can be categorized as CT-DSR, in which seeds are drilled in well cultivated field, and ZT-DSR, in which seeds are drilled under ZT condition. Basmati rice is ideal for DSR conditions. DSR helps in energy, irrigation water saving (20-30%) over TPR (transplanted rice) and also saves 5000/- on fuel and labour.

### *Legume integration*

Legume integration in rice-wheat system is required not only to protect from burning wheat residues but also to soil erosion and nutrient loss. Legumes have low carbon and water foot prints and yield stability under poor resource availability which make them an integral part of the sustainable farming system (Jat and Ahlawat, 2004).

### *Precision nutrient management*

It is an approach of supplying plants nutrients optimally to match their inherent spatial and temporal needs. It aims to recommend nutrients at optimal rates and times to achieve high profit for farmers, with high efficiency of nutrient use by crops across spatial and temporal scale, thereby preventing leakage of excess nutrient to the environment. Real time application of nutrients at right rate, right place with right source can be made using modern tools and techniques like leaf chlorophyll meter, leaf colour chart, green seeker and nutrient expert decision support tool.

### *Scalable evidences from northwest IGP on RCTs*

The problems of resource degradation, declining factor productivity and shrinking farm profitability vary not only with spatial and temporal dimensions, but also with managerial capabilities of the individual farmer. The response from science to problems in agriculture is often focussed on single resource conserving technologies. Therefore, more radical CA approach is required, which implies a qualitative change in the agricultural production system over a large demographic area.

The major RCTs and their integration with each other to slowed down the natural resource degradation while enhancing the productivity are as follows: -

### 1. Zero-tillage (ZT) and residue management

Zero-till (ZT) has practiced in large area (> 2 m ha) of Indian IGP and has several advantages to alleviate resource constraints in the rice-wheat production system. ZT seeder was found good for sowing with anchored residue, however Turbo Seeder for both anchored as well as loose residue load (anchored + loose) of 10 t/ha in single operation. ZT seeder permits earlier wheat planting in rice-wheat system, helps control obnoxious weeds like *Phalaris minor* by reducing the population by 68-80% when sown on 25<sup>th</sup> October instead of 25<sup>th</sup> November, compared to farmers business (Sharma *et al.*, 2015). Turbo Seeder can reduce the *Phalaris minor* population by 45-75% when a load of >6 t/ha maintained over soil surface in the rice-wheat cropping system (RWCS) of Indian IGP (Sidhu *et al.*, 2007; Sharma *et al.*, 2015). Due to lower cost of production with ZT, net return was significantly higher in ZT-based wheat production compared to CT-based production. Residue retention using ZT on soil surface lowered the canopy temperature by 1-4 °C in wheat at grain filling period and also helped in moderation of soil moisture and temperature.

Zero-till with full residue (ZTFR) recorded significantly higher grain yield over other treatments to the tune of 11.89, 9.71 and 5.61% than CT, ZT and ZTAR, respectively (Table 1). Significantly higher grain yield (4.96 t/ha) was recorded with sowing at 25-October than rest of the sowing dates. ZTFR produced significantly higher straw yield over others, and rests being at par with each other. Straw yield was varied significantly with planting dates and followed the trend; 25-Oct.>5-Nov.>15-Nov. The interactive effect of tillage with or without residue management and planting dates showed significantly higher grain yield (5.41 t/ha) with ZTFR sown on 25-October over rest of the combinations. Highest net returns ( 63520/ha) and B:C ratio (2.48) were realized with ZTFR, whereas, lowest with CT ( 45806/ha and B:C ratio 1.91), re-

spectively and followed the trend; ZTFR>ZTAR>ZT>CT. The net returns with ZTFR were increased to the tune of 38.67, 27.55 and 23.35% over CT, ZT and ZTAR, respectively (Table 1). Wheat planting at 25-October was proved better than other planting dates and resulted in higher net returns by 7.12 and 17.87% over 5-November and 15-November plantings, respectively.

### 2. Sustainable intensification and RCTs

Results of a long-term strategic research (average of 4 years) on sustainable intensification of cereal based systems conducted at ICAR-CSSRI, Karnal revealed that with CA based rice-wheat and maize-wheat system with integration of mungbean (scenario III and IV), increased the system productivity by ~16% compared to farmers' practice (scenario I), while saving other resources (Table 2). CA based sustainable intensification of rice-wheat system (scenario III) and maize-wheat system (scenario IV), saved 33 and 24 and 72 and 47% irrigation water and energy use respectively compared to farmers practice. In addition, the CA based management practices led to 22, 67 and 71% increase in soil organic carbon after 4 years of continuous cultivation with a sum residue load of 48, 56 and 66 t/ha, respectively compared to farmers practice (Table 5).

### 3. Secondary salinization and RCTs

Preventing reclaimed saline productive lands to turn in to secondary salinization or saline lands again, there is a need to explore the RCTs or diversification of rice-wheat system to sustain agriculture growth and productivity in northwest IGP. During two years (2014-16) of study, system productivity varied among different cropping system with their management practices. Highest system yield (wheat equivalent) was recorded with CT-DSR fb CT-wheat and it was comparable with other treatments and significantly higher than FBM-CTW (Table 3). DSR and maize based systems saved 18-19 % and 65-71% irrigation water on system basis compared to farmers practice (TPR-CTW). In treatment CT-DSR fb CT-wheat and ZT-DSR fb ZT- wheat, 31 and 27 % higher net re-

**Table 1.** Effect of tillage and residue management options and planting dates on yield, net returns and B:C ratio of wheat

Treatments	Grain yield (t/ha)	Straw yield (t/ha)	Net returns (Rs./ha)	B:C ratio
<i>Tillage and residue management</i>				
CT	4.54 <sup>c</sup>	6.52 <sup>b</sup>	45806 <sup>d</sup>	1.91 <sup>c</sup>
ZT	4.63 <sup>c</sup>	6.72 <sup>b</sup>	56505 <sup>c</sup>	2.35 <sup>b</sup>
ZTAR	4.81 <sup>b</sup>	6.75 <sup>b</sup>	58429 <sup>b</sup>	2.37 <sup>b</sup>
ZTFR	5.08 <sup>a</sup>	7.05 <sup>a</sup>	63520 <sup>a</sup>	2.48 <sup>a</sup>
<i>Planting dates</i>				
25-Oct.	4.96 <sup>a</sup>	7.17 <sup>a</sup>	61004 <sup>a</sup>	2.40 <sup>a</sup>
05-Nov.	4.72 <sup>b</sup>	6.78 <sup>b</sup>	55437 <sup>b</sup>	2.26 <sup>b</sup>
15-Nov.	4.61 <sup>c</sup>	6.34 <sup>c</sup>	51754 <sup>b</sup>	2.18 <sup>c</sup>

Where: CT- conventional tillage; ZT- zero tillage; ZTAR- zero tillage with anchored residue; ZTFR- zero tillage with full residue

turn was obtained than PTR fb CT-wheat. DSR followed by ZT wheat produced the highest system yield (12.62 Mg/ha) and net returns ( 1,17,00/ha) in case of rice based system while ZTM-ZTW-ZTMb produced the highest system yield (11.88 Mg/ha) and net returns ( 1,23,100/ha) in case of maize based systems. Secondary salinization in both rice and maize based system didn't appear in the first two year of experimentation as EC and pH were almost same in all the treatments. Therefore, with the results obtained, replacement of rice with maize is feasible in the reclaimed salt affected soils of north-west IGP.

#### 4. Precision nutrient management and RCTs

This approach aims to enable farmers to dynamically ad-

just their fertilizer use to optimally fill the deficit between nutrient needs of the crop and nutrient supply from naturally occurring indigenous sources such as soil, crop residues, organic inputs and irrigation water. In Karnal, Haryana, a total of 25 trials, 5 trials each village were conducted under wheat season 2015-16. In this precision nutrient management using green seeker (GS) and nutrient expert decision support tool (NE) were compared with farmers practice. Urea dose, wheat grain yields and net returns varied from farmers to farmers and village to village in the selected district. Higher yield was recorded under GS (4.9 to 5.2 t/ha) and NE (4.9 to 5.3 t/ha) compare to blanket application of urea (4.8-5.1 t/ha) in different villages (Table 4). Urea application on the basis of GS and NE saved 10 and 34%, respectively compared to farmers

**Table 2.** System yield, irrigation water and energy use in different CA based scenarios (4 years average), and soil organic carbon content after 4 years (in 2012–13)

Scenario	Systems	Residue management	Residue load (t/ha)	System yield (Rice Equiv)	Irrigation water (mm)	Energy use (MJ/ha)	SOC (%)
I- farmers practice	Rice-wheat (CT/TPR)	No residue	-	12.39	2710	75812	0.45
II- partial CA based	Rice-wheat-mungbean (CT/TPR-ZT-ZT)	Retention of full (100%) rice and anchored wheat residue, while full mungbean residue were incorporated	48	14.87	2179	62744	0.55
III- full CA based	Rice-wheat-mungbean (ZT-ZT-ZT)	Retention of full (100%) rice and mungbean; anchored wheat residue	56	13.73	1829	57569	0.75
IV- full CA based	Maize-wheat-mungbean (ZT-ZT-ZT)	Retention of maize (65%) and full mungbean; anchored wheat residue	66	14.38	754	40551	0.77

**Table 3.** Average (2 years; 2014-16) system productivity, input use, net return and pH affected by RCT based sustainable intensification

Treatments	Productivity (t/ha)	Irrigation water (mm/ha)	Energy use (MJ/ha)	Net return (1×10 <sup>3</sup> Rs/ha/yr)	pH (after 2 years)
T1- Puddled Transplanted Rice (PTR) followed by (fb) conventional till Wheat (CT- Wheat)	11.46 <sup>ab†</sup>	233.39 <sup>a</sup>	73650 <sup>a</sup>	92.1 <sup>b</sup>	7.5 <sup>a</sup>
T2- Conventional tilled dry drill seeded Rice (CT-DSR) fb Zero till wheat (ZT-Wheat)	12.62 <sup>a</sup>	190.70 <sup>b</sup>	64514 <sup>b</sup>	120.9 <sup>a</sup>	7.7 <sup>a</sup>
T3- Zero-till dry drill seeded rice (ZT-DSR) fb ZT-Wheat	12.22 <sup>ab</sup>	188.39 <sup>b</sup>	61353 <sup>b</sup>	117.0 <sup>a</sup>	7.5 <sup>a</sup>
T4- Maize on fresh bed fb CT-Wheat (FBM-CTW)	10.95 <sup>b</sup>	73.64 <sup>c</sup>	44444 <sup>c</sup>	100.1 <sup>b</sup>	7.6 <sup>a</sup>
T5- Maize-Wheat on permanent bed with anchored residue of both crop (PBM-PBW)	11.49 <sup>ab</sup>	68.48 <sup>c</sup>	38630 <sup>c</sup>	119.1 <sup>a</sup>	7.7 <sup>a</sup>
T6- Maize-Wheat on ZT flat with anchored residue of both crop ((ZTM-ZTW)	11.45 <sup>ab</sup>	80.76 <sup>c</sup>	41417 <sup>c</sup>	115.3 <sup>a</sup>	7.6 <sup>a</sup>
T7- Maize-Wheat-mungbean on ZT flat with anchored residue of maize and wheat and full residue of mungbean (ZTM-ZTW-ZTMb)	11.88 <sup>ab</sup>	80.45 <sup>c</sup>	41407 <sup>c</sup>	123.1 <sup>a</sup>	7.6 <sup>c</sup> (8.1)*

<sup>†</sup>Means followed by a similar lowercase letters within a column are not significantly different (p=0.05).

\*In parenthesis initial soil pH

**Table 4.** Urea dose, yield and net return under precision nutrient management (green seeker and nutrient expert) and farmers practice under rice crop in different villages of Karnal, Haryana

Villages	Urea (kg/ha)			Yield (t/ha)			Net return (/ha)		
	GS	NE	FP	GS	NE	FP	GS	NE	FP
Bastada	317±44	263±20	344±38	4.9±0.31	5.2±0.28	4.8±0.3	76129±8156	82728±5160	76035±6823
Sambhali	316±12	203±22	363±25	5.0±0.19	4.8±0.29	4.8±0.2	77016±4910	77238±6029	75059±4603
Chandsamand	303±30	225±4	317±25	5.2±0.24	5.3±0.22	5.1±0.1	83286±5422	83715±4023	81797±3702
Taraori	337±7.6	230±1	345±13	4.89±0.49	4.9±0.37	4.8±0.3	71049±10462	76522±6954	72149±8228
Birnarayan	286±27	217±1	361±37	5.2±0.22	5.1±0.12	5.0±0.1	79527±4943	81747±3020	79110±4496

Where: GS- green seeker; NE- nutrient expert decision support tool; FP- farmer's practice

practice on average basis in all the villages with a ~3% increment in yield under both the application methods (Jat *et al.*, 2016).

### 5. GHG mitigation potential and RCTs

Conventional cultivation of rice-wheat system not only requires intensive use of resources (labor, water and energy), tillage and crop establishment practices but also emit GHGs (CH<sub>4</sub>, N<sub>2</sub>O and CO<sub>2</sub>) in significant amounts. GHGs emissions from agricultural fields depends upon on the field (anaerobic/aerobic) and climatic conditions. SOC, tillage, fertilization, moisture, temperature, aeration etc. and their management and magnitude of interaction decides the temporal and spatial variability in GHG emissions. CA is the best-management including crop intensification and introduction of new plant type may help in mitigating their potential. The ZT-DSR (scenario 3; Table 2) showed a reduction in global warming potential (GWP) because of high reduction in CH<sub>4</sub> emissions relative to puddled rice. DSR in scenario3 reduced CH<sub>4</sub> emissions by ~50% compared to farmers' practice of puddled rice. However, diversification of rice-wheat by maize-wheat system in scenario 4, reduced GWP by ~20% in comparison to farmers' practice. It was estimated that switching rice crop establishment method from conventional to CA-based practices in Haryana could reduce GWP for rice by 23% or by 1.26 Tg CO<sub>2</sub> eq/yr. An intensive CA-based rice-wheat and maize-wheat system reduced GWP by 16-26% or by 1.3-2.0 Tg CO<sub>2</sub> eq/yr compared with the conventional rice-wheat system (Tirol-Padre *et al.*, 2016).

### CONCLUSION

RCTs and or CA based sustainable intensification is of utmost importance in northwest IGP to save natural resources and produce more at low costs with more crop per drop. To attain the objectives of output growth, employment generation and resource conservation in sodic soils, there is a need to overcome the formidable problems by address issues of water, labour, energy, pollution. Convergence of RCTs may help in improving the productivity, profitability and resource use efficiency on the principles of CA based sustainable intensification in cereal based systems while maintaining the envi-

ronmental quality. However, selection of RCTs should be based on socio-economic and bio-physical conditions of farmers to get higher benefits with the available resources. The CA based crop package, diversified cropping system and holistic approach is the need of hour to improve soil and environmental quality, promotes timely planting for higher yields and ensures crop diversification with the changing climate. Implementation of RCT-based intensification in IGP may be a productive way to build resilience into agricultural systems for national food security.

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**Symposium 6**  
**Efficient Soil, Water and**  
**Energy Management**





## Smart soils and agricultural resilience: A perspective

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Soil is imperative for the progression of a country’s economy and hence should be robust and possess high resiliency to withstand erosion and pollution while simultaneously being fertile enough to sustain crop growth and productivity. However, the type of soil varies from region to region and hence, conditioning of soil becomes critical to maintain the viability. The conditioning can be done by applying fertilisers or renewable materials like biochar (a biomass-derived carbonaceous material). These conditioning would ensure that the soil is resilient enough to bounce back to its original condition in case of an external perturbation. This presentation provides a perspective on the soils as a tool being the central focus, and how soils can be manipulated to main the agricultural resiliency by using novel approaches.

The economy of most countries, especially developing nations rely heavily on the agricultural productivity. The agriculture in turn is dependent on the quality of the soil in that country and the type of crop intended to be harvested. Even today, almost 75% of world’s population suffering from poverty maintains their livelihood through farming in rural areas. Therefore, it is clear that agriculture remains fundamental for poverty reduction, economic growth and environmental sustainability. Fig. 1 shows that the enhancement of the gross domestic product is almost four times more from agriculture as opposed to non-agriculture activities (Marjory-Anne, 2012).

However, there are many challenges that soil and agricul-

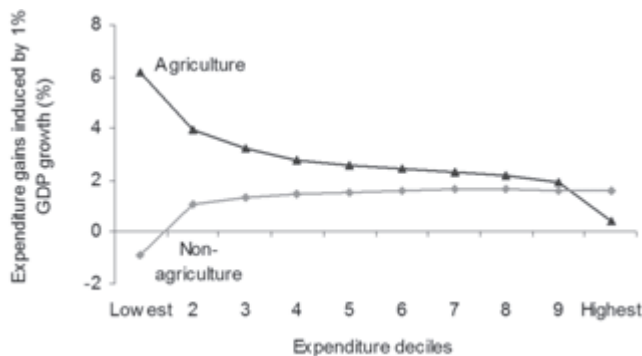


Fig. 1. Gross domestic product (GDP) vs. agriculture (Marjory-Anne, 2012)

tural sector faces in a given country (especially developing nations). These hindrances are related to but not limited to the lack of funding in agricultural research and development and erosion and pollution which leads to poor soil quality.

Followings are some potential solutions and/approaches which can be undertaken to facilitate betterment of agricultural development: a) undertake a comprehensive approach to reduce the disparity between the rural and urban scenarios; b) increase services related to sustainability and environmental improvement from agriculture, c). encourage use of novel materials which enhance soil health, d) the quality of governance should be improved in case of agriculture in all levels (local and national). The aforementioned points can be summarized into a five pillars plan as shown in Fig. 2. The independencies and connectedness between these attributes associated with each pillar ultimately determine the agricultural stability and productivity of a particular region manifested by the soils health and ability to maintain its resiliency against natural calamities such as flood, erosion etc.

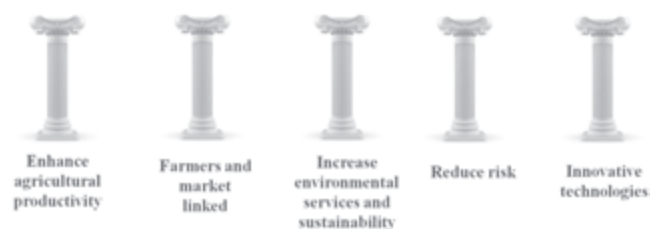
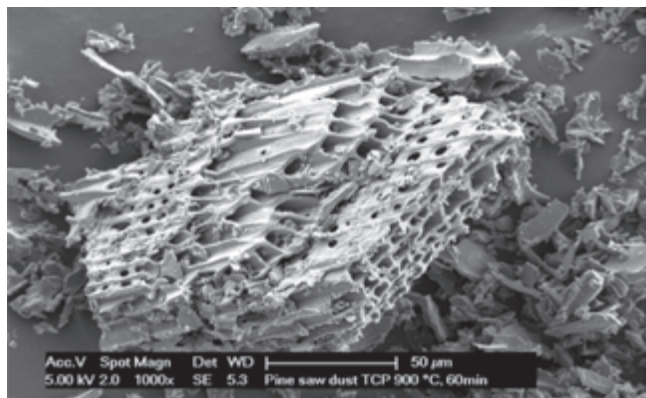


Fig. 2. Five pillars plan for agricultural development

One technique to enhance soil health is to add biochar as a low cost and renewable amendment. Biochar, a by-product of organic waste pyrolysis is a renewable material which has been extensively employed in agriculture and environmental management as a low cost carbon sequester and a natural adsorbent (Hajati *et al.*, 2014). Its exceedingly stable honeycomb like carbonaceous structure with high surface area has ensured its use in soil amendment and remediation (Zhang *et al.*, 2013). Following is a scanning electron micrograph of a pine saw dust based biochar showing numerous pores on its



**Fig. 3.** Scanning electron micrographs (SEM) of pine saw dust biochar

surface and a glassy and smooth surface. These biochars are highly carbonaceous and can stay stable in soil for thousands of years (Das *et al.*, 2015).

The resiliency of agricultural soil can be enhanced by the

application of biochar which would act as an efficient carbon sequester, contaminant remover and also facilitate beneficial soil microbial growth. As a result, an infertile soil can be made suitable for growth of certain crops while concurrently mitigating the adverse effects from pollution and erosion.

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**Symposium 7**  
**Precision Nutrient Management**





## Advances in precision nutrient management: Indian scenario

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Inadequate and unbalanced use of plant nutrients through fertilizers and manures led to depletion of the fertility of Indian soils, as evident by occurrence of widespread deficiencies of at least six nutrients *viz.* N, P, K, S, Zn and B (Dwivedi2015). A nutrient-starved soil cannot support high crop productivity. Any yield gains achieved on such soils owing to varietal or crop management interventions other than adequate nutrient input would be temporary; leaving the soil further depleted of its native nutrients reserves. Unless plant nutrients are supplied in adequate amounts and balanced proportions, there will be much greater drain of the native soil fertility, and the soil would not sustain high crop productivity. The nutrient use efficiency (NUE), particularly that of N, P and micronutrients continues to be very low, which need to be improved not only for soil health and crop productivity enhancement, but also to keep farming environmentally safe and economically attractive.

Soil health ailments could be effectively addressed through judicious management. The *ad hoc* fertilizer prescriptions for entire state do not address differences in indigenous soil fertility, crop management practices, yield responses to added nutrients, or differences in attainable yield potential across sites or years. Precision nutrient management (PNM), on the other hand, ensures a better synchrony between nutrient supply and crop demand, and involves assessment of soil fertility variation and suggesting nutrient prescriptions following the 4R (right rate, right source, right time and right method) principles. Extensive studies at research stations and farmers' fields underlined the significance of PNM practices such as soil test-based integrated plant nutrient supply (IPNS), site-specific nutrient management (SSNM), in-season real-time N supply, and decision support tools.

### Soil test-based nutrient supply

Soil testing is a time-tested tool for soil fertility evaluation and restoration of depleted soils by way of suggesting judicious application of plant nutrients and amendments. Beginning in 1955-56, soil testing service in India constantly expanded over the years, a network of 1244 static and mobile soil testing labs (STLs) with an annual analyzing capacity of

17.83 million samples. In addition, soil testing facilities have been created at more than 300 *Krishi Vigyan Kendras* (KVKs). The state agricultural universities (SAUs) and some of the ICAR institutes also offer soil testing service on a limited scale. With the Government initiative to distribute soil health cards to 140 million farm holdings in a given time frame, soil testing service came to the centerstage of soil health restoration and PNM. Despite large network of STLs and personnel engaged therein, the service could not gain desired acceptability amongst farmers. The soil testing service needs to be revamped with appropriate R&D and policy support to meet the farmers' aspirations. Ideally, it should be a farmers' demand-driven service rather than a government-driven programme. Government's recent initiatives namely Soil Health Card (SHC) Scheme and Soil Health Management (SHM) sub-mission of the National Mission on Sustainable Agriculture (NMSA) would help revamping soil testing service.

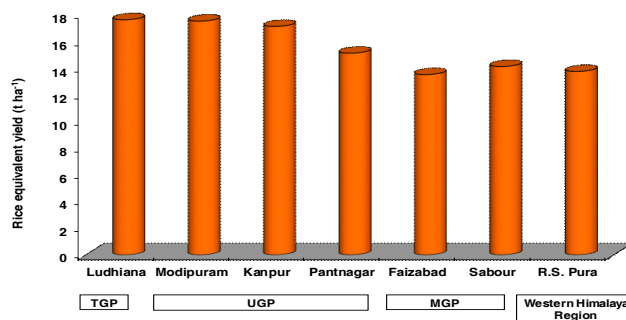
Development of digital soil testing kits involving low-cost programmable colorimeters such as Pusa Soil Testing and Fertilizer Recommendation Meter (Pusa STFR Meter) is a recent initiative that would go a long way in promoting PNM by taking soil testing to the smallholders' doorstep. Pusa STFR Meter quantitatively determines 12 important soil parameters *i.e.*, pH, EC, organic C, available P, K, S, Zn, B, lime requirement (for acid soils), and gypsum requirement (for sodic soils), and also provides soil test-based crop-specific fertilizer recommendation. Use of hyper-spectral remote sensing for soil testing is another emerging area, which may help delineation of soil fertility and development of site-specific nutrient prescriptions. These tools, however, need to be perfected and validated under diverse soil-crop conditions prior to their largescale adoption.

### Site-specific nutrient management

Site-specific nutrient management (SSNM) aims to increase profit through high yield and high efficiency of fertilizer, and also provides a locally-adapted nutrient best management practice tailored to the field- and season-specific needs for a crop. Plant analysis-based SSNM modules consider nu-

trient status of the crop as the basis for fertilizer prescription, whereas soil test-based ones consider soil nutrient values. Studies revealed that high productivity goals (*i.e.*, up to 80% of the variety-specific genetic yield potential) could be attained following SSNM. Crop growth models (*e.g.*, DSSAT and InfoCrop) could be used for assessing the yield potential of a variety, whereas QUEFTS is frequently deployed to relate crop yields with plant nutrient content and soil fertility variations. Indigenous nutrient supplies are calculated with the help of nutrient omission plot. Information on yield targets, indigenous nutrient supply and internal efficiencies of nutrients is used to develop site-specific fertilizer prescriptions. Studies revealed superiority of SSNM over farmers' practice (FFP) in different crops in terms of yield gain, and improvement in NUE.

Multi-location studies with intensive cropping system *viz.*, rice-wheat, rice-maize, pearl millet-wheat, pearl millet-mustard, and sugarcane-based systems underlined the significance of inclusion of secondary- and micronutrient deficiencies in the SSNM prescriptions, as against *ad hoc* NPK recommendations or FFP involving mainly NP fertilizers. Precision nutrient input improved NUE and economic returns over FFP. In rice-wheat system, it was possible to attain 14-16  $\text{tha}^{-1}$  annual grain productivity with the adoption of SSNM at different locations (Fig. 1). At most of the sites, both rice and wheat showed linear response to application of 120  $\text{kg K}_2\text{O/ha}$ , suggesting for an improvement in K application rates for higher crop yields (Tiwari *et al.* 2006).



**Fig. 1.** Annual productivity of rice-wheat system (rice equivalent yields) at different locations. TGP, Trans-Gangetic Plain; UGP, Upper Gangetic Plain; MGP, Middle Gangetic Plain

### Real time N management

Unlike fixed-time N-scheduling as usually practiced, real-time approach requires *in situ* monitoring of crop N status to take a decision on N application in synchrony with crop demand. At least, three decision gadgets namely leaf color chart (LCC), chlorophyll meter (SPAD) and GreenSeeker are available for *in situ* monitoring of leaf N status. A chlorophyll meter can provide a quick estimate of the leaf N status, but it is relatively expensive. The LCC, on the other hand, is inexpensive, simple and easy to use tool to monitor the relative greenness of leaf as an indicator of crop N status. The LCC used in India is typically a durable plastic strip (about 7 cm

**Table 1.** Grain yield, agronomic efficiency ( $AE_N$ ) and recovery efficiency ( $RE_N$ ) under three rice and wheat genotypes grown with different N management options at Modipuram

N-management treatment	Total N applied Kg/ha	Grain yield t/ha <sup>1</sup>	$AE_N$ kg grain/kg N	$RE_N$ %	Rice		Wheat	
					Cultivar: Basmati 370	Cultivar: PBW-343 (Early sown)		
<b>No N-control</b>	<b>0</b>	<b>2.7</b>	<b>-</b>	<b>-</b>	<b>0</b>	<b>2.1</b>	<b>-</b>	<b>-</b>
LCC $\leq 3$ , No basal N	20	3.2	26.7	69	60	4.2	34.3	71.6
LCC $\leq 4$ , No basal N	80	4.3	20.7	58	120	5.7	29.7	63.3
LCC $\leq 5$ , No basal N	100	4.1	15.2	52	160	6.1	24.0	55.6
Recommended N	80	3.7	14.5	49	120	5.2	25.0	52.5
		Cultivar: Saket 4			Cultivar: HD 2087 (Timely sown)			
No N-control	0	3.5	-	-	0	2.2	-	-
LCC $\leq 3$ , No basal	75	5.2	23.2	59	60	4.1	31.6	65.0
LCC $\leq 4$ , No basal	135	6.5	21.5	50	120	5.6	29.0	61.6
LCC $\leq 5$ , No basal	150	6.7	20.6	48	160	5.9	23.1	56.2
Recommended N	120	5.4	16.1	39	120	5.0	23.3	52.5
		Cultivar: Hybrid PHB 71			Cultivar: PBW 226 (Late sown)			
No N-control	0	3.8	-	-	0	1.8	-	-
LCC $\leq 3$ , No basal N	90	6.6	30.9	59	90	4.1	25.5	54.4
LCC $\leq 4$ , No basal N	135	7.6	28.1	57	120	4.5	22.7	52.5
LCC $\leq 5$ , No basal N	165	8.1	25.9	54	160	4.8	18.8	45.6
Recommended N	150	6.9	20.7	44	120	4.1	19.1	44.2

Source: Shukla *et al.* (2004)



**Table 2.** Fertilizer N use and yield gain under Nutrient Expert (NE)-guided N application *vis-à-vis* farmers' fertilizer practice (FFP)

Cropping system	FFP	N use (kg/ha)			% increase in yield over FFP
		NE	FFP-NE		
Rice- wheat system (5)*	Rice	168	119	49	13-27
	Wheat	153	113	40	9-35
Rice- rice system (3)	Rice ( <i>kharif</i> )	141	119	22	5-32
	Rice ( <i>rabi</i> )	154	115	39	9-23
Maize-wheat system (3)	Maize	69	113	-44	24-46
	Wheat	101	115	-14	16-38

\*Number of experimental sites. Source: VK Singh, RP Mishra and K Majumdar (Personal Communication).

wide and 13-20 cm long), containing 4 to 6 panels that range in colour from yellowish green to dark green. Use of LCC, however, requires determination of critical LCC score for a group of varieties exhibiting similar plant type and duration. Once the critical LCC scores are determined, the same would be valid for similar groups of varieties grown elsewhere. Critical LCC scores for rice were judged as:  $LCC \leq 3$  for Basmati,  $LCC \leq 4$  for inbred, and  $LCC \leq 5$  for Hybrid rice (Shukla *et al.* 2004). In these studies, LCC  $\geq 4$  was advocated as critical score for early, timely sown and late sown wheat (Table 1). Fertilizer N scheduling based on LCC proved superior to conventional practice i.e. application of 120 kg N ha<sup>-1</sup> in three-splits, and in some cases a saving of fertilizer N (up to 30 kg N ha<sup>-1</sup>) was recorded with the use of LCC.

Besides LCC and SPAD, optical sensors were evaluated for rationalizing N application rate and time. Spectral indices such as normalized-difference vegetation index (NDVI) may help predicting photosynthetic efficiency and productivity potential of a crop. Hand-held GreenSeeker has been used to evaluate N status of rice and wheat to develop real-time N prescriptions (Bijay-Singh *et al.* 2011; 2015). Their studies revealed that high N use efficiency in rice and wheat can be achieved by replacing blanket fertilizer recommendation by an optical sensor-based N management strategy.

### Decision support tools for PNM

In India, more than 84% of the farm holdings belong to marginal and small farmers, which exhibit substantial spatial variability owing to variable crop management practices (cropping systems, cultivars, input use, irrigation *etc.*) adopted by the farmers. Site-specific nutrient prescription for these smallholders is remotely possible unless a decision support system (DSS) is developed to address spatial variability in indigenous nutrient supply and link the same with crop demand to arrive at rational prescriptions. Development of decision support tools namely 'Nutrient Manager' by IRRI and 'Nutrient Expert (NE)' by IPNI in collaboration with CIMMYT and National Agricultural Research System have significant role to play in promotion of PNM especially under smallholders' farming situations. The NE for rice, maize and wheat has been widely validated, which showed substantial

yield improvement over FFP by rationalizing fertilizer input (Table 2). In response to few simple questions related to crop management, NE prescribes nutrient application rate, time of application and also apportioning of N into organic and inorganic depending on their availability.

### CONCLUSION

In the present scenario of ever-expanding multi-nutrient deficiencies in soils, low nutrient use efficiencies and soaring fertilizer costs, PNM assumes special significance in Indian agriculture. In recent years, different PNM practices and tools have been developed and validated. Yet, efforts need to be intensified for validation and need-based refinement in hyperspectral tools, and GreenSeeker and NE-based fertilizer prescriptions. Besides management practices, research and policy support for development of sustained release/smart fertilizers, strengthening soil testing services, and enhancing farmers' awareness and participation would help development and largescale adoption of PNM under different crops and soils.

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## Precision nutrient management in conservation agriculture systems

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In densely populated (1.5 billion) areas of South Asia; the natural resources are 3-5 times more stressed due to population and economic pressures compared to the rest of the world. Inappropriate management of production resources, especially land, water, energy and agro-chemicals, has vastly impacted the quality of the natural resources and also contributing to global warming. The region is especially vulnerable to climate change and predicted to suffer crop yield decreases of at least 20% by 2050 with massive risks of crop failure. It is therefore, vitally important to develop strategies for sustainably increasing food production in the region. Conservation agriculture (CA), comprising minimum soil disturbance, retention of rational amount of crop residues and crop diversification with efficient crop rotations, is widely promoted for resource conservation, reducing soil degradation, adapting cropping systems to climatic extremes and improving agricultural sustainability. The global empirical evidence shows that farmer-led transformation of agricultural production systems based on CA principles is already occurring globally (157 mha) and gathering momentum as a new paradigm for the 21st century (Kassam *et al.*, 2015). However, each principle of CA involves a set of practices adapted to local circumstances which affects the soil processes as well as nutrient dynamics (Lal, 2015).

Nutrients have paid dividends in yield revolutions in agriculture and will continue to contribute significantly to future food security. However, the increased use of fertilizer nutrients does not keep pace with productivity gains. For example, during last five decades nutrient use in India has increased by 1573% whereas the average yield increase of total food grains was only 125%. Therefore, partial factor productivity of nutrients has been declining as faster rate, posing a threat to future food security and environmental sustainability. Moreover, still there exist large 'management yield gaps' in South Asia ranging from 0.8-2.9, 1.4 and 3.1 t ha<sup>-1</sup> in rice, wheat and maize, respectively (Lobell *et al.*, 2009), a significant portion of which is attributed to inefficient nutrient management (Hengsdijk, and Langeveld, 2009).

Classical fertilizer nutrient recommendations, which have been developed and validated mainly under conventional tillage based systems, are not necessarily appropriate for CA based management (Jat *et al.*, 2011; Sapkota *et al.*, 2014) due to paradigm shift in production variables (Table 1). Therefore, the precise prescriptions (rate, time, method and source) of nutrients must be formulated taking into account the specific nutrient dynamics of CA systems (Lal, 2015). In this paper, we describe and discuss various aspects of precision nutrient management under CA based cereal system in South Asia and their implications for the future of food security in the region.

### Conservation agriculture and soil processes

We must better target nutrients for contrasting management scenarios (for example CA) so that farmers in emerging economies can balance risk and fertilizer application while expanding the use of nutrients beyond nitrogen, phosphorus, and potassium to a balanced approach that improves yields, use efficiency, and preserve our soils for the future. Research suggests that retention of crop residues as mulch under CA may immobilize some of the applied N during initial years but supplies additional N through remineralization in subsequent years. On the other hand, residue retention in CA systems also slows runoff or leaching of N and P (Kushwaha *et al.*, 2000), prevents surface sealing, increase water infiltration and increases stability of micro-aggregates, which allows more sequestration of carbon and N within macro-aggregates compared to CT system (Singh *et al.*, 2016). Surface residue retention also reduces the soil temperature, thereby reducing the rate of organic matter decomposition and increasing concentration of organic matter on surface soil layer (Dordas, 2015). Crop diversification through rotations, cover crops and intercrops contributes to recycling of nutrients. This needs to be factored into the nutrient management system in CA. In general, mineralization-immobilization, sorption-desorption, dissolution precipitation and oxidation-reduction determine the dynamics of nutrient in the soil systems. CA influences the above-mentioned chemical and biochemical processes con-

siderably. The changes in physical and biological properties of the soil associated with CA practices are expected to modify the direction and kinetics of the chemical and biochemical processes, leading to altered nutrient dynamics in the soil (Sapkota *et al.*, 2016). Not only rate but fertilizer application method also responds differently for CA and CT based management. Broadcast application of fertilizer N results in more volatilization loss under CA than under conventional systems. Sub-surface drilling of fertilizer during planting as well as in the standing crops (using solid as well as liquid formulations) has been found to be effective in improving nutrient use efficiency and increasing crop yields in CA systems.

### Nutrient management in conservation agriculture

Various tools, techniques and decision support systems have been developed and used for soil based and plant based precision nutrient management. However, there is still a large knowledge gap in understanding of nutrient dynamics and precision management of nutrients in CA systems, particularly in South Asia where fertilizer recommendations are largely based on the response trials conducted over wide geographical area. Experiences show that current fertilizer application practices under CA need revision with a thrust on nutrient management research to improve nutrient-use efficiency, soil health and crop productivity. In a fully established CA system the aim of fertilizer nutrient management is to maintain soil nutrient levels, replacing the losses from soil-plant system and from the nutrients exported by the crops. Because CA systems have diverse crop mix including legumes, and nutrients are stored in the soil organic matter, nutrients and their cycles must be managed more at the system or crop mix level. Thus, fertilization would not anymore be strictly crop specific. Zero tillage (ZT) conserves and increases the availability of P, K and other nutrients near the soil surface where crop roots often proliferate.

Our recent studies on use of new tools (GreenSeeker, Nutrient Expert), techniques (drilling of fertilizers, fertigation, sub-surface drip) for precision nutrient management in CA based cropping systems in South Asia have generated new evidence on the subject and showed promising response in

terms of yield, nutrient use efficiency, economic profitability and environmental foot prints. Use of Nutrient Expert (NE) decision support system (Pampolino, 2012) for nutrient management captures the spatial and temporal variability to provide precise prescriptions for CA based cropping systems and led to higher yields, profits, NUE and lower environmental footprints (Sapkota *et al.*, 2014). Under CA practices, drilling of same amount of nutrient increased grain yield of wheat by 0.43 t/ha and net returns by US\$ 60/ha compared to broadcast application. Green Seeker sensor calibration curve based calculator (Bijay-Singh *et al.*, 2011, 2015) for wheat and rice have demonstrated potential opportunities for precision N prescription in CA based systems (Jat *et al.*, 2016). Not only the rate and method but time of application of nutrients are critical for higher yield and NUE in CA based systems (Jat *et al.*, 2014). Our recent studies (Jat *et al.*, 2016) on a a medium-textured (loam) soil showed that drilling 50 or 75% of recommended N fertilizer at sowing significantly increased grain yield (by <10%) in comparison with drilling 20% at sowing with the remainder applied in two equal splits before the first and second irrigations in wheat sown into rice residue (Yadvinder Singh *et al.*, 2015). Our latest research on layering sub-surface drip irrigation and fertigation on CA based maize-wheat rotation, 0.34 t/ha/yr higher yield was recorded with 60 kg/ha/yr less N and 25 ha-cm/yr less irrigation water compared to conventional practices for tillage, water and nutrient management. Similarly, in our another set of study on a rice-wheat system, layering of sub-surface drip irrigation and injecting fertilizer N (fertigation) in CA based management lead to significant increase yield, partial factor productivity of nitrogen (PFP-N) as well as irrigation water productivity compared to conventional tillage, flood irrigation & farmers' fertilizer practice.

### CONCLUSION

Conservation Agriculture based management systems substantially influence soil processes and nutrient dynamics in soil. Limited research have been carried-out yet on layering precision nutrient management tools, techniques and strategies on CA based management. Our studies suggest a paradigm shift in nutrient management practices and strategies for

**Table 1.** Paradigm shift in production variables under conservation agriculture

S. No.	Production variables	Conventional tillage based system	Conservation agriculture based system
1.	Tillage	Repeated intensive tillage	No-till/dramatically reduced tillage
2.	Organic recycling	Animal based, incorporating/ burning residues	Crop based, surface retention of residues
3.	Cropping systems	Intensive monotonous	Intensive diversified
4.	Management	Crop/commodity based	Cropping system based
5.	Land levelling	Traditional	Laser assisted
6.	Water management	Flood, temporary ponding	Controlled flood, furrow, better drainage
7.	Fertilizer application method	Primarily broadcasting	Primarily drilling
8.	Weed management	Mix of cultural and chemical	Chemical

Source: Synthesized by the authors from various sources and own field experiences

attaining higher yield, NUE, economic profitability with lower environmental footprints. Not only the rate of fertilizers but also time, method and source of fertilizers plays critical role for higher efficiency. Among various tools, techniques and strategies, use of Nutrient Expert, GreenSeeker, sub-surface drip based fertigation and banding/drilling of fertilizers in CA based management practices are some of the field validated options which can be taken to next level for their scaling.

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# **Symposium 8**

## **Conservation Agriculture and Smart Mechanization**







## Conservation Agriculture: Lessons and opportunities in Africa and Latin America

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Conservation agriculture (CA) today occupies over 10% of the world's arable land, but there is relatively little adoption of this sustainable agricultural system on smallholder farms. The principles of CA (minimal soil disturbance, soil cover and crop rotations/associations) have been adapted to most biophysical conditions, and CA offers benefits to both large and smallholder farmers. However, CA involves change in multiple components of the farming system and as such is more difficult for smallholders given their socio-economic constraints. Technology adoption and agricultural development do not result solely from the biophysical feasibility and benefits of the technologies themselves but importantly from the institutional arrangements (markets, credit, policies etc.) that enable the adoption by farmers with different socio-economic circumstances. Policy makers at all levels need to support the development of innovation systems that can remove the institutional impediments to technological change and promote the adoption of sustainable agricultural systems by all farmers.

### The spread of CA in South America and Africa

Conservation agriculture, defined as a system encompassing minimal soil disturbance, permanent organic soil cover and crop rotation and/or associations (FAO, 2016a), provides multiple benefits (Hobbs, 2007; Derpsch *et al.*, 2010) including improved crop water relations, reduced soil erosion, reduced greenhouse gas (GHG) emissions, and improved crop economic productivity. CA is arguably the most sustainable method of production of field crops that we have available. There are today nearly 160 million ha of CA in the world (FAO, 2016b), which corresponds to about 11.5% of the globe's total "arable" crop area. Of this 42% is in South America, 34% in North America and 11% in Australia. These three continents account, therefore, for 88% of the CA in the world – compared to only 0.7% of the total CA area in Africa. Most of the CA area in South America is on relatively large-scale mechanized farms, and, similarly to Africa, there has

been relatively little adoption of CA on small farms (Wall, 2007). The development of CA in the mechanized (medium and large-scale) farm sector has been driven by farmers and farmer organizations, supported by the private and public sectors to different degrees in different situations. Where farmer-participatory research processes to help resolve technological problems has accompanied the farmer-driven development process, adoption has been faster than in areas where this did not happen (Ekboir, 2002). However, farmer-driven CA adoption has not occurred to the same extent among smallholder farmers, and overcoming, or supplanting, this will be a key factor in achieving sustainable production of field crops in the smallholder farm sector. However, even though the area of CA on smallholder farms in the two continents is not great, the numbers of smallholders who have adopted CA has been appreciable: in Brazil there have been an estimated 200,000 small farmers practicing continuous CA (Wall, 2007) and in 2010 nearly 24,000 smallholder farmers in Paraguay were practicing CA on at least part of their land (Froemherz-Rivas, 2010). In Eastern and Southern Africa, Wall *et al.* (2013) estimated that there were more than 500,000 smallholder farmers practicing some CA in the region.

### Smallholder farmers and CA

The soil and land degradation resulting from tillage-based agriculture is, or has been, glaringly evident in much of South America and Africa. CA aims to remove from conventional agricultural practices those components that are causing this degradation – soil tillage, monoculture and unprotected soils. Farming systems based on the principles of CA, adapted to different socio-economic and biophysical conditions, have been shown to increase the productivity and sustainability of agriculture in most situations. However CA involves a complex system change in many components of the current farming system including doing away with the plough – for many the symbol of agriculture. The ability to change is defined by

the social and economic circumstances of the individual farmer and the community in which (s) he lives. The circumstances of smallholder farmers are generally very different to those of larger-scale mechanized farmers, and therefore their ability to change is also markedly different. Generally smallholder farmers have little access to financial capital, are risk averse and prioritize the production of the family food needs, selling excess production when available. They use small manual, animal- or machine-powered equipment (or contract the use of bigger equipment), depend to a large degree on their own family labor for farm operations, and often engage in some off-farm employment if available. They generally manage mixed crop/livestock farming systems, where the animals may often be just as or more important than the crops in determining family food and livelihood security, and crop residues are an important component of animal feed (Wall, 2007). Smallholders usually have weaker access to extension services, input and output markets, and linkages to information and knowledge systems outside the community than larger farmers - who also generally have more formal education (Wall, 2007). Nearly all of these factors make the adoption of CA by smallholders more difficult than for their larger farm counterparts. Generally cost savings and, especially, labor savings have been cited as the most important benefits of CA by smallholder farmers (Ekboir *et al.*, 2001; Baudron *et al.*, 2015). Smallholder farmers have little capacity to absorb losses, and so the immediate cost and labor savings are extremely important, even if crop yields do not increase in the short term.

Equipment that allows seed (or seedlings) to be placed into undisturbed (or mostly undisturbed) soil is a prerequisite to successful CA. Seeding equipment for CA conditions is today available for multiple scales of farming operations and ranges from manual equipment (dibble stick, jab planter etc.) through animal traction seeders to seeders for two-wheel tractors and four-wheel tractors. Adequate sprayers, especially for uniform herbicide application are another requirement for most successful CA systems. Again markets for tractor-powered equipment utilized by larger-scale farmers are better developed than the manufacturing chain and markets for smallholder equipment. Because of this, and the marginal economic benefits to a smallholder of purchasing equipment for use solely on his/her farm, development agencies are tending to concentrate more on developing machinery service providers rather than developing, promoting and marketing equipment adapted to the size of single small-holder farms.

Weed control is often cited as the main reason that farmers till the soil, and weed control becomes one of the major limiting factors when soil tillage is stopped. The feasibility of CA grew in the early 1970's with the herbicides Paraquat, Diquat, and 2,4D but early advances in many countries faltered because of the proliferation of perennial weeds not controlled by these herbicides. Glyphosate, marketed by Monsanto as RoundUp®, could control perennial weeds, but was initially

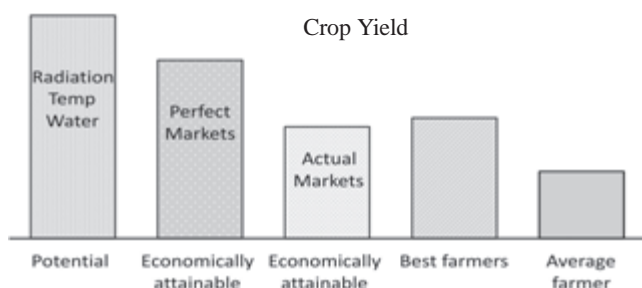
very expensive. Since then both the price of glyphosate and recommended application rates have fallen markedly – a factor that has probably impacted on the spread of CA adoption. However, the distribution, availability and packaging of glyphosate and other herbicides, as well as a lack of knowledge of their properties and management, still limit the feasibility of herbicide use for many smallholder farmers. Where smallholders have access to adequate herbicides, for instance in Malawi, their use often becomes the principal advantage of recommended CA packages because of the huge labor savings (and yield advantages) that their use represents (Thierfelder *et al.*, 2015). However, where farmers do not have access to adequate herbicides the extra labor required for weeding in CA can be an important deterrent to adoption (Rockström *et al.*, 2002). Given the complexities of adequate information and knowledge for the efficient and safe use of herbicides, again we recommend the preparation of trained and knowledgeable service providers for smallholder communities.

### **Innovation systems – the importance of institutional arrangements**

Many authors have stressed the need for adequate markets and policies to enable adoption of CA and other agricultural technologies, and Derpsch *et al.*, 2015, have shown that when project-based incentives to adoption are terminated, dis-adoption of CA has occurred among smallholders in Paraguay. Other authors have suggested that socio-economic factors necessarily limit the applicability of CA to relatively small pockets of potential adopters (Giller *et al.*, 2009; Corbeels *et al.*, 2013). However, it is well known that technology alone does not drive agricultural development – a supporting environment of enabling institutional factors is necessary to permit the use and the derivation of benefits from a new technology before widespread adoption and agricultural transformation can take place. The Green Revolution in Asia relied not only on technologies (improved varieties, fertilizer, irrigation water) but also on markets and distribution channels for inputs and farm outputs, seed production and subsidies – there was political will to overcome poor farm productivity (Gaud, 1968). Policy makers have used subsidies on inputs or produce support prices to stimulate technology use and productivity increases. However, there are generally problems in ensuring that the principal benefits of subsidies reach the target beneficiaries, and they are difficult to maintain financially in the medium to long term (Holden *et al.*, 2013). We believe that investment in services (input and output markets, credit, insurance, information, research and extension) together with non-prejudicial policies is far more important than in direct input or output subsidies.

Successful technological change involves changes in institutional arrangements<sup>1</sup> - the simpler the technological change, the simpler are the necessary changes in institutional arrangements. For instance, in many places new varieties of crops (a simple, single component change) are rapidly adopted even

by smallholder farmers – farmers have observed in the past the benefit of new varieties, the system for seed production is in place, and adequate markets and market channels for the seed exist. However, the more complex the technology, the more complex are the institutional arrangements necessary to enable the widespread use and adoption of the technology. This is not just the case for CA, but for all agricultural technologies, and the lack of adequate institutional arrangements often defines the poor development of agriculture in the smallholder sector in South America and Africa – and no doubt elsewhere as well. Fischer *et al.* (2012) showed an interesting depiction of potential yields (Fig. 1) – those imposed by the environment and those imposed by markets (and institutional arrangements) – these latter have a large effect on the economically attainable yield on the farm.



**Fig. 1.** Depiction of yield gaps between present farmer yields and potential Yield. Based on Fischer *et al.* (2009).

For complex agricultural change there is a need for the development of innovation systems which look beyond the ‘technology oriented’ stakeholders (farmers, agricultural researchers, and extension agents) and incorporate stakeholders from all important components of the farm production value chains into action groups to analyze and overcome limitations to agricultural productivity (Thierfelder and Wall, 2011). Larger-scale farmers have often achieved this because they have had sufficient market and political weight to be able to convene and convince the necessary players of the benefits to all sectors of achieving increases in production and production efficiency. However, small-scale farmers who have less time and opportunity for sectorial organization outside the community, have generally lacked the draw to get market agents, service providers and policy makers involved in the process. To overcome this some research and development organizations have become involved in proposing and catalyzing innovation systems in regions dominated by smallholder farmers. More effort is needed in this endeavor with the focus on the important task of demonstrating to local, national and regional policy makers that technology alone does not drive agricultural development, and that adequate institutional arrangements are a necessity for social and economic development of the smallholder agricultural sector. Without the enabling institutional environment, technology develop-

ment will remain simply at the level of ‘proof of concept’ without achieving agricultural change. Overcoming institutional impediments to smallholder farm productivity will indeed be difficult, but the urgent need to reduce poverty in the agricultural sector, to enhance the environment and to improve the food security of the population in general argue for a major initiative to develop innovation platforms around smallholder production systems to ensure more productive, equitable and sustainable agriculture.

## CONCLUSION

There are numerous lessons to be learned from experiences with CA in South America and Africa. Rampant soil erosion and degradation can be stopped and reverted with widespread adoption of CA as evidenced in Brazil and Argentina. The application of CA is feasible under most biophysical conditions and the principles of CA can be adapted to the circumstances of most farmers. However, the adoption of CA by smallholder farmers has been far slower than the adoption by larger-scale, mechanized farmers. The limitations to adoption have not been technical but rather due to inadequate institutional arrangements including input and output markets, credit, and agricultural policies and norms at the local and national levels. These factors affect any technological change, and developing adequate arrangements is more complex for technologies, such as CA, that involve changes in many components of the production system. However, the fact that inadequate institutional arrangements currently limit the adoption of sustainable production systems by farmers, especially smallholder farmers, emphasizes the need for the development of action groups representing all sectors of the agricultural value chains empowered to develop adequate markets, credit, policies and services, including information and knowledge services, for all farmers.

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## Adoption of conservation agriculture-based technologies in the non-Indo-Gangetic Plains of India

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Adoption of green revolution technologies during 1960s led to increased productivity and elimination of acute foodgrain shortages in India. These technologies primarily involved growing of high-yielding dwarf varieties of rice and wheat, increased use of chemical fertilizers and other agrochemicals, and spread of irrigation facilities. This was also accompanied by the other so called modern methods of cultivation, which included maximum tilling of land, virtually clean cultivation with complete removal of crop residues and other biomass from the field, fixed crop rotations mostly involving cereals, and elimination of fertility-restoring pulses and oilseed crops in the high productive north-western plain zone of the country.

Over the last 4-5 decades, India has achieved not only self-sufficiency in agricultural production but also the capability to export food commodities. This is often cited as a great accomplishment of the 20<sup>th</sup> century. However, the transformation of 'traditional animal-based subsistence farming' to 'intensive chemical- and tractor-based modern agriculture' has led to multiplicity of issues associated with sustainability of these production practices. Conventional crop production technologies are characterized by: (i) intensive tillage to prepare fine seed- and root-bed for sowing to ensure proper germination and initial vigour, faster absorption of moisture, control of weeds and other pests, mixing of fertilizers and organic manures; (ii) monocropping systems; (iii) clean cultivation involving removal or burning of all residues after harvesting leading to continuous mining of nutrients and moisture from the soil profile; and bare soil with no soil cover; (iv) indiscriminate use of pesticides, and excessive and imbalanced use of chemical fertilizers leading to decline in input-use efficiency and factor productivity, and increase in pollution of environment, ground water, streams, rivers and oceans; and (v) energy-intensive farming systems.

Continuous adoption of the green revolution technologies has resulted in emerging concerns about natural resource degradation. It is realized that soils are getting impoverished due to imbalanced use of fertilizers, discontinuation of traditional

practices like mulching, intercropping and inclusion of legumes in cropping systems. Further, the use of organic manures, compost and growing of green manure crops has also decreased considerably due to various reasons. Similarly, water resources are under great stress due to their indiscriminate exploitation and also getting polluted due to various human interferences. Burning of fossil fuels, crop residues, excessive tillage including puddling for rice cultivation are leading to emission of greenhouse gases, which are responsible for climate change and global warming. Further, there is now a growing realization that the productivity levels are stagnating and the incomes of the farmers are reducing due to the rising cost of the inputs and farm operations. It is feared that modern cultivation practices are not sustainable in the long-run, and there is a need to change the way we do crop production in arable lands.

Climate change is emerging as a serious threat to agricultural productivity globally as well as in India. Various evidences documented so far indicate global and regional impacts of projected climate change on agriculture, water resources, natural ecosystems and food security. It is known that Indian agriculture is more vulnerable in view of the tropical environment and a large population depending on agriculture. The various parts of the country have experienced large variations in weather patterns and occurrences of extreme events in the last 10 years. Droughts in 2002, cold wave in 2002-03, heat wave in 2003, high temperature in 2004, drought /cyclones in 2014 besides deficient monsoons in the last many years have seriously impacted agricultural production in many regions including Madhya Pradesh. It is feared that temperatures may increase from 1.7 to 4.8°C, whereas precipitation may increase by 4-14% by the end of century compared to 1961-1980 baseline. The rainfall will become more erratic with intense rainfall events and reduced number of rainy days; thus increasing the risk of drought and flood damage to crops. Studies indicate probability of 10-40% loss in crop production with increase in temperature by 2080-2100.

### Conservation agriculture – A new paradigm in resource management

The concept of conservation agriculture (CA) has been developed to reverse the process of land degradation, and ensure sustainable crop production and to combat the adverse effect of climate change. This involves: (i) minimizing soil disturbance – no tillage and minimum traffic for agricultural operations, (ii) maximizing soil cover – leave and manage crop residues on soil surface; and (iii) stimulating biological activity through suitable crop rotations including use of cover crops, and green manures. Further, this requires a systems approach, i.e. efficient seeding machinery, nutrient, water, weed and pest management. This technology has been adopted globally on more than 157 M ha in more than 50 countries, largely in rainfed areas. The major countries are; USA, Australia, Canada, Argentina, Brazil, Paraguay, Uruguay and New Zealand.

In India, this realization started in early 1990s when some experiments were initiated on zero-till wheat in north-western India, primarily through the efforts of IRRI, CIMMYT and world bank funded NATP. There was a good success obtained in many states, and the area under zero-till wheat reached up to 3 M ha by the beginning of current century. However, the acreage have stagnated now and some farmers have even switched back to minimum or conventional systems because of some practical constraints and lack of technical know-how. There is a need to reorient our strategies to tackle these problems based on the knowledge gained in recent years and developments in the farm machinery sector.

Harvesting of major crops like rice and wheat started with combines and the residue management has become a major issue in many states including central India. Burning of residues *in situ* is rampant despite restrictions imposed and incentives offered by the governments. This is the most unhealthy practice as it leads to loss of precious plant nutrients and environmental problems. In recent years, there have been some major developments, which have led to a change in our approach for promotion of conservation agriculture. New generation farm machinery has become available which can place the seed and fertilizer at an appropriate depth in the desired amounts. Further, these machines can work in standing as well as loose crop residues; thus, providing a very effective mulch cover for moisture and nutrient conservation, temperature moderation and weed control. Availability of new herbicide molecules has further necessitated a change in our thinking about weed management. Further, other triggering factors for shift towards conservation agriculture are labour scarcity, deteriorating soil health, declining factor productivity, rising cost and low income. Thus, conservation agriculture systems help in overcoming the problems being experienced in conventional farming systems.

Conservation agriculture (CA) is a holistic approach towards increased productivity and improved soil health. It does

have several advantages over conventional tillage (CT) based agriculture in terms of soil health parameters. However, weeds are the major biotic constraint in CA, posing as a great challenge towards its adoption. Presence of weed seeds on upper soil surface, due to no tillage operation, leads to higher weed infestation in CA, and so far herbicides are the only answer to deal with this problem. The modern seeding equipments, e.g. 'Happy Seeder' technology, that helps in managing weeds through retention of crop residues as mulches, besides providing efficient seeding and fertilizer placement, holds the promise of becoming an integral part of CA system. Outcomes of the experiments conducted in farmers' fields' show that the benefits of CA can well be taken in black cotton soils with rice-wheat-moongbean system as weed menace under this system can be managed by integrating suitable herbicides in the weed management programme.

### Adoption of conservation agriculture-based technologies

#### *Madhya Pradesh*

Rice-wheat is the major cropping system in the Indo-Gangetic plains and also followed in central and eastern parts of Madhya Pradesh. In this system, wheat is normally sown in fine seedbed prepared with 4-5 tillage operations which take 10-15 days time and Rs.2500-3000/ha financial liability for land preparation. The tillage operations increase the cost of production but they have hardly any benefit for increasing the grain yield of wheat. Further, there is a great concern about reduction in soil fertility, scarcity of farm labour, declining water table and high cost of production under conventional agriculture. In order to mitigate these problems, it is essential to adopt technically-feasible, economically-viable and ecologically-permissible technology to ameliorate late sowing, minimize weed infestation, lower cost of production, improve fertilizer/ water-use efficiency and improve soil fertility.

Crop production in the Central Plateau region of India is dominated by rice, soybean, maize and sugarcane in *kharif*, followed by wheat, chickpea, lentil, peas and mustard in *rabi* season. Soils are deep black cotton in most of the areas belonging to Vertisols. Farmers follow conventional practices like intensive ploughing of the land, clean cultivation (removal or burning of all crop residues and stubbles), fixed crop rotations, and little use of organic manures and moderate use of chemical fertilizers, and other pesticides including herbicides. Combine harvesting of major crops is followed predominantly and the crop residues are invariably burnt in most of the areas. There is only small area under greengram / blackgram and maize crops during summer due to social problems like open cattle grazing. Due to the rising costs of cultivation, the profitability margins are generally low (Rs. 10,000 to 20,000 per ha per annum). Keeping this in view, it was felt to promote the adoption of resource conservation technologies for reducing the cost of cultivation and improving soil health, besides other environmental benefits.

Initiatives have been taken to promote adoption of conservation agriculture-based technologies in the alluvial soils of Indo-Gangetic plains primarily in rice-wheat cropping system. These programmes were mainly implemented through the CIMMYT sponsored Rice-Wheat Consortium during the 1990s, which led to adoption of zero-till cultivation of wheat on nearly 3 million ha. No major efforts were made in the black soil region of central India until the establishment of Borlaug Institute for South Asia at Jabalpur in 2011. Subsequently, Directorate of Weed Research, Jabalpur also took initiatives to demonstrate the conservation agriculture technology among farming community for sowing of wheat and greengram for the first time under on farm research (OFR) programme during 2012. Initially, a survey was done and it was found that the farmers' were not aware about conservation agriculture system which involves no ploughing and retaining the standing crop residues in the field. They expressed serious doubt about growing a good crop without ploughing and removing or burning of the crop stubbles. With great difficulty four farmers' of Panagar block of Jabalpur in 2012-13 agreed to provide their lands for demonstrating the potential of CA technology only when they were assured that they will be compensated economically if the technology fails to perform. Accordingly, wheat was sown using a 'Happy Seeder', without tilling and removing the existing rice stubbles. Out of four, one farmer ploughed his land the next day out of his sheer disbelief and fear to conservation technology on the basis of the advice from his friends/other farmers'. After introduction of zero-till technology on farmers' fields, several questions were raised by the non-adopters and even by field functionaries about the success and merit of the technology. Wheat crop had good emergence and stand establishment. Weed population in three conservation agriculture OFR trials was less compared to other field trials in which the land was prepared by conventional cultivator and harrow. The herbicides used in these OFR trials, viz. glyphosate and clodinafop + metsulfuron were chosen on the basis of the weed flora prevailing in the concerned fields. The herbicide were effectively controlled the weed flora effectively and increased yield of wheat as compared to the fields cultivated by conventional practice with no weed control measures. However, the crop of the remaining three farmers' performed much better and produced 4.0-4.5 t/ha grain yield under CA than the conventional practice (2.4-3.0 t/ha). The results also showed higher grain yield and income, and lower production cost, resulting in sharp increase in benefit: cost ratio under CA system.

After getting very encouraging results from different stakeholders, on-farm research trials were undertaken in a participatory mode at 10 farmers field in 2013-14 in the same locality i.e. Panagar block of Jabalpur, and sowing of wheat was done on 1 acre (0.40 ha) in each farmer's field and sowing of greengram at 5 farmers fields. Sowing was done without any tillage operation (ploughing) and without removing / burning the standing crop stubbles of the previous crop. Ac-

ordingly from 2014 onwards, OFR trial on CA-based technology was expanded under *Mera Gaon Mera Gaurav* programme in different adjoining districts (Mandla, Seoni, Narsinghpur and Katni), which are about 80-100 km away from Jabalpur district headquarters. In each locality/ district, 5 villages and 7-8 farmers from each locality were identified and selected based on the interest shown by them and suitability of the land. Resource conservation technologies such as direct-seeding of rice, brown manuring with *Sesbania*, zero-till sowing of crops, residue retention on soil surface, growing of summer legumes like greengram or *Sesbania* in the crop rotation, and integrated weed management technologies were demonstrated in diversified cropping systems. About 100 on-farm research trials have been laid out in 20 villages during the current season.

Farmer's participatory approach adopted under OFR-cum-demonstration proved to be an accurate guide to its subsequent adoption by farmers not only in Jabalpur but also in other district of Madhya Pradesh. The technology has now evolved into something with far broader appeal including cost reduction, convenience, profitability and security. The successful demonstration of this technology was realized by following the principles of 'learning by doing' and 'seeing is believing' in a participatory mode. After the successful introduction of this technology, area under zero tillage has been rapidly increasing and farmers stopped burning the residues of previous crop. The farmers of these localities are highly enthusiastic about wheat and greengram sowing under conservation agriculture. The technology adoption by farmers is very encouraging and the performance of this technology has become a household discussion amongst the farmers of this locality. This CA-based technology have made significant impact on farmers of Jabalpur region. The farmers are positive in their attitude about this technology. Saving time, cost, fuel during land preparation, labour and the overall profitability gains have shown positive change in the attitude of farmers towards this technology. It is a matter of pleasure that many farmers' are now expressing their willingness to adopt the technology and enquiring about the availability and price of the 'happy seeder.'

Conservation agriculture-based technology like zero-till sowing of crops in the presence of residue of the previous crop with improved weed management practices is the most promising technology. This technology has spread in more than 1000 ha and the Happy Seeder machines are now in great demand in the area. Farmers are highly convinced with this technology as it saved time, provide good weed control, maintain soil moisture status, and improve soil fertility and environment friendly.

Based on the systematic research efforts at the research farm of Directorate of Weed Research and at the farmers' fields of 5 districts of Madhya Pradesh over the last 5 years, the following conclusions can be made:

- Equal crop yields were recorded under zero-till (with or

without residue) and conventional till conditions in the first two cropping cycles.

- Beneficial effects of residue retention under zero-till condition were apparent in the 3<sup>rd</sup> cropping cycle.
- Control of most weed species was successfully achieved following integrated approach.
- There was no major shift of weed species towards perennial weeds.
- Sowing of most crops was possible with Happy Seeder under crop residue up to 6 t/ha.
- Systems approach involving suitable adjustment of sowing date, seed rate, basal fertilization, early first irrigation, uniform residue spreading, pest management etc. was required.
- Physico-chemical and biological properties of soil showed improvement in the 3<sup>rd</sup> cycle.
- CA appears to be the most promising technology for Vertisols / black cotton soils and can revolutionize wheat cultivation in central India.

#### *Andhra Pradesh*

Rice is predominantly grown in eastern and coastal areas of India, following which lands remain mostly fallow. Relay / sequence cropping with short duration pulses / oilseeds is practiced in limited areas but yields are low due to poor crop stand and weed growth. Blackgram was popular in coastal Andhra Pradesh but affected by yellow vein mosaic (YMV) and parasitic weed *Cuscuta*. There is immense potential for productive utilization of these lands through CA technology.

Zero-till maize (in assured irrigated areas) and sorghum (less irrigated areas) are gaining popularity among farmers in rice fallows. Sowing is done manually in wet soil in holes after harvest of preceding rice crop during mid-December, and fertilizers are applied after about one month, and 2-3 irrigations may be applied thereafter. Weeds are controlled by tank-mix application of atrazine + paraquat (0.75 kg + 0.50 kg/ha) just after sowing but before crop emergence. It has been reported that a grain yield of maize (8-10 t/ha) and sorghum (6-8 t/ha) are obtained under zero-till cultivation compared with <0.5 t/ha from blackgram. This is often cited as one of the success story of adoption of zero-tillage in coastal Andhra Pradesh and has immense potential for extension in other states including Orissa, West Bengal, Bihar and Assam.

#### *Maharashtra*

In the Konkan region of Maharashtra including areas around Mumbai, zero-till broad-bed technology has been developed and promoted for rice cultivation. Known as Shaguna Rice Technology (SRT), technology developed by Mr. Shekhar Bhadsavle, it is primarily meant for rice but can also be extended to other crops like groundnut, lablab bean, greengram and vegetable crops grown in succession. This technology involves preparing broad-beds (about 1 m wide)

either manually with spade or with tractor-drawn bed maker, markings on the beds with a specially-designed implement, placing the seeds and fertilizer manually, and using herbicides for weed control but without any crop residues as mulch cover. The technology has found wide acceptance among the farmers who are highly impressed as it saved time, cost, improved soil fertility, crop yields and profitability compared with conventional transplanting of rice following puddling. Several farmers have adopted it and more are following as they are learning and becoming aware of it.

Considering the erratic rainfall pattern of the region, it is advisable to advance the sowing of rice to last week of May or early June so that seeds germinate with the early monsoon showers by mid-June and attain enough growth before heavy rains start from June-end. Farmers having irrigation facility can go for irrigation immediately after sowing. Fertilizer should be basally placed to provide a initial boost to the growth of plants. It is essential to use herbicides before sowing, after sowing and also during crop growth period for weed control. A light manual weeding can also be done to avoid seed set from the left over weed plants and minimize the problem in the next season. Crabs are a serious problem in early stages, which must be controlled using the appropriate insecticides like thimet/furadon. Similarly, wild boars, birds, rats, termites and other insects should be controlled with available technologies.

SRT appeared to be more suitable to small farmers and those having family labour as a team of 4-5 persons is required for sowing an area of one acre in a day. Large farmers owing >10 acres of land can use a tractor-drawn zero-till seed-cum-fertilizer drill which will further reduce the cost / time and also ensure optimum crop stand. The benefits will multiply if a part of the crop residues is retained on the soil surface. Large increases in the soil organic matter content over a short period of time and increase in earthworm population due to zero-till cultivation and recycling of root biomass are reported.

This technology has been adopted by over 2000 farmers who are reporting very high rice yields of >10 t/ha. Based on the experiences of the farmers and also witnessing the excellent crops of rice in the fields under SRT despite aberrant weather conditions this year, this technology has the potential to replace conventional puddling / transplanting, and thus revolutionize rice cultivation in the high rainfall areas of Konkan region of Maharashtra.

#### *Other states*

There is a growing awareness about conservation agriculture in many other states of India due to the rising cost of cultivation, stagnant yields and deteriorating soil health. We have initiated long-term experiments in network mode since 2012 with focus on tillage, residue and weed management in all the centers of AICRP on weed management located in the non-Indo-Gangetic plains. The following cropping systems are



adopted in different locations:

- Rice-based cropping system (Jorhat, Raipur, Bhubaneswar, Hyderabad, Coimbatore, Thrissur, Bengaluru, Dapoli)
- Maize-based cropping systems (Ranchi and Palampur)
- Pearl millet-based cropping systems (Gwalior, Udaipur, Raichur)
- Cotton-based cropping system (Anand, Akola)

Based on the experiences gained over the last 3-4 years, the technology has a definite scope in specific situations with suitable manipulations. At most locations, the yields of no-till crops with or without crop residue are almost the same as the conventionally-tilled crops. Weeds appear to be a serious problem initially but can be overcome with development of expertise and application of integrated approach. It has been observed that the crops grown in winter and summer are more successful in the early years due to better weed management. Therefore, it is suggested to start conservation agriculture-based farming with these crops first and extend later to the rainy season crops after gaining confidence in weed management. Sowing of seed and placement of basal dose of fertilizer needs to be done with a well calibrated machine (Happy Seeder), the non-availability of which is a serious limitation in the adoption of this technology.

Failures of CA-based farming at some locations may be due to the following factors;

- Lack of assessment of the time period between conversion of native vegetative and no-till adoption
- Lack of knowledge or experience on how to manage crops with no tillage techniques
- Lack of a systems approach when eliminating tillage
- No tillage may have been performed with bare soil conditions or with insufficient crop cover with crop residues
- Lack of experience of the machine operator at seeding
- Inadequate no-tillage machinery, leading to poor plant establishment
- Poor weed control
- Poor disease control
- N fertilization may not have been adjusted during the first few years of applying no-tillage technology
- No-tillage may have been implemented on an extremely degraded and/or eroded soil
- Inadequate crop rotation diversity

### Constraints in adoption of CA-based technologies

Conservation agriculture is not a panacea to solve all agricultural production constraints but offers potential solutions to break productivity barriers, and sustain natural resources and environmental health. Despite several benefits, the adoption of CA systems by farmers in central India is still in its infancy as they require a total paradigm shift from conventional agriculture with regard to crop management. CA technologies are essentially herbicide-driven, machine-driven and knowledge-driven, and therefore require vastly-improved ex-

pertise and resources for adoption in large areas. For wider adoption of CA, there is an urgent need for policy maker, researchers and farmers to change their mindset and explore these opportunities in a site- and situation-specific manner for local adaptation. However, as this is a highly technology-driven agriculture and its very basic principles of sowing seeds in an untilled land and without removing crop residues are in sharp contrast to the traditional belief. Tremendous amount of efforts will be needed to pursue the farmers' for adoption of this technology.

Several factors including bio-physical, socio-economic and cultural limit the adoption of CA by resource-poor farmers. The current major barriers to the spread of CA systems are: (i) competing use of crop residues in rainfed areas, (ii) weed management strategies, particularly for perennial species, (iii) localized insect and disease infestation, and (iv) likelihood of lower crop productivity if site-specific component technologies are not adopted. In addition to these, there are several other factors restricting the adoption of CA technologies in Madhya Pradesh, such as the following:

#### *Technical constraints*

- Non-availability of quality seed drills.
- Non-availability of machine on custom hiring basis
- Requirement of high power tractor for running the machine (seed drill)
- Lack of trained mechanic for repairing the machines
- Lack of awareness, training/ capacity building
- Appropriate moisture at the time of sowing
- Spare parts are not available locally
- Lack of local manufacturers of machines
- Problems in operation under unlevelled field/small size of holding
- Fear to hardening of upper layer of soil
- Old mind set /social fear
- Straw burning

#### *Extension related constraints*

- Lack of extension support from state agriculture agencies
- Lack of extension literature
- Lack of attention by mass media/authorities/policy maker
- Lack of knowledge of extension agencies
- Inadequate extension facility at disposal of input agencies
- Lack of cooperation from fellow farmers

#### *Financial constraints*

- Lack of credit facilities
- Lack of money to buy new machines and inputs
- High cost of seed-drill/Happy Seeder

### **Tips for successful adoption of conservation agriculture**

- Ensure perfect levelling of the field through laser aided

equipments

- Kill all previously growing green vegetation (weeds) through non-selective herbicides before sowing
- Optimum soil moisture at sowing – neither too dry nor too wet
- Adequate amount of crop residues or any other biomass as surface mulch
- A perfect well calibrated Happy Seeder machine for the given crop
- Proper placement of seed and fertilizer at the desired soil depth
- Use 20% more seed and N fertilizer than normal
- Apply at least 50% N along with full P and K at sowing. Do not broadcast basal fertilizer.
- Target the weed seed, rather than weed plant. Kill weed plants before they flower and set seeds.
- Spray the recommended pre- and / or post-emergence herbicides for weed control. Use broad-spectrum herbicides or mixtures wherever available.
- Top dressing of N should be done after about a month (rice, wheat, maize), following post-emergence herbicides and irrigation, if applicable.
- Use appropriate insecticide for control of termites, rodents and other pests.
- Ensure a good initial crop stand – apply first irrigation after sowing if the initial soil moisture at sowing is not enough for germination.
- Irrigations can be delayed by 7-10 days under conditions of sufficient mulch cover compared with conventional owing on clean land surface
- A manual weeding may be necessary after about 50-60 days of growth. Don't allow the perennial weeds to proliferate and nip them in bud.
- Grow 3 crops annually under irrigated conditions. Follow intercropping system wherever feasible. Do not leave the land uncovered at any time.
- Must include a cover crop like summer greengram, blackgram or green manure crops of sunnhemp, *Sesbania*, cowpea etc.
- Follow zero-till (ZT) sowing in all crops in the sequence to get maximum benefit in the long-run. Start ZT with *rabi* season crops, and then extend to rainy season crops as well after gaining experience in this method of cultivation.
- Follow raised-bed method for sowing for crops like maize, cotton, pigeonpea, soybean, greengram, and even wheat and mustard.

### **Consortia Research Platform on Conservation Agriculture – A new initiative of the ICAR**

Indian Council of Agricultural Research has launched a Consortia Research Platform on Conservation Agriculture from 2015, which is a major step for developing, capacity building and adoption of these resource conserving technolo-

gies. This programme is led by the ICAR-Indian Institute of Soil Science, Bhopal, and the ICAR-Directorate of Weed Research (DWR), Jabalpur has taken lead in developing and promoting weed management in conservation agriculture in diversified cropping systems in the black soil region of Central India. DWR has converted its research farm of 150 acres with conservation agriculture - based technologies, and now taken up the task of disseminating these technologies on the farmers' fields on a large scale. Needless to say that the technology is spreading very fast for growing wheat and chickpea in winter season, and greengram in summer season. The farmers after having some initial apprehensions are fully convinced with these technologies. There is a growing demand for suitable farm machinery like Happy Seeder, which can do sowing, place fertilizer and also work under residue conditions. Undoubtedly, this technology has the potential for revolutionizing wheat cultivation in Central India, for which, greater collaborative efforts are needed by different institutions, state departments, and other agencies concerned with agricultural development.

### **Way forward**

Conservation agriculture based technologies have been developed and adopted in rice-wheat cropping systems mostly in the light-textured soils of north-western India. Limited work has been done in the heavy-textured black cotton soils of central India. However, adoption of these technologies at the research farm of BISA and ICAR-DWR, Jabalpur have shown great promise for promotion of these technologies in other areas of the state. Further, large areas in Madhya Pradesh remain fallow during both rainy and winter seasons due to various operational constraints. Summer season also remains virtually fallow due to open cattle grazing but has a lot of potential for cultivation of summer pulses. There exists a large scope for bringing these areas under profitable cropping systems with the adoption of CA-based technologies. There is required to be coordinated effort involving multi-stakeholders to make the farmers aware and demonstrate these technologies on a large scale. Further, necessary back-up in the form of suitable farm machinery is required to be provided to enable farmers adopt these technologies. It is believed that adoption of these technologies can mitigate the adverse effects of climate change and revolutionize cultivation of most crops, particularly wheat in the vertisols of central India. It will help in managing crop residues in the combine-harvested fields by avoiding their burning, reduce cost of cultivation by eliminating elaborate tillage operations, improve soil health through residue recycling, improving pulse production by introducing a legume in summer season, and thus ensuring better livelihood security to the resource-poor farmers of the State.

The conventional agriculture-based crop management systems are gradually undergoing a paradigm shift from intensive tillage to reduced/zero-tillage operations as a result of the success and benefits of ZT wheat. The need of the hour now

is to infuse new technologies for further enhancing and sustaining the productivity as well as to tap new sources of growth in agricultural productivity. The adoption of CA offers avenues for much needed diversification of agriculture, thus expanding the opportunities for cultivation of different crops during different seasons in a year. The prospects for introduction of sugarcane, pulses, vegetables etc. as intercrop with wheat and winter maize provide good avenues for further intensification and diversification of rice-wheat system.

Research should be conducted on soil biological aspects and the rhizosphere environment under contrasting soils and crops with particular emphasis on optimizing fertilizer management. Other areas of research includes machinery development for local farming systems, sowing into crop residues, understanding herbicide performance in crop residues with reduced tillage, changes in nutrient cycling and nitrogen demand, leaf and root diseases, etc. More focus is required on the influence of residue and weed management components.

There is a need for analysis of factors affecting adoption and acceptance of no-tillage agriculture among farmers. A lack of information on the effects and interactions of minimal soil disturbance, permanent residue cover, planned crop rota-

tions and integrated weed management, which are key CA components, can hinder CA adoption. This is because these interactions can have positive and negative effects depending on regional conditions. The positive impacts should be exploited through systems research to enhance CA crop yields. Information has mostly been generated on the basis of research trials, but more on-farm-level research and development is needed. Farmers' involvement in participatory research and demonstration trials can accelerate adoption of CA, especially in areas where CA is a new technology.

Following is needed to promote this technology:

- Adopt resource conserving technologies on-station fully
  - Large scale demonstrations / On-farm research trials
  - Trainings and exposure visits to farmers and other stakeholders
  - Collaboration with multi-stakeholders
  - Subsidy on new farm machinery
  - Incentives for not burning crop residues
  - Easy availability of custom hiring services
  - Good quality and easy availability of herbicides
  - Policy support.
  - Skill developments especially in farm machinery
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## Mechanization: A need for sustainable intensification

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Rice-wheat (RW) system is responsible for phenomenal agricultural growth in North-West (NW) India. However, sustainability of conventional RWS is threatened by scarcity of water, energy and labour, increasing cost of production, air pollution due to burning of crop residues. A much-needed re-vamping of whole farm operations (e.g. seeding, irrigation water, fertilizer application, residue management, herbicide application) of the wheat-based cropping systems is needed to effectively develop and promote technologies for conservation Agriculture (CA) in relation to site- and climate-specific conditions. Zero tillage (ZT) in cereal systems has helped in saving in fuel, water, cost of production and improve system productivity. Residue management as surface mulch in ZT system further helps in improving soil health, reducing GHG emissions equivalent to nearly 13 tonnes/ha of CO<sub>2</sub> and regulating canopy temperature at grain filling stage to mitigate the terminal heat effects in wheat. Although efforts have been made in developing and promoting machinery for seeding wheat in zero-tillage systems, CA technologies are yet to be developed/evaluated for a range of crops and cropping sequences. Relay seeding of different crops in wheat based systems offers an excellent opportunity to improve crop productivity and farmers' income in NW India. Optimal nutrient and water management practices for CA-based cropping systems are poorly understood. There is a need for robust and farmer friendly methods for farmers to schedule irrigation to crops under CA. Most farmers in the irrigated areas use traditional surface (flood) irrigation method. Most of the irrigation water under flood irrigation is lost as deep drainage which is energy consuming process when irrigation water source is ground water. Adoption of drip irrigation in several crops can markedly reduce crop water requirements. However, there have been very limited efforts on the use of drip irrigation system for high water consuming cereal crops (rice, wheat, maize, etc) across the world. The biggest bottle neck in adoption of surface drip irrigation in cereal based systems is labour use in frequent shifting of drip lines for different operations. Layering sub-surface drip in CA based systems is one of the best way to resolve this problem and hence will facilitate faster adoption of drip irrigation system. Subsurface drip irri-

gation (SDI) eliminates necessity of anchoring laterals at the beginning and removing it at the end of the season, and thus longer economic life. Moreover, it is easier to perform cultural farming practices in SDI system, particularly under CA. Simultaneous delivery of water and nutrients directly to roots can be advantageous in increasing water and nutrient use efficiency. There is a clear need for developing SDI packages for cereal -based systems. In order to promote CA in the region, Borlaug Institute for South Asia (BISA), Ludhiana have addressed a number of critical issues of machinery development suitable for CA, for sustainable intensification of wheat-based systems.

### Machinery development for conservation agriculture

**Laser land leveller:** Water is the most important resource for agricultural production on the earth. However, availability of water is limited in many parts NW India. Fall of water level have been more than 1 meter per year in several blocks of the NW states of India. According to one estimate the average depth of tube-wells in Punjab was 41 m in 1997 and has increased to 71 m in year 2004. There is therefore, an urgent need for judicious use of our limited water resources. Precision land levelling (PLL) is the foremost step in this direction which could assist in efficient utilization of water by reducing unproductive losses. This will also result in uniform maturity of the crop, better quality and higher yield. Results from several studies have indicated that PLL saves water to the tune of 20-25% and irrigation time by 30% and also improves crop productivity by 10-15%.

The laser leveller requires 50 hp tractor for smooth operation in the field. Keeping in the view, a two-wheel tractor operated laser leveller was also developed for the small land holdings. Prototype of laser unit for two-wheel tractor has been developed to help the marginal & small farmers of South Asia and Africa and the results of the preliminary testing of the prototype are quite encouraging and the detailed evaluation is in progress.

**Multi-crop planter for direct seeded rice:** All the operations in wheat are almost mechanized while rice transplanting is totally manual making this system highly energy intensive. A

shift in rice production system from transplanted rice to dry direct seeding of rice (DSR) is testimony of the resource conservation technologies (Gupta *et al.*, 2006). The uncertainty in the availability of water/electricity early in the season, is another reason for adoption of DSR for timely planting of rice in Punjab & other parts of India. Thus, there was a dire need to develop a complete mechanized technology package for DSR & other crops so that farmers can be benefited in the event of low erratic rain fall or longer dry spell during the rainy season.

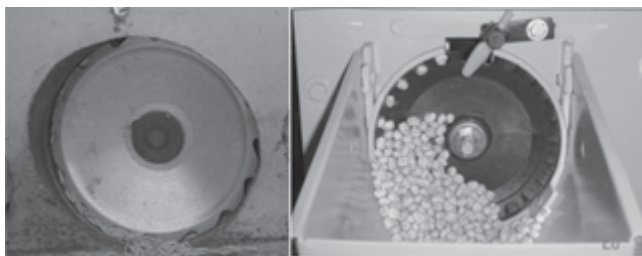
**(a) Functional requirements of direct seeded rice planter:**

The machine for DSR should be able to maintain optimum plant to plant and row to row distance without any mechanical seed injury using a seed rate of 15-20 kg/ha at seeding depth of between 2-3 cm.

**(b) Machines with inclined plate metering mechanism:**

The machines/planters with multi-crop inclined plate metering mechanism are more suitable for seeding rice (see figure). These planters can also be used for planting other crops like maize, cotton, groundnut etc by simply changing the inclined plates designed for a specific crop and adjusting row to row spacing. More than 400 machines were used during the 2016 rice season and covered more than 100000 ha in states of Punjab and Haryana. An additional inclined plate box can also be attached to the existing zero till drill as an alternative to buy a separate machine. This machine can be operated with any 35 HP tractor. The efforts are being made to develop an inclined plate metering mechanism attachment for two-wheel tractor to increase its use and make it multi crop and multifunctional machine.

**Inclined plate metering mechanism**



**Development of Turbo Happy Seeder for direct drilling of crop in any residue:**

In NW India combine harvesting of rice and wheat is now a common practice leaving large amount of crop residues in the fields. Rice straw has found no economic use and thus remains unutilized. In order to seed wheat on time, the majority of the farmer's burn rice straw in-situ in Punjab and Haryana States of India as it is an easy and cheap option causing intense air pollution and losses of plant nutrients. A new machine called Happy Seeder (HS) was developed by PAU Ludhiana to sow wheat into rice residue without burning. A new light-weight machine named the "Turbo Happy Seeder" is now commercially available & can

be operated with 35-40 hp tractor. Evenly spreading of loose straw is a precondition for the smooth operation of all second-generation drills including the HS. The weighted average wheat yield of 154 demonstration sites for HS sown plots was 3.24 % more than the conventionally sown wheat (Sidhu *et al.*, 2015). Additional advantages like less weed growth, water savings, improved soil health and environment quality were also noted under the use of HS technology. To speed up the adoption rate of HS technology, some state Govts. are providing 50% subsidy to farmers for buying the HS (costing Rs. 125,000/- approx.). Like wheat, short duration variety of mungbean (cv. SML 668), maize fodder and DSR can also be directly sown into wheat residue in combine harvested wheat fields to increase its annual use and making it more viable for custom hiring. Instead of penalising farmers who burn crop residues it is suggested to provide an incentive of about Rs. 1500/ha to farmers for not burning crop residues for an initial period of five years. Two-wheel tractor THS attachment was also developed for the farmers having smaller land holdings. This attachment can be mounted on the two-wheel tractor by removing the tiller attachment. This machine sows five rows of wheat in one pass.



There remain significant issues with the capacity of THS (i.e. limited daytime operational ability, slow work speeds, straw choking under wet straw conditions). Wet straw early in the morning restricts working hours to 8-9 hours in a day. The option of using double discs over inverted T type furrow openers for uniform seeding and greater forward speed of travel is also under preliminary testing. Discs would be more effective under wet straw conditions and can be used with greater efficiency on permanent raised beds.

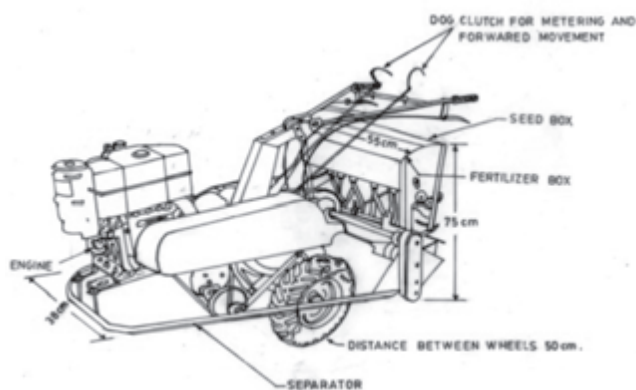
**Straw spreaders (SMS):** Straw management system (SMS) is an attachment to the existing combine for managing and spreading the straw in the harvested area. Straw spreader is attached to the rear side of combine harvester just below the straw walkers and behind the chaffer sieves. The loose resi-

dues falling from the harvester straw walker is spread behind the harvester by the spinning discs. This SMS (spreader) has already been jointly recommended by PAU, Ludhiana and CIMMYT-BISA Ludhiana to the farmers of the state.

**Super SMS:** A new version of SMS called super SMS was developed and evaluated jointly by PAU and CIMMYT-BISA. Super SMS is mounted at the rear of the self-propelled combine harvester having 4.27 m cutter bar and engine power of 110 hp. The straw coming out of the straw walkers of the combine harvester is fed to the unit from one side and is discharged from the outlet of the housing. The chopped material is blown off tangentially and deflected using a deflector for uniform spreading the residues in the entire width of combine harvester. The comparative performance of combine with Super SMS and traditional combine harvester is given in Table 1.

**Relay seeder for wheat in cotton-wheat system and summer moong in rice-wheat system:** Cotton-wheat (CW) rotation is one of the potential candidate for major gains in future wheat production of the NW India. In the conventional CW system, wheat planting after cotton harvest is often delayed (by 20-44 days) due to late picking of cotton and subsequent tillage and field preparation operations needed for wheat planting. This leads on average  $> 0.5 \text{ t ha}^{-1}$  lower wheat productivity planted after cotton compared to that after rice.

Therefore, timeliness in wheat planting under CW system warrants an innovation to overcome the problem of delayed wheat planting. A two-wheel self-propelled relay seeder was developed in 2009 by the Cereal Systems Initiative for South Asia (CSISA)/ CIMMYT team in collaboration with Amar Agro Industries, Ludhiana, India. However, farmers of CW belt in Punjab showed little interest in adoption of two-wheel tractor driven relay seeder due to their large size farm holdings. Keeping this in view, efforts were made to develop high clearance platform for 4-wheel tractor which can be used in the standing cotton. An initial prototype of tractor operated relay seeder has already been developed and evaluated by



**Table 1.** Performance of the combine harvester (with and without SMS)

Sr. No.	Parameters	Combine with Super SMS	Traditional combine harvester
1	Power source	Self-Propelled, 110 hp	Self-Propelled, 110 hp
2	Fuel consumption (l/h)	13.20	11.85
3	Field capacity (ha/h)	1.51	1.53
4	Average Chop size, mm	311.4	539.0
5	Loose straw uniformity, CV (%)	17.9	173.2
6	Threshing efficiency (%)	98.8	99.1
7	Cleaning efficiency (%)	95.5	95.6
8	Collectable losses (%)	2.38	1.37
9	Non-collectable losses (%)	0.36	0.16
10	Total loss (%)	2.74	1.53



**Fig. 1.** Super SMS (left) and SMS (spreader on right) while harvesting rice

BISA, Ludhiana in collaboration with PAU Ludhiana (Manpreet-Singh *et al.*, 2016).

Net returns from the cotton-wheat system with relay seeding of wheat were higher by Indian Rs. 19300 to 26500 ha<sup>-1</sup> compared with the conventional CW system. The high clearance 4-wheel tractor driven relay seeder has also been evaluated for relay seeding of mungbean in to the standing wheat (see Figure). to advance the seeding of mungbean by 20-25 days to get the assured yield (about 1 t/ha) of mungbean without facing the challenge of early onset of monsoon obstructing the harvest of the crop.

### Sub-surface drip irrigation system for rice-wheat and maize-wheat systems

A majority of farmers in the irrigated areas use traditional surface (flood) irrigation method. To overcome such situations, precision irrigation management have demonstrated potential for saving water and improving water use efficiency. The advancements in precision irrigation or pressurized irrigation systems (PIS) systems are; sprinkler irrigation and drip irrigation, etc. Drip and sprinkler irrigation systems are much more water-efficient than conventional basin irrigation practices. These have a conveyance efficiency of almost 100% and an application efficiency of 70-90%, while the corresponding values of efficiency for basin irrigation are 40-70% and 60-70%, respectively (Narayanamoorthy, 2006). Sprinkler irrigation method has relatively lower water saving (up to 70% efficiency) than drip irrigation, since it supplies water over the entire field of the crop (INCID, 1998; Kulkarni, 2005). Adoption of drip irrigation for a number of crops (other than cereals) can reduce crop water requirements to the level of 44.46 BCM in India (Sharma *et al.*, 2009). However, there have been very limited efforts on the use of drip irrigation system for high water consuming cereal crops (rice, wheat, maize etc) across the world. The biggest bottle neck in adoption of surface drip irrigation in cereal based systems is labour use in frequent shifting of drip lines for different operations. Layering sub-surface drip in CA based systems is one of the best way to resolve this problem and hence will facilitate faster adoption of drip irrigation system. Recently, BISA-



CIMMYT at Ludhiana, India; the heartland of Green Revolution with a major threat to physical water availability due to very high ground water withdrawals with very low replenishment, has an initiated new research programme on precision-conservation agriculture using sub-surface drip irrigation in rice-wheat and maize-wheat systems. Results of the studies at BISA-CIMMYT Ludhiana, India revealed that switching from conventional (CTTPR-CTW) to conservation agriculture (ZTDSR-ZTW), rice-wheat (RW) system productivity was increased by 4 % using ~15% less irrigation water. However, with layering sub-surface drip irrigation with CA based the RW system productivity was increased by 8.6% with 50% less irrigation water use and 116% higher water productivity compared to conventional practice. In maize-wheat system, the gains in productivity under CA+ sub-surface drip are even larger than RW system.

### CONCLUSION

The development of suitable agricultural machinery is the key for the adoption of conservation agriculture in the region. The machines for managing residue like turbo happy seeder, straw management systems, multi-crop attachments for DSR, Laser leveller and relay seeders etc. are required for practising and adoption of CA in the region. The residue management machineries like THS and straw spreaders/chopper will reduce the residue burning in Rice-wheat rotation. Relay seeding of wheat can help timely sowing, capturing residual soil moisture of last irrigation to cotton, and increase productivity and profitability of cotton-wheat system. In conclusion, there is a need to develop appropriate mechanization strategies as a collective movement for CA in the region. For accelerating the pace of adoption of CA & diversification in the region, development & evaluation of multi-crop, multi-utility machines for CA and human resource development need immediate action as “*Un-sustainability cannot be an option in the modern agriculture*”.

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**Innovation Systems and**  
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## Models of scaling agronomic benefits among resource poor farmers –integrated scaling in the SIMLESA project

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Scaling is meant to spread benefits of a technology, practice or even a whole programme such as the Sustainable intensification of maize-legume cropping systems for food security in eastern and southern Africa (SIMLESA). It is used in this paper to mean taking ‘options’ (of technologies, practices and knowledge) to the scales and catalysing their possible adoption. It must rely on innovation that tailors options to suit beneficiary conditions. Scaling therefore needs to be preceded by a *holistic* understanding of the target context and beneficiaries. The SIMLESA experience illustrates that deciding the type and amount of knowledge and options to be scaled is a *balancing act* between what is available, suitable and its utility among smallholders. Utility is determined relative to smallholder requirements of economic, social, ecological and agronomic knowledge types. It also depends on the known value of the options, for instance, SIMLESA research illustrates steady income increases with increased combinations of SI portfolios. For instance, net crop income increased by 14–41% when improved maize varieties were cropped under Conservation Agriculture (CA) based practices, improved variety and fertiliser. Such economic analyses were therefore included when preparing farmer materials, along with: i) agronomy — yield gains and stability, weed management, etc. ii) improved seed/ varieties iii) labour economy or reduced cost iv) social benefits, such as reduced drudgery, gender, and reduced effects of climate change. Although SIMLESA will reach more than 4 million, the core goal is to have at least 650,000 adopting different options of sustainable intensification, with 30% productivity increase and 30% reduced downside yield risk by 2023. The most difficult part in any scaling programme is to influence adoption. To realise adoption, SIMLESA integrated different scaling models i) to enhance learning and adoption ii) to enable wider reach among farmers iii) increase benefits. An integrated scaling model means combining different complementary approaches and tools. Success of integrating different approaches depends on good leadership, reliance on pre-existing programmes and investments (through a competitive grant scheme), exploiting existing policy, clear scaling vision, local business incentives,

partner institutional capacity, monitoring, evaluation and learning (M & EL), and efforts aimed at institutionalisation. Institutionalisation is key for leveraging recurrent national micro and macro financial instruments, necessary for sustainability.

“Scaling” is a major component of successful research and development programmes (IIRR 1998). It has long been a priority of agricultural initiatives (Uvin and Miller 1994). Justification for scaling is straightforward, especially to spread benefits of a technology, practice or even a whole programme such as the Sustainable intensification of maize-legume cropping systems for food security in eastern and southern Africa (SIMLESA). Scaling here means increasing SIMLESA Programme initiative’s impact while maintaining quality (see IIRR 2000; Proctor 2003). Impact is a critical fixation of any scaling scientist. It cannot be discussed without reference, or even critical analyses of nature of ‘items’ or ‘portfolios’ to be taken to the scales and their successful adoption (Misiko and Ramisch 2007). SIMLESA Programme ([simlesa.cimmyt.org](http://simlesa.cimmyt.org)) is therefore unique in this regard, having had Phase I that recorded adoption and impact (Kassie *et al.*, 2015). In reality, scaling has been occurring in SIMLESA i) spontaneously, esp. through actor networks ii) based on initial design including through Agricultural Innovation Platforms (AIP). Now, Phase II is iii) including a broad scaling plan right from the start, to build on Phase I successes.

### SIMLESA Phase I in perspective

SIMLESA is a large programme being carried out mainly in Ethiopia, Kenya, Malawi, Mozambique and Tanzania. It also has few activities in Botswana, Rwanda and Uganda, and formerly in South Sudan. It is funded by the Australian Centre for International Agricultural Research (ACIAR) and led by International Maize and Wheat Improvement Center (CIMMYT) and implemented in collaboration with the National Agricultural Research Systems in these target countries. Its core mission is sustainability of maize legume systems, especially through application of Conservation Agriculture based science and innovations. It was initiated in 2010.

Successful CA-based portfolios, although spreading spontaneously and based on Phase I initiatives, need to be further strengthened and systematically expanded through direct interventions (e.g. ILEIA 2001). The task of scaling SIMLESA portfolios is serious given they are knowledge intensive, not single items and have different benefits-accrual timeframes. For instance, improved germplasm or fertiliser use show immediate term yield changes. Crop rotations or intercrop systems need few seasons; benefits manifest in the medium term. Minimum tillage, residue retention, or soil structures are long term investments. To achieve a combination of these benefits means scaling must be an integrated process, flexible/ adaptive and continuous. Scaling SIMLESA benefits cannot be an event or an activity. The current SIMLESA scaling strategy is therefore a transition initiative from a research-development project to an investment programme, based on components explained in Figure 1. It is designed as a handover plan, to larger initiatives.

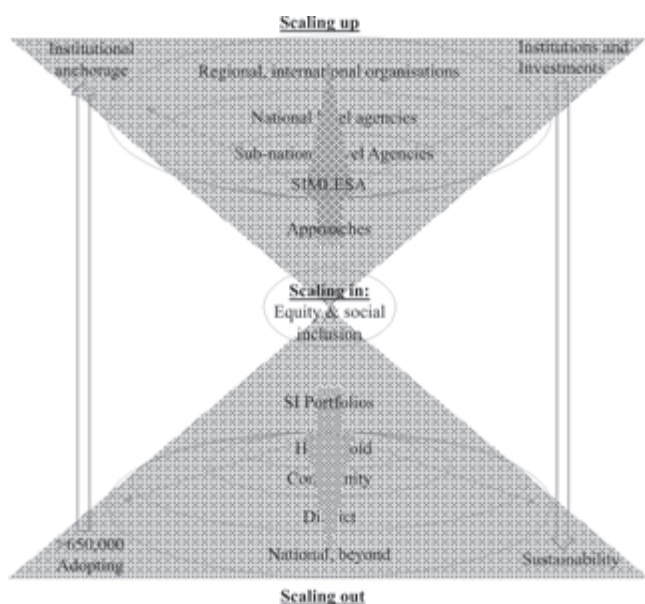


Fig. 1. SIMLESA scaling strategy

SIMLESA Phase I addressed a fundamental challenge of deciding which innovations or portfolios are worth reproducing or systematising for scaling. We now know what knowledge (on portfolios) is necessary to support adoption (e.g. Misiko and Ramisch 2007). For instance, understanding that soil cover reduces erosion, soil moisture loss or weed population is as critical as knowing trade-offs and/ or indeed basic science underlying these benefits. Deciding options to be scaled, therefore was not a portfolio fine-tuning task, but rather the search for a balance between minimum required science and applied value for smallholder application and innovation. SIMLESA scaling strategy therefore relies on achievements from Phase I and how new skills or process are brought to bear on that work.

### What is being taken to the scale in eastern and southern Africa?

Both economic and agronomic research on application of Sustainable Intensification (SIMLESA) portfolios shows combining technologies is more beneficial. For instance, Kassie *et al.* (2015) illustrate income increases as combination of SI portfolios increases. Net crop income increased by 14-41% when improved maize varieties were cropped under CA, and mineral fertiliser. The current scaling strategy therefore emphasises SIMLESA SI portfolios have been fine-tuned, and need to be scaled out:

- i). CA components: cereal-legume rotations and intercrop systems, soil cover, minimum soil disturbance (esp. minimum till methods), soil fertility (incl. fertiliser and manures)
- ii). new germplasm – esp. new maize, legumes (common bean, pigeon pea, ground nut, soyabean), livestock forage
- iii). Storage technologies, not tested under SIMLESA but by partners and CIMMYT sister projects
- iv). Minimum agronomic practices, esp. early planting, appropriate spacing (based on contexts)

Evidence on SIMLESA portfolios are mainly from i) participatory varietal selection (PVS) ii) on-station and on-farm trials iii) economic and adoption research. These have shaped key message focus:

- (i) Agronomy — yield gains and stability, weed management, soil moisture retention, erosion control
- (ii) Germplasm — drought tolerance or drought escape, low fertility tolerance, yield
- (iii) Economic benefits: net increase in incomes relative to yield gains; reduced costs resulting from CA, improved storage, labour economy; stable income resulting from stable demand/ access to markets, reduced postharvest loss
- (iv) Social – reduced drudgery, better nutrition (e.g. soyabean)

### Forms of portfolios being scaled out

Print e.g. decision support tools and illustrative photos, Electronic decision support systems, Videos on case studies e.g. disseminated through video vans, existing ICT resource centres, Audio – radio transcripts, verbal — esp. during field days, ICT – particularly sms simple messages, demonstrations, or learning sites.

### Theoretical framework

We refer to *scaling* to mean dissemination, replication, new learning and adaptation of technologies and approaches, as well as their entrenchment through expansion, development or structural adjustment of organisations (see also Pound *et al.*, 2003). SIMLESA is implementing three levels of scaling.

(i). **Scaling in** – reaching hard to reach, or unreached targets in *existing sites*, especially youths, women, marginalised smallholders or simply those previously overlooked beneficiaries like rural agro-dealers, schools or churches. These are people or groups living side by side with those already reached, and for whom the project needs to reach by *strengthen its approaches*. SIMLESA Phase II is therefore relying more on agribusiness, AIP skills (acquired in Phase I) such as brokerage for better participation or collective action. This is motivated by the pursuit for local *sustainability*, equitability and quality benefits. Although agribusiness has a clear role in scaling in (bringing internal equity) through supporting women enterprise, it has limitations. The business environment in Africa often frustrates the poor, and excludes their access to otherwise good technologies. Therefore, established NGOs have a niche in giving support to marginalised groups beyond agribusiness.

(ii). **Scaling out** – this is quantitative expansion, with more emphasis on horizontal spread to increase the number of people involved. Operationally, SIMLESA is including the CGS, to increase partners, sites, approaches (including agribusiness). Agribusiness may link with many more people through input supply (including herbicides, equipment, new varieties and fertiliser) whilst acting as selling points for smallholder outputs.

(iii). **Scaling up** – this refers to strengthening of involvement of key organisations willing to invest their funds, deploy their staff to bolster SIMLESA-initiated scaling and network to improve their influence. In effect, this goal builds on SIMLESA Phase I that invested significantly in partner staff training for advanced skills. The current challenge is to trigger structural or institutional changes among the right partners, for instance as targeted through the 2015 policy meeting in Uganda. This is vertical reach, more institutional acceptance (of SIMLESA approaches and portfolios) and policy aspects support. It is the search for an “anchorage plan”, SIMLESA being able to influence efficiency and effectiveness through organisational acceptance or growth necessary to carry on with key interventions. This is tied to i. and ii., especially evidence to show as meritorious to move beyond SIMLESA to a complex, mainstreamed, hierarchical developmental process that esp. attracts annual budgets of governments and development initiatives. This mission will *not end in 2018*, but rather will need further work related to mentoring or technical backstopping.

A plan is critical in operationalising the SIMLESA scaling strategy (e.g. Management Systems International 2012).

### SIMLESA scaling model

The core hypothesis is “integrating linear or prescriptive (standardised) dissemination with interactive (learning) processes shortens time of reach and creates sustainable impact among millions of smallholders”. In other words, benefits resulting from integration are holistic and superior than the

totality of scaling activities. Scaling activities are connected through SIMLESA to form one process, rather than stand-alone silo operations.

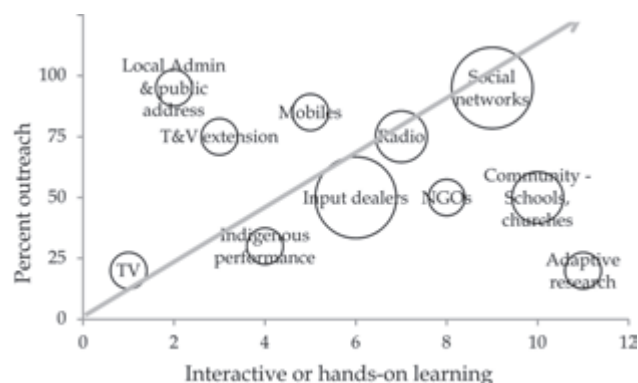


Fig. 2. Reaching numbers fast, with sustainable impact through combining approaches of scaling

Figure 2 is an illustration of the value of SIMLESA approaches. It is based on past studies (e.g. Tumsifu and Silayo 2013). We carried out cases studies (Gerring 2007), through 2 focus group discussions (FGD) – workshop type among purposively sampled participants (based on those adopting SI portfolios) in February 2014 to illustrate importance of farmer sources of information in Bungoma, Kenya as follows:

- sample: women = 8, men = 8 purposively sampled in Kanduyi, Bungoma, Kenya
- size of bubble shows perception of importance of existing sources of agricultural information
- o cards of 4 – 12 inches diameter were used to show importance (regularity) of source
- X axis shows a scale of 0 – 12, which participants used to plot how they rate their interaction (esp. touch, see, use and question the technology and medium being disseminated). For instance, adaptive research was rated quite interactive compared to public administration
- Y axis was used to plot how effective the approach was in reaching number of farmers – based on percentage
- o i.e. what % in participants’ village they judged was reached by each approach
- Participants plotted cards on each axis separately – what they called “height” (Y axis) and “weight” (X axis). Findings were merged before discussions or analyses
- Women and men groups had different FGD. However, their plots were strikingly similar, and we therefore merged the two findings

More field studies are planned in June 2016. Such analyses show integration is the way to reach numbers fast, for lasting impact by ensuring learning through combinations of approaches (Pachico and Fujisaka, 2004).

### Why Social networks in SIMLESA plan?

Key change agents i.e. resource<sup>1</sup> persons must be identi-

fied<sup>2</sup>, linked with key development initiatives (in CGS) and MoA extension, and supported to reach *women and the marginalised*. A study on social networks, esp. through AIP will help unlock this trusted yet unexploited mechanism to reach and influence the marginalised. At the core will be interactive learning and spontaneous sharing over demo plots, SIMLESA Objective 2 trials and exemplary farmer fields.

### Why Private business in SIMLESA scaling?

SIMLESA II is prioritising market-led technology adoption facilitated through public-private partnerships (PPP). The inclusion of business approaches is motivated by:

i). reduced input prices – ensuring supplies are continuous

- and nearer to farmers
- ii). increased income – through improved smallholder links to better markets
  - iii). stronger access to credit, insurance, and information especially through links between local and higher level businesses. Also building on Phase I successes in enhanced access to credit (through AIP negotiated low interests, etc., or collective collateral) and insurance (learning from KilimoSalama example in Kenya).

Business-based scaling works well with efficient input markets. SIMLESA will therefore device business models ideal for nurturing agro-dealers, local service providers, traders and agro-processors to support smallholders. Besides,

**Table 1.** Summary of SIMLESA scaling models

Approaches	Mechanisms	SI Portfolios	Key partner (level)	Scaling out (primary unit)	Scaling up (level)	Equity and Social inclusion
<b>Extension</b>	Field days	CA, seed, forage	MoA, NGO, NARS	Household	SIMLESA	Inclusive selection of participants, open venues
<b>Participatory</b>	Demonstrations	CA, crop varieties, soil fertility	NARS, CG	Household	SIMLESA	Participatory selection of hosts, decision support tools, recommendation domains, farm typologies ( <i>Lineage and friendship are key social vehicles</i> )
	Scientific trials Social networks (harnessed)	All SIMLESA and other portfolios	NARS, CG Informal ( <i>spontaneous sharing</i> )	Cross cutting (incl. cross border)	SIMLESA Indigenous institutions, (varied)	
Agr. Innovation Platforms (AIP)	Capacity building	Inputs, marketing, post field	NARS, CG	Community (Collective, village, interest groups)	Local/ sub-national (few District) partners	Women, youth and self-help groups form AIP <i>Adaptive</i> research, “next generation” skills Inclusive value chains, needs assessment and targeted trainings
	Business approaches, value chains	Insurance, credit, feedback	Private, farmers (CBOs, cooperatives) Value addition	Private		
<b>Public Private Partnerships</b>	Packaging	Seed, info., SI portfolio bundles	Private, NGO	Community/ District wide targets	District	Targeted distribution, of packages in accessible quantities, distributed through local company offices, risk management
	Bulking, promotions Radio, TV	Seed *All portfolios	Seed companies Private, NGO	District level companies National audience)	District, national actors	
	Print (e.g. brochure) ICT – sms, video	*All portfolios	QAAFI, private	Nationwide audience	National	
<b>Policy</b>	Round table, high level	CA, seed, H. storage	MoA, NARS, CG, ASARECA	National/ international audience	International	Participatory content development (applicable) Multidisciplinary (attention to gender, marginalised groups)
	Briefs	AIP, CA, Seed				

agro-dealers must not be over-burdened as information conduits:

- i). provide them with well packaged info, esp. those most sought after by farmers – needs assessment is critical
- ii). seed quality is most sought information, working closely with breeders is critical
- iii). sustainable demand for inputs is being created through AIP, which is necessary for CA related intensification.

### Why ICT? Supportive tool, not stand-alone approach

Sms, radio call-in sessions, interactive video events, etc. will be designed to maximise learning based on social networks within AIP. The sms programme will be led by The Queensland Alliance for Agriculture and Food Innovation (QAAFI) of Australia. Most critical element is participatory content development, which will ensure women and men smallholder inclusion. Measurable success may depend on strong CBOs. See Appendix 2 – Table 3.

### WHY AIP in scaling?

AIP<sup>3</sup> are preferred in SIMLESA as a support system for integrated scaling. AIP is not an organisation, but rather a process-support formation to facilitate the integration of different scaling actors and approaches. It is innovation-led, to ensure sustainability and inclusivity through:

- i) broad mechanisms that bring business approaches into scaling partnerships
- ii) inclusion of critical actors in the initiative, to especially bring complementarity necessary to nurture benefits: lower input costs, equitably share benefits, leverage finances for joint initiatives, initiate/ broker business deals, seed commercialisation, linkages to policy etc.
- iii) creation of a scaling pathway that aligns interests to sustain the scaling process – Fig 3.

SIMLESA will enhance this AIP based process through Competitive Grant Scheme (CGS). It is planned the CGS will bring on board additional players, especially for scaling up (see Figure 1).

- i) an CGS logframe has been prepared, which in part spell out indicators for impact evaluations
- ii) ensure buy-in among communities, governments, key stakeholders esp. through AIP process – meeting planned for early 2015 to explain SIMLESA esp. among new actors – immediately CGS are finalised – see Appendix 1
- iii) generate SI portfolio explained above – a workshop has been planned for early 2015

Successful AIP therefore need to ideally embrace a public service, not-for-profit initiative, and private business venture.

An analysis of SIMLESA scaling success factors

- i) Clear scaling vision – equitable and lasting impact, rapidly – reach more than two million smallholder households, with at least 650,000 adopting. Improve maize



**Fig. 3.** The totality of actors and approaches for scaling in SIMLESA countries. Minimum combination of actors depends on needs and capacities of participants to ensure a functional AIP. AIP plays the role of: (a) uniting fragmented partner effort (b) aligning disjointed scaling approaches (c) nurturing actor incentives and (d) linking and/ or integrating dif. scaling levels (national, regional and district)

and legume productivity by 30%, reduce the expected downside yield risk by 30% by 2023.

- ii) Scaling leadership – momentum to reach stage-of spontaneity requires perpetual leadership at country, project, and esp. leading partnerships.
- iii) External catalysts – relying or exploiting policy processes – leadership support.
- iv) Incentives and accountability – clear AIP stakeholder benefits and incentives, SIMLESA understands community demands.
- v) Spaces – SIMLESA identified constraints and pursued opportunities.
- vi) CGS – bringing on board development initiatives with capacity to scale and sustain.
- vii) Gender and youth – AIP roles and benefits need to be shared, and gender strengthened for equity
- viii) P-M&E – knowing “What works” and how — lessons.
- ix) Scaling up — align with devolved governance structures, rural governance – leverage national budgets for funding. Seeking support of policy leaders. Mainstream SIMLESA-led technologies — Ethiopia: MoA extension, and Agricultural Transformation Agency — Kenya: MoA extension, Kenya Agri. Sector Dev. Programme — Malawi: Malawi Agricultural Sector Wide Approach (ASWAp) — Mozambique: National Agricultural Extension Programme (PRONEA) — Tanzania: Agricultural Sector Development Programme (ASDP)

## CONCLUSIONS

Scaling out demands different approaches are integrated, because each tool or method has advantages and weaknesses. Combining approaches must be innovative, to ensure comparative advantages are maximised, and weaknesses are eliminated. A good scaling programme must ensure i) wider and equitable reach ii) support for adaptation, adoption iii) good value for the dollar.

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## Up-scaling and out-scaling of farmer-led innovations for sustainability and maximizing farmer's profitability

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Agriculture is one of the oldest and most important professions practiced over 5000 years for the livelihood development in India. Farmers live and work under a wide range of ecological, climatic, economic and socio-cultural conditions, and the range of farming systems is quite diverse, not just across regions or countries but also within districts and even localities. In their pursuit for betterment, the Indian farmers consistently tried to make this occupation more efficient and cost effective which resulted in numerous innovations over the generations and helped in improving farming practices ensuring better livelihood options. Their local innovations include both “hard” technologies, and “soft” innovations (World Bank, 2005). Farmers have not only identified several new/indigenous traditional crops and developed varieties with enhanced productivity and better quality through selection but also developed low cost processing technologies for value addition to preserve, process and package various farm products both for increased shelf life and better market opportunities, designed new farm implements and tools, and developed effective market linkages. Obviously, these innovations supported food security of the country. Most of the farming practices traditionally adopted by the farmers are those which were evolved after long experiences of the farmers and communities under specific agro-climatic and socio-economic conditions. Therefore, such practices have been widely adopted and are sustained. In fact, farmers are silently innovating, adopting the new practices and continuously improving them.

Farmer led innovation refers to the dynamics of indigenous knowledge (World Bank 2004, Mariam *et al.*, 2011, Soedjana *et al.*, 2015), consists of processes of developing new technologies or modification, adaptation, and experimentation of own or external ideas, practices, techniques or products by individuals or group of farmers without direct support from external agents or independently of formal research (Wettasinha *et al.*, 2008, Sule akkoyunlu 2013). Farm innovators are those who often undertake innovative efforts to solve localized problems, and generally work outside the realm of formal organizations (Olga, 2015, European Union report, 2011). Agricultural development is innovation driven, hence

innovations ultimately makes the difference in farmers' adoption decision. Even though farmer-led innovations have a high potential for the economic development and sustainability building in the rural economy, over generations, these have neither been duly acknowledged nor documented. These innovations led by farmers have neither been institutionalized for their horizontal and vertical expansion nor properly recognized. Value of traditional knowledge and its documentation has often remained unnoticed by scientists (TAAS, 2011). Also, the Intellectual Property Rights (IPR) on the innovations made by farmers has often been ignored. Thus, many technologies developed by innovative farmers have not reached to other farmers. Even though, some initiatives for protection of propriety rights of the farmer-led innovations have been taken in recent past by government and non-government bodies, but they are still at the budding or dormant stage only. In order to promote development of farmers-led skills as well as protect their rights, it is necessary to recognize and further promote these innovations. It is also desirable to blend the farmers' innovations with the modern scientific knowledge and properly upscale them for the benefit of farming community at large.

### Impact of farmer led innovations

- **Ease of dissemination of innovations and improved technologies among the farmers:** Farmer led innovations are created and invented by the farmers themselves. The credibility and acceptability of these innovations are high as compared to the technologies developed by other organizations or the person outside the social system in which farmer belongs. The most common ways of sharing of the innovations were spontaneously from farmer to farmer through informal networks and through deliberately created opportunities, such as innovation fairs, where farmer-researchers could exchange knowledge among themselves and with other farmers. Innovations that required no or few external inputs and brought obvious benefits spread quickly in these ways (Waters-Bayer *et al.*, 2015).
- **Impact on the livelihood of the rural people:** Farmer-

led research in ecological farming techniques often led to higher household incomes compared to conventional farming techniques using external inputs, primarily because of reduced costs, and allowed farmers to accumulate savings and to invest in economic assets. It is argued that innovation generation practices of farm households may also be making impacts in poor people's livelihoods and might form the basis for food security (Letty *et al.*, 2011).

- **Impact on capacity to innovate:** Strengthening individual capacities (confidence, knowledge and skills to experiment and innovate) were features in the farmer led innovations (Leeuwis *et al.*, 2014). This will also help the farmers and communities to continuously identify and prioritise problems and opportunities in a dynamic environment; the capacity to take risks, experiment with social and technical options, and assess the trade-offs that arise from them; the capacity to mobilize resources and form effective coalitions around promising options and visions for the future and the capacity to link with others in order to access, share and process relevant information and knowledge (Waters-Bayer *et al.*, 2015). It will create a situation where Women became more confident and active in innovation and community development by engaging with some civil society organizations or SHGs.

#### **Current status of institutional support in India for up scaling and out scaling of farmer led innovations**

“Scaling-up” of innovations is the process of reaching larger numbers of a target audience in a broader geographic area by institutionalization of that identified innovations which in turn benefits the farmers and the rural society (Sunding *et al.*, 2000). Upscaling strategies and assessments should not be divorced from concerns with the nature of an innovation, asking the fundamental question whether the innovation has enhanced farmers' options when facing increased input costs, reduced state support, and greater vulnerability due to market, ecological and climate stresses. Local level working institutions are essential for proper documentation and scale up of these innovations without losing the core concept. On this background, in addition, to the PROLINNOVA (Promoting Local Innovation in ecologically-oriented agriculture and natural resource management) an NGO at global level, many donors, policy makers, Civil Society Organizations (CSOs), government organizations, NGOs, farmer organizations are now seeking ways in promoting local innovations (World Bank 2005). In India, many institutions/organizations like Indian Council of Agricultural Research (ICAR), National Innovation Foundation (NIF), PPV&FRA (Protection of Plant Varieties and Farmers Rights Authority), NABARD (National Bank for Agriculture and Rural Development) etc. are vigorously working for documentation, validation, commercialization and scaling up of farmer led innovations.

Among these institutions, Indian Council of Agricultural Research, the apex body for research, extension and education has started some initiatives for recognition, up scaling and commercialization of the farmer led innovations like maintaining data base of successful farmer innovations for better dissemination, recognizing the outstanding contributions of innovative farmers in innovation adoption, modification and dissemination through various awards, ICAR also act as Agri Business incubator to Incubate new start up businesses from these farm innovations. Besides this, IARI (Indian Agricultural Research Institute), the premier institute, started fellow farmer scheme, inviting Innovative farmers to the institute to share their experiences, documenting success stories of innovative farmers and to recognize and awarding the innovative farmers in its annual krishi vigyan melas. Almost all the State Agricultural Universities, state departments, KVKs (Krishi Vigyan Kendras), ATMAs (Agricultural Technology Management Agency) are documenting the farmer led innovations at district level and recognizing them through kisan melas, exhibitions, seminars, conferences etc. (ICAR report 2015). PPV&FRA is providing an effective system for protecting the rights of farmers and farmer breeders in conserving; improving and making available plant genetic resources for the development of new varieties of plants. It is also involved in documentation, indexing and cataloguing of farmers' varieties (PPVFRA Annual report, 2014). Technology Information, Forecasting and Assessment Council (TIFAC) and National Bank for Agriculture and Rural Development (NABARD) is providing the technical and financial support for the documentation and scale up of the farmers led innovations (TIFAC, 2014; NABARD, 2010). NIF a voluntary organization has made many attempts to protect the farmer innovations, with the desire that the tremendous wealth of traditional knowledge and rural based innovations in agriculture be explored and documented before the same is lost forever. NIF has been able to document thousands of rural based innovations, which are made public and disseminated through “Honey Bee” – a periodic news bulletin (NIF, 2015)

#### **The major challenges of up scaling of farmer led innovation**

Although farmers have developed diverse innovations but their potential could not be realized to the extent possible, because of several confounding challenges like

- **Lack of resources at farmer level:** Despite the great interest and enthusiasm of the farmers to try new things, many farmers are constrained with resource limitations, apparently not able to take risks and carry out experiments with their meager resources. Farmers are opt to stick to their traditional experiences of doing agriculture and creativity and risk taking ability, two factors to innovate, may remain dormant if resources and enabling environment are not there (Rivera and Alex, 2004; Akinngbe and Ajayi, 2010).

- **Lack of peer's support:** Innovations by the farmers are sometimes facing the problems like difficulty to get accepted by fellow farmers and the community in general. Many people have the tendency to believe that it is only the literate and intellectual people (like the extension workers) who could bring something new and important to the farmers. Because of this reason, many people do not only provide no support but also discourage the innovative farmers, considering them someone wasting time for no good reasons.
- **Illiteracy:** There are many works involved in innovation process requires understanding measurement. Sometimes the farmers are innovative and risk bearer enough to experiment many methods and practices but due to the lack of proper knowledge and lack of technical understanding they may fail to come up with a new product what they intended to make. Because of this reason farmers being forced to do it by trial and error ; and that made them commit mistakes and redo things again and again.
- **Lack of financial support:** Lack of financial support to promote and encourage farmer's innovation processes has constrained the development of the local practices. Traditionally, farmers do not claim for financial or material support from the government and/or aid agencies to improve their innovations. Funds are provided only to research projects that can meet scientific standards that smallholder farmers cannot come up with. Grassroots innovators are facing other problems like difficulty in getting formal funding through financial institutions due to lack of the financial guarantee and collateral (Olga, 2015).
- **Lack of proper documentation:** Identification of innovative farmers is not an easy task as it requires a different approach than the traditional survey method. It also requires time, patience and commitment (Akinngbe and Ajayi, 2010). According to Anil Gupta (2013), the government and aid organizations have little consideration in acquiring ideas or innovative products and services designed at the grassroots by the people they are trying to assist. Even if these organizations are incorporating these innovations, one cannot find many databases, either online or offline, of innovative solutions developed by disadvantaged people themselves. Many times, grassroots innovators don't even know that they have innovated.
- **Ignorance from researchers and scientist:** Scientists in universities and research laboratories around the world have continued to ignore local knowledge and innovations. Many researchers are not familiar with the concept of farmer innovation. They don't have the trust and confidence that farmers could innovate. Because of this reason, many are neither motivated to discover innovative farmers and establish partnership with them nor recognize their works. There is a gap between the formal and

informal knowledge production systems. Every State Agricultural University publishes its own package of practices but the farmer led innovations do not find any place in it. The pressure from local innovators and traditional knowledge holders to influence policies is feeble, fragmented and easy to ignore (SciDev Report paper 2007).

- **Lack of assistance for validation and commercialization:** Very few grassroots innovators could commercialize their innovations by themselves, but for others, there were many difficulties in securing funds to start a business. The institutional innovations are validated by multi disciplinary experts and commercialized at larger scale but there is lack of adequate institutional support to local innovations, as they don't have such set of indicators for validation. Funds crunch, lack of adequate assistance from government officials and private sector firms, and lack of awareness among people have been the main deterrents in making this a national movement and there is a disinterest from the scientific institutions of India to promote rural innovations (Anil Gupta 2010).
- **Lack of proper dissemination:** Positive impacts of these farm innovations are not realized by many smallholders whose adoption decisions are hampered by several constraints. It is also dependent on the innovative farmer contacts with other persons and the distance from the locality (Sunding *et al.*, 2000). Dissemination is mainly depends on the affordability, validity and compatibility of the farmer innovations. Even though these factors are favourable, the dearth in the institutional support for the wide spread of the farmer led innovation, creating pressure on them to confined in the local places only

### Strategies for up scaling and out scaling of farmer led innovations

Small-scale farmers worldwide are unrelenting innovators, in their efforts to adapt to changing conditions and to survive. Many scientists and research organizations in their zeal to instruct farmers and disseminate their own technologies overlook this local creativity and source of thrust for change. One way to tap this creativity is to identify innovations developed by farmers and then explore them jointly. In this way, local and scientific knowledge can be blended to develop locally appropriate solutions. As KVKs and ATMs are at the district level and in touch with farmers, a network of these organizations can be utilized for identification and documentation of grassroots level farmer led innovations and maintains a repository at district level. Social networking sites, farmer's portals of different organizations like ICAR, NIF, PPVFRA, DST (Department of Science and Technology), NRDC (National Research Development Corporation) etc. can be better utilized for documenting of innovations. Establishment of a "National Innovation centre" at ICAR head quarters linking all 8 ATARI (Agricultural Technology Application Research

Institute) with ATMA and KVKs as partners for documentation, refinement, validation, commercialization and scaling up of innovations can be the crucial step at apex level.

There is a need to facilitate the sharing of available knowledge and innovations among the other farmers. Farmer-to-farmer extension will create space for innovation because farmers learn best from their peers, and they are often more willing to accept innovations observed in the fields of other farmers than messages disseminated by extension workers. Farmer led innovations identified in one region need to be popularized in similar eco-regions elsewhere, through publication, documentation and dissemination of Success Stories. The farmers' innovations should be incorporated in "package of practices" of SAUs (State Agricultural University). There is a need to start Front Line Demonstrations (FLD) in innovative farmer fields and experimentation sites to promote farmer to farmer learning. Farms of innovative farmers should be recognized as agri tourism centres to facilitate the visits of other farmers. Agro-tourism around farmers innovative efforts would not only generate public awareness but will also help in revenue generation and greater community involvement in protecting our rich biodiversity.

Behavioural and attitude changes of the scientists and researchers are necessary to accommodate and acknowledge the farmers' innovations because supporting farmer-led innovations and creativity is an unaccustomed role for scientists and extension agents: shifting from control and just to say to facilitation calls for changes in behaviour and attitude. Stimulating scientists and extension agents to join farmers' innovations requires new job descriptions, research approval procedures, and ways to reward performance.

Many of the farmers are lacking resources to do further improvement and refinement of the innovations which were at their farm. There should be a financial provision to help the farmer to come out from these situations and motivate them to do the further refinement. Access to such funding allows a wide range of innovations to be tackled, and under proper conditions may expand enthusiasm and innovation capacity among smallholders, other rural stakeholders, and those who support them.

In assessing the potential to replicate farmer led innovations, policy-makers need to consider the balance among the social, economic and environmental impacts, the number of beneficiaries and the cost effectiveness. Other prerequisites that determine whether scaling-up is feasible include, whether there are adequate financial resources, human capacities, extension services and infrastructure present in the area to support scaling-up processes of the identified farmer led innovations. These factors are also need to be taken care off for betterment of the innovation identified and its quick dissemination among the fellow farmers. Political commitment and support at the national, regional and decentralized levels, financial assistance and supportive legal and regulatory frameworks can create an enabling environment for scaling up of

farmer led innovations. Farmer may be illiterate about the IP issues and regulatory systems. For any scaled up of farmer led innovations due acknowledgement should go to the farmers, in the form of finance and fame.

## CONCLUSION

Farmers adapt their farm management practices and actively enhance agro biodiversity to suit changing conditions. This describes most of the agricultural innovation that has taken place since the beginning of agriculture. With intimate knowledge of their natural landscapes, farmers continually conduct experiments and observe subtle changes over time. Although farmers' innovation has always been happening but quite slowly and has seldom been recognized by communities itself and the scientist also. Efforts to measure farmers' innovation in absence of outside intervention are in their infancy. The innovation process at farmers could be speeded up by giving opportunity and promoting entrepreneurship to bring in their ideas and skills. The capacities and potential contributions of the farmers must be valued. Identification, documentation, validation and dissemination of the farmer led innovations are very essential for the development of resilient farming community in the changing agricultural situation.

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## Innovative approaches for effective last mile delivery of agricultural technologies

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Last mile is the final leg in point of service delivery. In agriculture, the technologies developed by the research system should reach the end users who are the farmers. To achieve this, the extension educational activities are carried out by both public and private agencies. Agricultural Extension is conceived as a system of informal education which relates useful, practical knowledge to the needs, problems and opportunities of farmers. Thus, it is essentially a system of non-formal adult education, aimed at improving agriculture, by working with farmers. The extension functionaries use different methods and approaches in delivering the technologies and making the farmers to accept and adopt. Adoption will not take place immediately after the delivery or dissemination of technology. Adoption process is the mental process through which an individual pass from first knowledge of an innovation to a decision to adopt or reject and to later confirmation of this decision. Thus, the farmer passes through different stages before adoption takes place. The stages in the order of occurrence are, (a) awareness: at this stage, an individual first hears about the innovation and thus exposed to an idea but lack detailed information about it, (b) interest: at this stage, an individual is motivated to find out more information about the new idea, (c) evaluation: at this stage mental trial of new idea takes place, (d) trial: at this stage, an individual tests the innovation on a small scale for himself, and (e) adoption: if satisfied with trial an individual will decide to use the innovation on large scale in preference to old methods. Duration and length of time between any two stages varies with each practice and individual. The rate at which different individuals go through the different stages varies with the personal characteristics of the individual and the nature of the group influences on him. A variety of extension methods and approaches need to be employed at different stages of adoption to influence the farmers to accept and adopt. The innovative approaches followed by the authors in different projects related to natural re-

sources management are described in this paper.

### Innovative approaches followed in last mile delivery of agricultural technologies

The innovative approaches used at various stages of adoption process in different programmes implemented by the authors is as follows.

**Awareness stage:** to expose the farmers to the new and emerging technologies, traditional media was used extensively in different programmes. The traditional media have no grammar or literature but they are surviving through oral and functional sources and it is one of the most important vehicles of social change and rural development. Further, they arouse interest among people, powerful in touching the deepest emotions of the illiterate millions, changes attitudes and help to gain knowledge, and can overcome the difficulties of verbal communication.

In a watershed development project funded by Danish International Development Assistance (DANIDA) implemented in five northern Districts of Karnataka during 1992-99, used Lavani<sup>1</sup> and Gigi<sup>2</sup> which are very popular folklore of the project area to create awareness about the importance of watershed development in conservation of natural resources. The impact assessment on the effectiveness of these media by Surekha (1999) revealed that, the increase in knowledge about the watershed development was found to be 56,78 percent due to exposure to *gigi* and 52,4 percent in case of *lavani*.

To promote water use efficiency in tank command areas, of four southern districts of Karnataka, six folk songs on different themes including system of rice intensification was adopted in Karnataka community based tank management project, funded by the World Bank during 2002-2008. The results were very much encouraging.

Puppet show was employed in promoting bi-voltine silkworm race in a project titled, 'productivity enhancement in

<sup>1</sup>Lavani is a combination of traditional song and dance, which particularly performed to the beats of a percussion instrument and it is noted for its powerful rhythm.

<sup>2</sup>Gigi is a ballad form with three singers. One in the foreground with a local instrument dappu and two in the background with local instruments, thala and thunthuni.

sericulture' funded by *Rashtriya Krishi Vikasa Yojana* (RKVY). This project was in operation in two districts where, traditional sericulture was in practice. Overwhelming response from the sericulture farmers was observed due to exposure to puppet show. Further, several folklores like *hagaluveshagaararu*, *burrakatha*, *jogihadu*, *thamburipada*, *kamsale* were used during the agricultural fairs to create awareness about improved agricultural technologies (UAS, 2014).

Therefore, use of traditional media will help in establishing rapport with local communities before taking up developmental activities, popularization of new programmes/schemes, spreading key messages quickly on improved agricultural practices/ natural resources conservation.

In a unique project, use of Milk Producers Cooperative Societies<sup>3</sup> (MPCS) as satellite extension centres in agricultural development in Karnataka, synthesized, customized short messages as relevant to 2-3 days on crop production, weather and marketing was prepared by jurisdictional KVKs and sent to the MPCSs through internet. The MPCSs secretaries download the message and display in LED TV for facilitating the farmers visiting the MPCS to read and conceptualize the message. This was proved to be very effective in understanding the important field operations to be done and deciding about the harvest dates based on the weather data.

A web based agri-tech portal was established in UAS, Bangalore during 2014 which covers about 280 technologies on agriculture, horticulture, sericulture, animal husbandry, fisheries, forestry and other related subjects. The contents are, production, post-harvest and marketing technologies, e-books/ e-manuals, research repository, slides bank, gallery of audio, video-clips and digital photo library, weather data and contingency crop plans, market information, ITKs, success stories/ farmers innovations, FAQs, extension approaches, trainings calendar, statistics of state, districts, taluks, villages, expert answers / queries/ upload information directly by expert. This has proved to be a very effective electronic means to create awareness and increase the knowledge base of the farmers as well as the extension functionaries.

**Interest stage:** at this stage, it is important to expose the farmers to the new agricultural technologies established either in research stations or in the on farm demonstrations. In DANIDA watershed development project, thousands of farmers were taken on study tour/ exposure visits to innovative watershed development project areas within the country. Similarly, in Karnataka community based tank management project.

**Evaluation stage:** it is a very important and critical stage in the adoption process. The important approaches adopted at this stage in various projects are, (a) farmers field schools (FFS) and (b) participatory technology development (PTD).

FFS is a discovery learning method, where the farmers are empowered individually and as a group so as to solve their field problems by fostering participation, interaction, joint-

decision making and self-confidence. This approach was followed in different projects is given below.

In Karnataka community based tank management project, 1320 FFSs were conducted between 2002 and 2009 on various subjects *viz.*, water use efficiency, integrated pest management, integrated nutrient management in agriculture and horticulture crops, management of problematic soils of tank command area. The results have shown that, average water use efficiency in agricultural and horticultural crops increased to an extent of 49.0 per cent and yield increase was about 50.0 per cent. In productivity enhance of sericulture project, 90 FFSs were conducted on improved methods of mulberry production and bi-voltine silkworm rearing. This approach has provided an opportunity to farmers to critically evaluate the performance of technologies in their own setting and convinced them to accept the introduced technologies (UAS, 2009).

PTD is essentially a process of purposeful and creative interaction between rural people and outside facilitators. Through this interaction, the partners try to increase their understanding of the main traits and dynamics of the local farming systems, to define priority problems and opportunities, and to experiment with a selection of 'best bet' options for improvement. The options are based on ideas and experience derived from both indigenous knowledge (both local and from farmers elsewhere) and formal science.

In Karnataka community based tank management project, during 2003 to 2005, introduced PTD process in 174 villages based on the problems identified in the crops paddy (77), sunflower (45), maize (15), groundnut (15), finger millet (3) and horticultural crops (19). The tank command area farmers, the staff representatives of community facilitation teams (NGOs), Department of Agriculture and University were involved in the PTD process. The important topics covered were (a) standardization of cultivation practices, weed management, simplification of sowing techniques, irrigation scheduling in aerobic rice cultivation, (b) integrated crop management approaches in sunflower, maize and finger millet (c) integrated pest and water management practices in groundnut and horticultural crops.

The significant outcome of PTD was standardization of cultivation practices for rice production under aerobic condition. The packages were first standardized in 10 hectares in 26 locations during 2003-04. Later, it spread to about 600 hectares in the project area by 2005-06. Similar results were also observed in maize, sunflower, groundnut and horticultural crops. The farmers as well as the project staff were enthusiastic in the process of experimentation at the village level. It has built the confidence of the field staff in technology identification / modification and dissemination. Hence, it proved to be an important approach to be tried by all those engaged in agricultural development process.

A PTD on underground piped water supply to tank command area in Kolar district was implemented in a tank com-

mand area of 22.5 ha covering 65 farmers. The main object of the study was to minimise the conveyance losses and to improve the distribution system. The old system of flood irrigation was dismantled and for the entire command area, underground piped system was established with an outlet and water meter for each farmers plot. To pump the water collected in the tank, a jackwell was constructed and solar power system was used to lift and pump the water to the individual farmers fields. The participatory study revealed that, the conveyance efficiency was found to be 96.4 per cent and the water use efficiency measured in kg/ha-cm in paddy was 122, finger millet 87.5, capsicum 625, radish, 888, tomato 1857 and cauliflower 2250.

The experience in the projects has shown that, the FFS and PTD approaches are very effective approaches in convincing the farmers to accept the technology as it provides an opportunity for them to evaluate the performance in their own field situations (UAS, 2009).

**Trial stage:** at this stage, it is important to provide an opportunity for the farmers to try an innovation in smaller area to observe the performance in the farmers' conditions and resources. At this stage, the on farm trials and demonstrations are important methods. In DANIDA funded watershed development project, during 1994-99 the integrated farming systems demonstrations (synergetic integration of agriculture, horticulture, sericulture, animal husbandry, fisheries, forestry and bio mass based income generating activities) were established in upper reach, middle reach and lower reach of micro watersheds (approximately 500 ha), as per the suitability of the situations and natural resource base available. The results after five years, revealed that the profitability in terms of returns per unit area increased by 90.0 per cent, improvements in conservation of natural resources and availability of water compared to the conventional system of mono cropping, (DANIDA, 2000).

In World Bank funded Karnataka community based tank management project, 400 on farm demonstrations on integrated approaches in arable crops (200 numbers), horticulture crops (100 numbers) and water management (100 numbers), during 2002- 2009. Each demonstration was conducted in an area of 10 ha. Nine agricultural and twenty horticultural crops were demonstrated in the tank command areas spread in four districts. The results of the arable crop demonstrations revealed that, the average increase in yield was 40.62 per cent with a range of 31.40 to 52.63 per cent. The average increase in yield among four cereals was 41.95 per cent. In pulses (3 numbers) the increase was 52.63 per cent and in oil seeds (2 numbers), it was 45.0 per cent. Among the horticultural crop demonstrations, the average increase in yield was 43.27 per cent. Among vegetables, it was 51.00 per cent increase whereas, in case of flowers it was 56.52 per cent and among fruit crop (water melon), it was 30.59 per cent. The water management demonstrations were conducted considering the technologies, crops selection based on water availability,

adoption of crop specific irrigation layouts, promotion of efficient irrigation methods, optimising the irrigation, conjunctive use of rain and ground water and ensuring irrigation at critical stages. The results of these demonstrations revealed that, the average increase in water use efficiency was 45.37 per cent with a range of 30.59 to 75.05 per cent (UAS, 2009).

In the RKVY funded project on productivity enhancement in sericulture, 50 demonstrations on improved mulberry production technologies covering the technologies like improved varieties, integrated mulberry management techniques and modified plant spacing, paired row technique and wider spacing of 6m x 6m during 2010-13. Each demonstration was conducted in an area of 5ha spread over in two districts. The results revealed the increase in mulberry yield per unit area was 59.0 per cent. To promote bi-voltine race of silkworms, the farmers existing silkworm rearing houses were modified by providing better ventilation, sanitation and disinfection technologies. The farmers have accepted the rearing of bi-voltine races as their net income increased by 75.0 per cent over rearing of cross breeds (UAS, 2014).

Thus, the on farm demonstrations provided an opportunity for the farmers to try new technologies on limited scale and observe the results.

**Adoption stage:** this is the last stage of the adoption process where large scale application of potential technologies are implemented by the farmers. The approaches followed in ensuring large scale adoption of proven technologies in different projects are as follows.

Organizing field days during impressive stage of the crops considered for various types of on farm demonstrations.

Organizing interaction sessions involving the farmers directly involved in conducting demonstrations (demonstrators) and potential farmers in the neighbouring areas. The opportunity was created for the demonstrators to share their experience on the technology to potential farmers.

Publicizing the results of the demonstrations through print media in the form of feature articles in dailies, news coverage, leaflets, brochures, booklets etc. The results were also publicised through electronic media in the form of TV coverage and CDs. The salient features of the technologies was also presented in the villages through wall paintings at an appropriate place.

Community technical forum which was also called as Samudaya Tantrika Vedike (STV) was established in every village under the tank management project. This is the forum at the village level to guide farmers on technological aspects of crop/ livestock production, water management, post-harvest etc. They were the para technicians available at the village level. The educated, willing and un employed youth (5-10 per village) were selected in a participatory way and they were given complete training on the subjects relevant to their villages and the interest evinced by the youth. Series of need based trainings were organized over a period of one year to equip them to provide information support, advisory service



and input supply and services to the farmers. On the same lines, in RKVY funded project on productivity enhancement in sericulture, in every village, technical forum was established to take care of the sericulture related issues.

### CONCLUSION

The research system is continuously engaged in development of agricultural technologies based on the emerging needs and problems. All the developed technologies have not reached the ultimate users. It is a challenging task to the extension functionaries to take forward these technologies using appropriate methods and approaches to make them to adopt. Adoption process is the mental process through which a farmer passes from first knowledge of an innovation to a decision to adopt. There are five stages in the adoption process namely, building awareness, creating interest, providing opportunity to evaluate and try the technologies on smaller scale leading to large scale adoption. At each stage of the adoption

process, it is important to use appropriate methods to achieve desired results. The important methods could be use of traditional and electronic media, farmers field schools, participatory technology development, on farm demonstrations, field days with suitable forward and backward linkages.

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## A fresh look to agriculture innovations capacity development for extended reach

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India achieved exemplary increase in food grains production since independence, however, these gains have been offset by population increase. The food grains availability per person/annum of 164.2 kg in 2012 was even less than in 1985 (Agricultural Statistics at a Glance, 2014). Further, as per projection from global studies, India will face the largest decline (minimum 25%) in agricultural productivity from climatic change in 2050 (Singh, 2015). Therefore, one of the most challenging policy issues for a long-term food security is of producing 'more from less for more'. The productivity change in Indian agriculture because of focused research, extension and infrastructure has been well documented by Evenson and Mckinsey (1991). With agriculture becoming more and more knowledge driven, it is necessary to reach the farmers with technologies which are location-specific, easy to adopt, socially compatible, and are economically viable. The extent of agricultural information improves farm income (Birthal *et al.*, 2015). As per report (2014) of the National Sample Survey Organization of the Ministry of Statistics and Programme Implementation, Govt. of India, overall 40.6% of the farmers accessed different sources of information for improved agriculture technologies (Table 1). Out of those who accessed different sources, maximum obtained information on improved seeds/variety (59.6%), followed by fertilizer application, and plant protection. There was a wide variation in number of farmers accessing different sources in various States. Earlier studies showed that the information seeking behaviour was not 'technology' neutral but varied as per complexity of the technology (Parshad and Sinha, 1969).

### States-wise agricultural sustainability in India

Agricultural sustainability is one of the important indica-

tors of the progressive change due to planned interventions (Lee, 2005). A study of change in agricultural sustainability in States from 2001 to 2011 (ICAR-NAARM, 2014-15) showed that there was a positive change in five States (Kerala, Maharashtra, Gujarat, West Bengal and Jharkhand); negative change in ten States (Punjab, Uttarakhand, Tamil Nadu, Andhra Pradesh, Karnataka, Chhattisgarh, Madhya Pradesh, Assam, Uttar Pradesh, and Bihar), and no change in two States (Himachal Pradesh and Haryana). This amply indicates that the country's agricultural technology development, policy framework, technology fatigue, farmers' awareness of the technology options were not appropriate and require relook for extended technology reached.

### Bridging the yield- gaps

As the scope for expansion of arable area is negligible, one important area of intervention for productivity increase is to minimize the wide yield gaps amongst and within the States by appropriate technology transfer and decision support. In case of food grains during 2012-13, only in eight States per ha yield was above the All India Average, while in eleven States it was even less than the All India Average. The highest yield of Punjab was over four times the lowest yield in Maharashtra. Similarly, wide yield gaps are among Districts in the same State (Source: <http://apy.dacnet.nic.in>). Is it that amongst States, the awareness of the available technology options and/or their relevance is varying? This is an area of serious concern for the extension system to critically analyse the determinants and develop specific technology matrices for facilitating adoption (Parshad, 2013).

The National Agricultural Research System (NARS) has generated several technologies, innovations and approaches

**Table 1.** Farmers (%) information seeking behaviour on different crop production aspects

Aspects	Farmers accessing different sources (%)	Highest accessing State & % accessing	Lowest accessing State & % accessing
Improved seeds/variety	59.6	Maharashtra(80.0)	Odisha(40.6)
Fertilizer application	49.4	West Bengal(61.4)	Rajasthan(22.3)
Plant protection	24.0	Kerala (41.1)	Rajasthan(9.6)

which need to be up- scaled for time-bound effect. In the present scenario, ‘business as usual’ mode will no longer lead to accelerated adoption at the farm level, thereby not achieving the much-needed food and nutritional security. A matter of serious concern was the decrease in share of total investment in extension (from 35.05 % in 1961-1970 to 18.57 % in 2001-2010), while the share of investment in research increased from 64.95 % to 81.43 % during the same period (Joshi *et al.*, 2015). It has been reported that significant gains in agricultural production is possible by tapping the untapped production reservoir by effective transfer of technology along with appropriate policy support (Parshad, 1997; Haque, 2000; Mishra *et al.*, 2009).

As per front-line transfer of technology by the ICAR, Frontline Demonstrations (FLD) are undertaken by the Krishi Vigyan Kendras (KVK) to demonstrate the production potential of available technology on farmer’s fields. The % increase in yield (Table 2) of cereals, major pulses, and oilseeds average was 28.1, 34.5 and 29.4% respectively (DARE –ICAR Annual Reports 2013-14 to 2015-16). However, bridging the gap at different levels is a herculean task for the extension system (Parshad, 2013).

**Table 2.** Additional gain in yield (%) under FLDs by KVKs during 2013-14 to 2015-16

Crop	No. of FLDs	Increase in yield (%)*
Cereals	1,08,379	28.1
Major pulses	67,483	34.5
Oilseeds	47,251	29.4

\*weighted mean for three years

## Technology generation and transfer

### Paradigm shift

Over the years, the development in agricultural technologies by research has witnessed a paradigm shift to communication in agricultural extension for raising farmers’ knowledge for accelerated adoption (Parshad, 2013; Sasmal, 2015). Awareness regarding latest agricultural technologies facilitates the adoption of an innovation while its lack can hinder or slow down the adoption process. Electronic media can play a vital role in providing information about production as well as protection technologies of various crops (Holz – Clause, 2011). Radio can be an effective tool for educating the rural community in agricultural context (Manohri, 2002; Anandaraja, *et al.*, 2003). Establishment of Community Radio Stations are being especially focused for accelerated location –specific technology reach. TV has its important role in disseminating information regarding various spheres of agriculture, especially hotline information, be it droughts, floods, and other such vagaries of nature, and live demonstrations for skill development. Internet including mobile services has opened new av-

enues for diversified agricultural information, including dairy- ing and fisheries (Jones, 1992). Farmers need agricultural information predominately regarding agronomic practices and plant protection measures. Specific extension approaches at cognitive (information), affective (positive disposition), and psychomotor (skill acquisition) levels are required for rational decisions to allocate available resources for optimal use (Parshad, 2011; Reddy, 2002). Further, to achieve multiplier effect, different ‘tiers of technology transfer’ be effectively linked.

### Transfer of technology

Adoption of technology is an individual process and involves a number of stages (Rogers, 1962). It has been reported (Parshad, 1979) that different extension methods be adopted as per stage of the adoption process viz. mass media at awareness; formal and informal methods at technology evaluation (mental or trial), and individual and group contacts at decision to adopt stage. Agricultural technology transfer in the context of greater coverage in an economically viable manner seems to be a major challenge. Since the first green revolution, substantial discussions and thoughts for fostering agricultural innovations through appropriate extension systems were introduced with a focus on (i) agricultural research - the main driver of creating new knowledge; and changing the linear model of transfer of technology by introducing farmer’s participation in technology development and on-farm testing and evaluation; (ii) innovation system concept, recognizing innovation as an interactive process. An important view appeared in late 1980s and was marked by the publication of ‘Farmer FIRST ‘in 1987 to fulfil ‘populist’ approach of involving the users of technology in its generation at assessment (Chambers, 1987).

## Strategies to meet diverse demands

### Technology matrix

In the Systems view of Innovation, a well-developed knowledge and innovation system has seven functions (Bergek *et al.*, 2010) - Knowledge development and diffusion; Influence on direction of search and identification of opportunities; Entrepreneurial experimentation and management of risk and uncertainty; Market formation; Resource mobilisation; Legitimation; and Development of positive externalities. Since the transfer of technology system *per se* role is of ‘operationalization’ of bits of research information in a manner that it is easily understood by the farmers as regards its design ‘technology matrix’ for each technology to be introduced in a social system. An example of one such operationalization matrix- Zero Tillage in Plains (Prasad *et al.* 2015) is given in table3 for the purpose of illustration. The columns left blank need multidisciplinary consultation with extension education scientist leading the team for directed intervention as to application within their farming system, and perceived gain from its adoption. It is necessary to design

'technology matrix' for each technology to be introduced in a social system. An example of one such operationalization matrix- Zero Tillage in Plains (Prasad *et al.* 2015) is given in table 3 for the purpose of illustration. The columns left blank need multidisciplinary consultation with extension education scientist leading the team for directed intervention.

### Transition from AKS to AKIS

In India since 1950s in one or the other form, there was a focus on Agriculture Knowledge System (AKS). This continued till a specific extensive planned extension effort in the form of Training & Visit System (T&V) supported by World Bank was introduced. Since it was found that T&V programme could not achieve the desired results being focussed primarily on fixed schedules of meetings, and contact farmers, and excluding arrangement of inputs; a new emphasis was laid in future programmes on Agriculture Knowledge & Innovation System (AKIS). Some such examples of Transfer of Technology (TOT) introduced in recent past included National Agriculture Innovative Project (NAIP), Diversified Agriculture Project, National Food Security Mission, 'Farmer FIRST', and National Skill Development Council for up-gradation of skills required at the farm level. Innovation System design includes mobilising existing knowledge, more bottom-up or interactive than top-down approach, and socially embedded in a process with all the stakeholders.

### Capacity building of stakeholders

While at present the capacity of the extension system to meet the high knowledge demands is very limited, the challenge of reaching all the villages and all the farmers is becoming more and more difficult. The farming community needs an integrated technology generation and dissemination system trained to work in a problem-solving mode rather than subject mode, on a continuous basis. The low extension contact intensity, inadequacy and relevance of printed information, etc.

have been found to be important constraints for effective extension.

### Development & use of ICT enabled technologies

The ICT applications such as multi database technology, decision technology systems, and web enabled applications, agriculture portals, knowledge based expert systems, e-governance, multimedia application, video conferencing, etc. are now widely used for transfer of technology, especially, in agriculture. Among the newer digital opportunities, the Information Kiosks, interactive multimedia can prove useful to solve farmer's problems (Reddy, 2002; Ram Kumar *et al.*, 2003; Anandaraja *et al.*, 2003; Raju, 2004). The multidisciplinary team (s) of scientists should develop more and more compact disks with interactive component for easy dissemination of good agricultural practices with a focus to enhance income at the farm level.

Though India's is second among world's top IT exporters, yet eighty per cent still don't have internet access (News item Hindustan Times- 12 May 2016). This is more so in rural areas, therefore, farmers reach to such services had been very less so far. However, there are some of the successful ICT based projects like *Bhoomi* project in Karnataka, *e-Shringula*, *Drishtee*, *Info-Village*, *Gyan Ganga*, *e-Choupal*, *SEWA* in Gujarat; *vKVK* (Voice Krishi Vigyan Kendra), where agropedia platform acts as 'middle ware' for interaction, one-to-many and many-to-one (Venkatasubramanian and Mahalakshmi, 2012; Kokate and Singh, 2013). At a time when the transfer of technology focus is from one-to-many, it is very opportune for India to make its transition to the knowledge economy through use of ICT ensuring easy reach and low cost internet connectivity. Unmanned aerial vehicles (UAVs), also called as drones, provide a good opportunity for accelerated reach of agriculture technology (ICT Update, 2016). UAVs can be engaged by extension services for early detection of crop pests, crop hunger signs; thereby the transfer of technol-

**Table 3.** Technology matrix-zero tillage in plains

Technology components	Essential conditions	Desirable conditions	TOT mechanism in relation to resource endowments and stage of adoption	Plan of action including type and level of skills to be imparted through training and education
Checking of machinery; Calibration of drill ; Measuring the width of drill or else multiply the number of tines with distance between two tines; Adjustment for fertilizer; Soil moisture at tillage; Selection of crop varieties having vigorous early growth and tillering; Use of relatively higher seed rate, etc.				

ogy team can devise location specific advisories for timely control measures.

### Extension programmes by public and private sectors

#### *Front-line extension programmes of the ICAR*

The ICAR continues to play a vital role in devising and implementing front-line extension programmes like National Demonstrations (1964) complementing Green Revolution; Lab to Land Programme (1979) with a focus on small and marginal farmers; Operational Research Project (1974) for area specific problem oriented approach; Institute Village Linkage Programme (IVLP-1995) involving farmers in technology assessment and refinement; and National Agricultural Innovation Programme (NAIP-2006). ICAR has also established Agricultural Technology and Information Centers (ATICs) in some of the SAUs, and ICAR Institutes for providing technology products and services as a single window offering. With recent implementation of Farmer FIRST for ‘enriching knowledge – integrating technology’, the NARS seems quite keen on integrated participatory innovative models of technology generation, assessment and dissemination.

#### Ministry of Agriculture, Govt. of India

The Govt. of India launched a comprehensive *Rashtriya Krishi Vikas Yojna* (RKVY) in 2007. Other programmes include Agriculture Technology Management Agency (ATMA) at District level; National Food Security Mission, ‘Mass media support to extension project’, *Kissan* Call Centre (KCC) scheme in January 2004, DAESI out-reach diploma, Agri-clinics, Community Radio Stations, Mobile Apps, *Rashtriya Parampragat Krishi Vikas Yojana* and recently 24-hrs Krishi Channel have been started.

#### Public-private partnerships

Of-late there have been some good examples of public-private partnerships (PPP) in agricultural extension. Dhanuka Agritech Limited (DAL) was the first to join hands with the Govt. of Madhya Pradesh for complete agricultural extension management in Hoshangabad District way back in 2001, through a holistic development (Table 4) approach (Parshad, 2013, *op. cited*) and found to be highly effective as per study by Chandra Shekara *et al.* (2010). DAL also was the first to join with National Institute of Agricultural Extension Management (MANAGE), Hyderabad for supporting Diploma in

Agricultural Extension Services for Input Dealers (DAESI), and at its initiative such courses have been jointly launched with three SAUs in Gujarat- AAU, NAU, and JAU (Parshad, 2014). Many extension initiatives also emerged without any active public funding like Tata Kissan Kendra; ITC e-chaupals; DAL private-private partnership; IFFCO & KRIBHCO fertilizer advisories, DSCL *Hariyali Kisan Bazaars*; Pepsico (Sulaiman, 2012).

### CONCLUSION

We need to look forward to restructuring ensuring well integrated innovations generation, operationalization and transfer in the form of AKIS; develop appropriate technology matrices as per local situation; undertake capacity building of the State Extension Services Subject Matter Specialists (SMSs); focus on developing specific extension programmes by utilizing researches in extension education; institutional mechanism for empowering communities through local collective action, and introducing well-structured and implementable convergence mechanism between various players engaged in AKIS. Though AKIS has been in operation as a part of adhoc projects in the country, yet in order to be effective mode of innovation generation and transfer, consistent policies by the Govt. are urgently required. The experiences of PPPs and other transfer of technology projects should be used as ‘tool boxes’ for up-scaling such PPPs. There is a scope of having private-private partnership like the one by DAL with Bihar Litchi Growers Association. Agricultural Universities (AUs) need to play a decisive role in capacity building of different stakeholders, especially KVKs, Farmer Producers Organizations, Agri-Clinics, and Private extension service providers. Establishment of ‘community radio station’ be encouraged. Further, different ‘tiers of technology transfer’ be effectively linked.

The ICT technology holds a scope for increased reach of new technology thereby minimizing the time-span between its generation and diffusion among the users. UAVs increased use for agriculture in the near future offers enormous opportunity. However, in no way ICT and other such devices can replace individual and group contact methods, on-farm demonstrations, and field exhibitions which will continue to play a decisive role in decision to adopt at an individual level, and technology diffusion in a social system. The research in agricultural extension should continuously back-stop develop-

**Table 4.** Shift to holistic development under PPP by DAL with Govt. of Madhya Pradesh

Shift from	To
Technology dissemination	Supporting rural livelihood
Improving farm productivity	Improving farm and off-farm income
Providing services	Enabling to access services
In-put out-put targets	Skill development
Perspective	Facilitating adoption of locally relevant approaches

ment of credible approaches for “Last mile” reach. Overall the transfer of technology focus should be increased farm income generation to make agriculture a long term profitable enterprise.

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## Sustainable intensification of rice-wheat cropping system: Challenges and approaches for evolution and delivery

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South Asia's Indo-Gangetic and Indus plains constitute one of the most agriculturally productive areas of the continent. In South Asia, rice-wheat cropping systems (RWCS) cover 13.5 million hectares and provide incomes and food to millions of people. The development and deployment of high yielding Green Revolution varieties laid the foundation for transformational changes in the agricultural growth in this region. The success was reflected through more efficient dry matter partitioning to reproduction and therefore, higher harvesting index with significant gain in the yield potential. However, in recent years, the yield growth rate of many crops especially cereals has started declining. The mono-culture of RWCS exemplifies both promise and challenges for second generation problems. Reasons for declining in the productivity growth are multiple. Farmers, however, would seek to increase output by using more inputs rather than farming more acres. To do that farmers who borrow heavily against their land are hit particularly hard. The slowdown in growth has been due to groundwater table declining, micronutrient depletion, mono-culture, reducing bio-diversity and build-up of insect, diseases and weeds, development of resistance against pesticides and high concentration of pesticides or fertilizer-derived nitrates and nitrites in water courses. These developments indicate that despite significant achievements, there is no room for complacency and we may have to redesign our strategies not only to produce more food but also to improve profits of farmers in sustainable manner with lower environmental footprint.

### Components of agriculture growth

There are five major components of RWCS growth: varieties (selected for high harvest index, hybrids, and genetically modified crops); inputs (how much and how efficiently they are used and what are ecological shifts they are creating); rate of returns (are they negative or positive in any current year?); the natural resources (how land, water, energy, plants resources are maintained and conserved?) and gaps (are research, extension and education gaps, small, moderate or big farmers). The boundaries between what type of role private

and public sector plays for first two components cannot be drawn too tightly. For last three components, public sector will be key players in bringing reforms and adjustments to support the sustained growth of agriculture for improving the economy of farmers and consumers and for maintaining the ecology at the same time.

### Role of varieties/hybrids in sustainable intensification

Western Indo-Gangetic Plains (WIGP) emerged as star performers for making best use of Green Revolution technologies but Eastern Indo-Gangetic Plains (EIGP) did not respond to growth that typically followed the Green Revolution varieties. Only half of genetic potential of long duration wheat varieties like PBW 343 has been realized in EIGP compared to north-western India because of late planting. Wheat is very sensitive to late planting and wheat yield decline at 35-40 kg/ha/day if planted late beyond its optimum timing of November 15. Until 2006-07, states like Haryana were lagging in realizing the genetic potential of such varieties but now with new management options like zero tillage and early sowings it has even surpassed Punjab in the recent past for getting highest yield. Similarly, there has been no major success for releasing rice varieties which can match the yield potential of MTU 7029 released in 1982. Same thing happened in maize. Private sector has taken the advantage of this vacuum in rice and maize by bringing number of hybrids which were largely accepted by farmers. Medium duration rice hybrids and maize hybrid have been a big success for average yield improvements in these crops. Varieties with high yield potential are rare and we cannot stay complacent. In the context of South Asia, the success will depend more on how best we integrate varieties with the cropping systems without looking at the commodity crop approach. For commodity crops, the prospects for yield growth through evolution of new high yielding varieties should be revised down. In wheat, we need to find ways to focus the breeding for terminal heat from terminal phase (shorter duration late planting varieties tolerant to terminal heat stress) to crop establishment phase (long duration early planted varieties with high tillering ability at relatively



higher temperature and beating terminal heat stress by maturing before onset of heat stress). In the later approach, the focus should be on improving the emergence and tillering capacity at relatively high temperature. With this approach, early sown varieties may withstand and cope with the stress of terminal heat because by this time they are near or at physiological maturity. This is another dimension of cropping system intensification, though for a different reason that deals with terminal heat in EIGP. The question is how to perceive the idea differently as was done in the Cereal Systems Initiative for South Asia (CSISA) project (2009 to 2015) where the combination of hybrid rice followed by long duration wheat was the best combination for advancing wheat sowing in the region. Hybrids in maize and rice have attracted the interest of farmers due to their better performance. In case of maize, single cross hybrids have changed the direction. Hybrids in rice with relatively shorter duration than long-duration varieties allowed farmers to advance the wheat sowings by vacating fields early, resulting into much higher system productivity and profitability.

### Second generation problems

Reports of decline in total factor productivity have been published from 1993 onward (Herrington *et al.*, 1993; Hobbs and Morris, 1996; Malik *et al.*, 1998). In a survey conducted by Harrington and his associates in 1993 concluded that the annual regional productivity loss for wheat of 8% estimated due to severe infestation of *Phalaris minor*- a highly competitive grass weeds of wheat, higher than any wheat related problem that was identified. These findings were later backed by first ever report of resistance in this dreaded weed against isoproturon- a most common herbicide used for its control in India (Malik and Singh, 1995). Later on, this turned out to be the largest single factor that reduced the average productivity of Haryana and Punjab. The system at that point of time was going through "crisis" where the farmers were hit hard and that is why all forces came together again and brought new opportunities in the form of new tillage systems. We took this as a challenge rather than a threat and widened our thinking to find solutions with greater focus on agronomic management and then integrating it with herbicides. Details of the delivery process are given by Malik *et al.* (2002). Main advantage of this combination is seen when we consider the sustained improvement in wheat yields in Haryana since 2005-06. Most of these interventions were done with greater engagement with farmers.

### Tillage reforms

Zero-tillage was considered impractical to the point of impossibility because it was not researched for introduction in conjunction with farmers. By working closely with farmers at farmers' field in a participatory approach during 1996 to 1999, it was observed that the farmers, in fact, spotted an opening in the zero-tillage system of wheat growing. Farm-

ers think that the zero-tillage (ZT) is promising because it is just as good as and cheaper than conventional tillage (CT). In a remarkable tillage based transformation, the management of cropping systems has become easy. It has taken almost 25 years starting from 1970s before farmers started accepting this technology. Since mid-1990s the introduction of zero-tillage has been most aggressive reform.

India has managed all such reforms largely within RWCS through multi-institutional and multi-departmental cooperation rather than individual efforts. Such reforms were setup in the context of environmental benefits and to solve second generation problems.

Had research been more focused, better conclusions would have convinced planners to put more emphasis on this technology? There have been successes particularly with the development of a prototype by GBPUA&T, Pantnagar based on New Zealand zero-tillage machine brought to India by CIMMYT in 1983. There had been failure to transform this advantage into a technology as it is today. The key requirement in the form of a multi-disciplinary and multi-institutional framework and good accidental economic cause in the form of herbicide resistance provided a way forward for much better creativeness through multi-institutional collaborations by CCS HAU, Hisar, Extension agencies and private sector including service providers are necessary but they cannot be a substitute for researchers working directly at farmer's field. Therefore, during the mid-1990s, the ZT was evolved not in the linear mode of conducting research at experimental farms but through a farmer's participatory process in a non-linear mode. Number of surveys conducted between 2007 and 2011 has shown that the zero tillage fields have yielded 4 to 6% more yields than CT fields in the Western Indo-Gangetic Plains (WIGP). Farm household surveys in 2003/04 confirmed significant adoption of zero-tillage wheat in the rice-wheat systems of northwest Indo-Gangetic Plains: 34.5 percent of sample farmers in India's Haryana and 19 percent in Pakistan's Punjab (Erenstein *et al.*, 2007; Farooq *et al.*, 2007). In a recent impact assessment study by Keil *et al.* (2015) published in *Food Security* found that ZT increases grain yields by 458 kg ha<sup>-1</sup> in eastern IGP. Refocusing on the methods of delivery in Eastern IGP (EIGP) like Bihar where ZT accounts for 19.4 % gains in wheat productivity, up from 4 to 6% in WIGP is expected to raise the cropping system productivity in EIGP. The implementation of CSISA project has shown that most of this gain will come from advancement in wheat sowing. This is what we are striving to ensure in CSISA project that early sowing of wheat will optimize the whole cropping system in EIGP. This is also addressing the issue of terminal heat that EIGP experiences every year. Work done in Haryana in the past showed that the soil health after 15 years of zero tillage looks more secure. Grain yield of wheat and the cropping system yields (Rice-wheat, pearl millet-wheat and sorghum -wheat) stayed higher in last 15 years and should support the cropping system intensification (Ashok Yadav and

R.K. Malik Per. Comm).

### Optimization of cropping system

In EIGP, it is environment of late crop establishment that sets the context of cropping system optimization. Scientists have given enough attention of management of individual crops, mostly during the release of new varieties. Working out the management of cropping systems has received little attention. The cropping system research has not been approached the way it should be. During the implementation of CSISA project, we could see that concerned specialists and even farmers were refusing to see that the time management in RWCS and MWCS is most crucial factor to improve the system productivity. Now the efforts of CSISA and its partners are taking shape and will drive the productivity growth in coming decades. The time management by introducing rice hybrids, direct seeded or machine transplanted and mechanical harvesting of rice created enough space which was addressed by introducing early wheat sowings. This enabled individual crops and their varieties especially long duration wheat in the cropping systems to show their potential. The evolution of technologies like zero tillage, hybrid rice, hybrid maize, and mechanical harvesting have given way to a significant change in the management of cropping systems. Whether the benefit of lower cost trickle down to farmer's profits will depend on how we intensify the cropping system. Indian agriculture is still seen through the prism of crop improvement with the idea that the evolution of new varieties will solve all problems. This was true during the first phase of Green Revolution but not now. It is the agronomic management which guides us as to which hybrids or varieties fit in particular cropping system. If the yields are not improving, we need to see how different pieces of technologies are put together. If the management strategies are reworked in favor of timeliness of crop establishments, there could be potential advantage in favor of improvement in the cropping system productivity. This would need redrawing the traditional lines of trans-plantings in rice and sowing of wheat for creating more space between rice harvesting and wheat sowing. That is the only way to maximize the profits by increasing cropping system productivity and reducing the cost of cultivation.

### Research for development and delivery

Traditional linear approach, which allows research at experimental farms followed by inclusion of recommendations in the package of practices and then followed by extension of recommended technologies, did not work to generate technologies that can help optimizing the cropping systems and conservation of resources at the same time. The farmers' participatory approach is the best approach to track the most appropriate technologies. Accurate tracking of technologies based on the opinion of stakeholder should eventually save millions in the investment that are needed to generate technologies. The partnership between academic researchers, ex-

ension agencies and farmers is the best hope to find solution to various issues, which have been catalogued in different reports in the recent past. The existing linear approach may be useful for disseminating simple technologies such as new seeds but for better bet agronomy, different approaches including farmers' participatory research, strengthening/supporting change agents such as private service provider (PSPs), input dealers & distributors, and fostering public-private partnerships are needed for both innovation and adoption of technologies.

### Why some technologies fly and some flop?

The development and delivery of technologies is greater than sum of its parts. Following examples will show why farmers participatory research (FPR) is must for situations like India. The Green Revolution was scaled out in mid-1960s because the imported wheat seed directly went to the farmers' fields where it was tested, assessed, validated and accepted. The adoption BT cotton was more rapid and pervasive because it brought big advantage out of crisis and farmers created pressure for policy changes. The zero-tillage technology is more transformational because it was a paradigm shift and mind-set issue which could be resolved through the FPR. Why hybrid rice adoption is more in Bihar and Jharkhand? This was because we were not able to replace any competitive variety against MT 7029. Moreover, hybrids could fit in the stress environment. Why laser land levelling was adopted with no research in India? This is because it had a business case and was tested and adopted at the same time. Why early wheat sowing was accepted in all ecologies? This is because everything was tried and tested at farmers' fields

Farmers' participatory approach is the progress of collaboration that optimises greater technology extension and then adding value to it. It gives an extra ordinary access to modify technologies. For years scientists tested ZT technology at research stations and generated pieces of information and saw no opportunity to introduce this technology. To evolve ZT in RWCS, scientists in India were slow to seek farmers' opinion. For introducing such reforms, we needed a paradigm shift in the process of doing this research. The growing role of this process challenges the conventional ways of doing such researches in small plots at research farms. The farmer's participatory process is less costly, allows more access to modify technology, easy to notice small problems which are less complicated, optimizes greater technology delivery and add value to it, consolidates technology development and delivery, and it is more innovative with data to adapt to rapidly changing field conditions. The adoption of technology is faster because farmers keep too much weight to recent experience, they have vision of future, ready to make changes for the better, cheaper to implement because once convinced it is easy to justify investment, involve farmers in the process of designing new technology in least possible time, avoids potential problems and collects more information on farmer's preferences and

create bundles of service in real time. With the introduction of FPR as part of research platform and increased return on investment (ROI), this approach is expected to benefit institutions because it takes away guesswork out of technology development, the standardization at farmers' field will be a guard against factors deterrent to acceptance of technology, and it is easy to notice small problems which are less complicated

### CONCLUSION

The success of various management options including tillage reforms, laser land levelling, herbicides resistance management, early crop establishment and the optimization of cropping systems during last 20 years was due to the shift in research efforts solely from experimental farms to farmer's fields. With the adoption of this approach since mid-1990s, the implementation of many multi-institutional projects led to relatively high return on investment (ROI). This approach is even more useful when there is shortage of public investment in research and development as the case now. This is paradigm shift from linear model to non-linear model. It is good time to reflect how much can be accomplished by changing the way we combine the process of developing and delivering technologies to the stakeholder especially we have a large population of farmers.

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## Innovations in knowledge sharing and technology application

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About 72.2% of the population of India lives in 638,000 villages having 156144200 rural households. There are 22.5% marginal (0.39 ha), 22.1 % small (1.42 ha), 23.6% semi medium (2.71ha), 21.2% medium (5.76 ha) and 10.6 % large farmer (17.38 ha) with average land holding of 1.15 ha who are dependent on agriculture for their livelihood. Due to large number of farmers in India, extension service reach to only 6.8 percent of the farmers (GFRAS, 2013). The extension worker to farmer ratio in India is 1:5000 compared to China's 1:625 (Ragasa *et al.*, 2013). The situation is further aggravated as out of the 143,863 positions in the Department of Agriculture, only 91,288 posts are filled (Chandregowda, 2011) in India making it difficult for the extension workers to reach the farmers. The existing extension workers have to perform multiple roles including administrative, supervisory, health department, census and panchayat department's works (Burman *et al.*, 2015) with no conveyance and communication facilities.

The diverse agro-ecological, socio-economic and cultural conditions of the Indian farmers calls for different extension approaches as a single system may not be effective in responding to the demands and technological challenges of various types of clients and to reach the rural poor (Rivera *et al.*, 2001; Davis 2008; Birner *et al.*, 2009). A number of technologies developed in agriculture and allied sectors do not readily reach the farmers due to low extension worker and farmer ratio and poor delivery mechanism. The ICAR is the apex body at the centre to promote, undertake and coordinate research in all fields of agriculture in the country and also renders vital support in agricultural development through its outreach services. The outreach services of ICAR are of 'front-line' nature, i.e., to develop, test and mainstream innovative approaches for extension and rural advisory services. Over the past six decades, the ICAR has piloted several innovative extension approaches (Table 1). Many of these approaches have successfully been up scaled and integrated in to the National Agricultural Extension System.

### Krishi Vigyan Kendra (KVK)

Agricultural innovations and diffusion of new technologies are important factors in developing countries' quests for food

and nutritional security. Farming in different resource endowments must be sustainable, economical, and intensive in order to provide dependable, long-term support for rural households. To achieve these capabilities, farmers must have access to sustainable technology in crop, livestock, forestry, and fisheries sectors. In this regard, the ICAR has established a network of 645 Krishi Vigyan Kendras (KVKs) covering 583 districts and these KVKs are functioning to conduct technology assessment, refinement and demonstration through various activities. This system has over the years evolved as an effective and well-tested frontline extension system, which is exemplary and admired all over the world.

The KVKs have been established in different host organizations viz., State Agricultural Universities (SAUs)/Central Agricultural University (CAU), ICAR Institutes, State Governments, Public Sector Undertaking (PSU), Non-Government Organizations (NGOs), and Central University (CU)/Deemed Universities (DUs)/Other Educational Institutions (OEI). This kind of arrangement brings in a lot of cross learning on processes and methodologies adopted by different organizations.

In view of the changing scenario of agriculture, the mandated activities of KVKs are being reformed from time to time to address the newer challenges in the areas of climate change, secondary and speciality agriculture, conservation agriculture, market led extension and agri-business. The KVK activities include on-farm testing to identify the location specificity of agricultural technologies under various farming systems, frontline demonstrations to establish the production potential of improved agricultural technologies on the farmers' fields, training of farmers and extension personnel to update their knowledge and skills. At present, KVK appears to be the only institutional system at the district level for technological backstopping in agriculture and allied sectors. During 2015-16, the KVKs organized 'On Farm Trials' (36,942), 'Front Line Demonstrations' (98624), trained farmers (13.49 lakh) and extension personnel (1.99 lakh), participated in extension activities (102.39 lakh), produced seed (19600 tonnes), planting material (228.75 lakh) and livestock strains and fingerlings (116.86 lakh), tested soil, water, plant and manure samples (3.35 lakh) and provided advisory to farmers

(223.94 lakh). Providing manpower, developing infrastructure facilities, conveyance to field staff, regular upgrading skill of staff, uninterrupted power supply, net connectivity, working only on mandated activities will help the KVKs to perform efficiently.

### Attracting rural youth in agriculture (ARYA)

Farmers in India depend mainly on agriculture for their livelihood but the young generation is opting for other avenues due to poor returns from farming and they look for any alternate job opportunities. Realizing the importance of rural youth in agricultural development, the ICAR has initiated a program on “Attracting and Retaining Youth in Agriculture” during the XII plan to establish economic models for sustainable income through self employment in agriculture, allied

and service sector. The program enables the farm youth to establish network groups to take up resource and capital intensive activities like processing, value addition and marketing, demonstrate functional linkage with different institutions and stakeholders for convergence of opportunities available under various schemes/program for sustainable development of youth. The project is being implemented in 25 States through KVKs, one district from each State with technical partners from ICAR Institutes and Agricultural Universities. In each district, 200-300 rural youths are identified for their skill development in entrepreneurial activities and establishment of related micro-enterprise units in Apiary, Mushroom, Seed processing, Soil testing, Poultry, Dairy, Goatry, Carp-hatchery, Vermi-compost etc. The trained youth function as role model for other youths, demonstrate the potentiality of the agri-based

**Table 1.** ICAR innovations to reach farmers

Year	Innovations of ICAR to reach farmers	Salient features
1965	National Demonstration Project (ND)	Demonstrate the genetic production potential of new technology of major crops per unit of land and per unit of time and to encourage the farmers to adopt and popularise the technologies
1972	Operational Research Project (ORP)	Demonstrate proven technologies in a contiguous area using cluster approach to influence farmers and extension agencies, study barriers in the way of rapid transfer of technologies
1974	Krishi Vigyan Kendra (KVK)	Science-based interventions for technology application based on on-farm testing, frontline demonstration and capacity building and feedback of operational problems to research system
1979	Lab-to-Land Programme (LLP)	Improve the economic condition of the small and marginal farmers and landless agricultural labourers, particularly scheduled castes and scheduled tribes, through technologies developed
1998	Institute Village Linkage Programme (IVLP) Agricultural Technology Management Agency (ATMA)	Technology assessment and refinement using farmer participatory approach Bottom up approach and adopted as the main extension system in India
2000	Agricultural Technology Information Centres (ATICs)	Single-window delivery of technology products, diagnostic and advisory services
2002-07	ICT models	Various models ranging from voice-based SMS to call centre, expert advise
2009	Agropedia	All aspects of agriculture, agroforum, library, text messages, knowledge repository delivery over cell phones-voice message, text messages, KVK net
2009	Post Office Model of IARI	Innovative model to reach the farmers in remote areas to enhance their income
2001& 2010	Expert System on Wheat Rice Knowledge Management Portal	Provide expert opinion on variety, disease, weed control, agronomic practices, etc Repository of knowledge and data on rice crop across the globe
2015	ARYA	Attract and empower the youth in rural areas to take up various agriculture, allied and service sector enterprises for sustainable income and gainful employment
2015	Mera Gaon Mera Gaurav	To promote the direct interface of scientists with the farmers to provide the information, knowledge and advisories to the farmers
2016	Farmers FIRST	The program focus on farmer’s Farm, Innovations, Resources, Science and Technology (FIRST) and

enterprises and also give training to other farmers. During 2015-16, about 1100 youth were trained and during 2016-17, 4400 are targeted.

*Mera Gaon Mera Gaurav* (MGMG)/ My Village My Pride

ICAR has started an innovative programme “*Mera Gaon Mera Gaurav*” to promote the direct interface of scientists with the farmers to provide the information, knowledge and advisories to the farmers on regular basis in the adopted villages to hasten the lab to land activities. The scientists cater to the needs of all categories of farmers, particularly the small and marginal as they play a crucial role in food production. The problems being faced by the farmers are included in the research proposals by the scientists to suggest remedial measures.

In this initiative, 20,000 scientists of National Agricultural Research and Education System (NARES) are working in the selected villages. The multidisciplinary team of 4 scientists at every Institute/University adopt 5 villages within a radius of 50-100 km from their place of working. KVKs, Panchayats and other related departments provided necessary cooperation to the scientists at the local level in the selected villages. In addition, scientists encourage the ideology of clean and good agricultural techniques for producing good quality agricultural products and link it to *Swachh Bharat Abhiyaan*. During 2015-16, 10712 farmers were covered by the various teams and targeted 20000 farmers during 2016-17.

Separate budget allocation for MGMG, conveyance facilities to the team of scientists, strengthening linkages with line departments, research on the problems faced by the farmers will help in serving the farmers in adopted villages.

### **Farmers FIRST**

The Farmer FIRST Programme (FFP) is an ICAR initiative to move beyond the production and productivity, to privilege the smallholder agriculture and complex, diverse and risk prone realities of majority of the farmers through enhancing farmers-scientists interface. The new concepts and domains emphasises resource management, climate resilient agriculture, production management including storage, market, supply chains, value chains, innovation systems, information systems, etc. In this initiative, the farmer plays a centric role for research problem identification, prioritization and conduct of experiments and its management in farmers' conditions. The focus is on farmer's Farm, Innovations, Resources, Science and Technology (FIRST).

In earlier approaches, farmers were just recipient and little role to play in technology development. Experience shows that the farmers have indigenous technologies which need to be recognised, experimented upon, validated and up scaled. Under the changing situation of increased smallholders, women led agriculture, need for higher return per unit area and changing socio-economic conditions, the Farmer FIRST approach necessitates new approach for project development involving innovation and technology development with the

strong partnership of the farmers for developing location specific, demand driven and farmer friendly technological options. The Components of FFP includes i) Enriching Farmers –Scientist interface, ii) Technology Assemblage, Application and feedback, iii) Partnership and Institutional Building and iv) Content Mobilization

ICAR Institutes and Agricultural Universities (AUs) are implementing the project at field level. One institute adopts about 500-1000 farm families spread over in nearby cluster of 2-4 villages. The farmers will be the major target groups with emphasis on small and marginal farmers and farm women. The program targeted 5000 families during 2016-17 and 10,000 during 2017-18.

Participatory technology development, validate and up-scale indigenous technologies, strengthening linkages with multiple stakeholders will make the program successful.

### **Post office model**

The Indian agriculture is passing through a changing phase in the form of diversification, sustainability, efficiency and commercialization. The ratio of extension worker and farmer has also widened making it difficult for the extension workers to reach all the farmers particularly in remote areas. In this scenario, it is pertinent to think of alternative front line extension models having wide reach and cater to the needs of farmers. An innovative extension model is being initiated at IARI New Delhi in 2009-10 to cater to the needs of farmers even in remote areas through Post Offices. The vast network of post offices can take the agricultural technologies to most of the farmers to enhance their income and make India self sufficient in food production. There are 155,015 post office branches in every nook and corner of the country making it one of the largest network in the world with 139,144 post offices (90%) in the rural areas. Most of the post masters in the rural branch of post offices are from rural areas and caters to 5-15 villages and act as a change agent. The Branch Post Masters (BPM) being from rural background understands the technicalities involved in agriculture and enjoy good relationship with the farmers due to same background.

The pilot project was initiated in Sitapur district of Uttar Pradesh in which seven branches of the post office were selected to carry out the activities particularly timely delivery of the seed along with requisite package of practices. Regular discussions were held with the stakeholders to identify the suitable crops for the region under different agro-climatic conditions. Training programmes were organized for branch post masters and farmers to implement with technical backstopping from the Krishi Vigyan Kendra (KVK) working in the project areas. The program started in 2009-10 involving 2 post offices which has increased to 406 in 2015-16, so far 8599 demonstrations on various crops have been conducted. IARI-post office linkage model was found as cost effective and successful means for making the improved agricultural technologies available in rural areas in relatively

less time. More than 90 % farmers received seeds within 4-6 days of dispatch. Yield of major cereals, oilseeds and vegetables increased 11-3-%. Capacity building activities benefited both the village post masters and farmers. Knowledge gain (23-36%) was recorded.

The farmers and other stakeholders perceived the model is currently involved mainly in seed distribution and awareness programmes, provide advantage to the well off and politically active farmers, therefore a robust mechanism (independent agency) is needed to monitor the activities. To motivate the post masters who are not involved in farming and have urban background to carry out agricultural activities with no financial benefits is a challenge.

### Information and communication technologies (ICTs)

With the changing global scenario and use of ICTs in daily life, the ICAR has initiated a number of programmes through KVKs to reach the farmers even in remote areas. The initiatives include community radio, SMS, Toll Free Number, Advisory to Kisan Call Centres, Video films, Expert Systems, Decision Support System, Rice Portal, etc. These initiatives have given the extension system a wide reach to transfer technologies to the farmers.

### Expert system

The Project “Expert System on Wheat Crop Management” has been developed by IASRI, IIWBR, IARI and NCIPM. The expert system is designed in such a way that it solves the problems faced by a farmers even in remote areas where the services of the extension workers is not always available. EXOWHEM is an information bank for Farmers. It provides all the relevant information about the Wheat Crop Management. It advises farmers on variety selection, crop protection and practices like field preparation, fertilizer application, schedule of irrigation etc through on line queries. It helps in diagnosing any pathological disorder in the plant and suggests control measure. It also helps in identifying insect/pest attack and suggests defence mechanism. The Expert system carries a large amount of research work done by the ICAR institutes, Indian Institute of Wheat and Barley Research formerly known as Directorate of Wheat Research and SAUs. It will also enhance the efficiency of Agricultural Extension personnel.

To extract maximum benefit out of the developed expert system, it is important that it should be thoroughly tested and demonstrated in front of stakeholders. Under the network project it will be thoroughly tested and validated by the experts/scientists. It will be installed at few KVK's to get their feedback. Few training programmes need to be organised to train the extension personnels and KVK officers. A multimedia based sub module exclusively for farmers in Hindi and other local languages will help the farmers to use the system in a better way.

### Rice knowledge management portal (RKMP)

Rice Knowledge Management Portal ([www.rkmp.co.in](http://www.rkmp.co.in)) is a repository of knowledge and data on rice crop across the globe. The research data repository has more than 27000 datasets of multi-location testing done for last 50 years in India. The real time data flows are enabled (using AICRIP Intranet) from 106 research centres from across India. The Independent Consultant group of NAIP- World Bank empirically assessed the benefits accrued of Portal in terms of B:C ratio (1.46 :1.00). The Rice Portal is acclaimed as one of the finest ICT applications in agriculture by Food and Agriculture Organization (APAARI, FAO) in 2013. The RKMP has several global firsts in terms of comprehensiveness and utility (<http://www.rkmp.co.in>). Built on web 2.0 standards, this portal caters to location specific information needs of many stakeholders (policy makers, farmers, extension professionals, researchers, traders, NGOs etc.,) on 24X7 basis and multi-lingual.

In *Research domain*, ICT services are provided through platforms- data repository, AICRIP Intranet (Real time Data sharing across 106 rice centres in India), status of rice production province- wise, RiceVocs (rice vocabulary for All), bio-informatics tool suit, research themes (for young researchers), research fora (Community of Practices), directory of rice researchers, India Rice Research Repository (i3R), guidelines for rice researchers, research tools and techniques, history of rice breeding in India, rice research platform. In *Extension domain*, ICT services are provided through platforms- Production Know How (2500 heads), Package of Practices (Province specific), Expert Answers on Rice (EAR), Government Schemes, Extension Methods, Diagnostic Tool, FAQs (from Farmers Call Centre 1800 180 1551), Frontline Demonstrations, Production Concerns of the Month, Farmers Innovations, Ferti-meter (Online Personalized Fertilizer Recommendation for Rice Farmers), Spot nearest Research/Extension Office/Dealer, Recap Sheets, Audio Gallery (6000 minutes of audio), Video Gallery (more than 50 video clips), Weed Information System (Wisys), Indigenous Technical Knowledge (ITK), State-wise Contingency Plans, RKMP on YouTube. In *Farmers domain*, ICT services are provided local languages through platforms- Production Know How, Package of Practices, Expert Answers on Rice (EAR), Government Schemes, Farmers Innovations, Audio Gallery, Video Gallery. In *Service domain*, ICT services are provided through platforms- Trade Information System (Trade Know How), Mandi (Market) Prices (3500 Regulated Market Yards are indexed for day to day Market Prices), Spot nearest Research/Extension Office/Dealer, Weather Information, Rice Varieties recommended, Contingency Plans (in climate change context). In *General domain*, ICT services are provided through platforms- History and Evolution of Rice, Rice in Indian Culture, Rice in Human Nutrition, Rice End-Products, News and Events, Seed Availability. In Rice Stats, ICT services are pro-

vided through platforms- Rice Almanac, GIS Maps, Decision Support System

### CONCLUSION

The ICAR has initiated a number of front line extension programs to reach the farmers and establish strong linkages with all the stakeholders. KVKs have been established in almost every part of the country which is appreciated globally as an efficient system. The MGMG program has created awareness among farmers and provided solution to their problems at doorstep. The ARYA project has been initiated to provide gainful employment to the farmers in rural areas. The Farmer FIRST project has given an opportunity to the scientists, farmers and other stakeholders to join at a common platform to solve the problems of farmers in a participatory mode. Alternative models like Post Office have been successful to reach the farmers and enhance their income. The ATMA model is being adopted by the states to use bottom up approach. ICTs are being used to reach the farmers and availability of internet in the rural areas has hastened the process. To make these programs more efficient, there is need to work on the problems faced by the stakeholders.

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**Symposium 10**  
**Livelihood Security and**  
**Farmers Prosperity**





## **Agricultural diversification for farmers prosperity**

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Indian agriculture has been diversifying towards high-value crops and animal production. Horticulture and animal production now make up more than half of the value of output of the agricultural sector. In this paper we examine trends in agricultural diversification and effects on farmers' prosperity.

Diversification is the second largest source agriculture growth and its share in growth has improved from a little over 26% in the 1990s to about one-third in the latter two decades. Interestingly, throughout the past three decades, diversification toward high-value crops occurred displacing less profitable crops, mainly coarse cereals and pulses, and not wheat and rice, which implies that diversification generates sustainable growth without have any adverse effect on cereal-based food security.

In an environment where average landholdings are declining and the rural population is still growing, diversification of agricultural in favor high valued and labor-intensive crops such as vegetables and fruits is a favorable trend for alleviation of poverty which is largely concentrated among small farmers. Small farm households (d"2.0ha) that comprise close

to 85% of the total farm households, and cultivate, on average, half a hectare of land need to rely especially on this source of income growth. Compared to other categories of farmers, small farmers are more efficient in production of high-value crops and thus allocate a larger share of their land to these crops. The poverty is also estimated to be less by about 5% among those who cultivate high-value crops than those who do not, and the effect is stronger among smallholders.

With economic growth accelerating further, there is an opportunity to further speed up the pace of diversification toward high-value crops for accelerating agricultural growth, improving viability of small farms and reducing rural poverty. Harnessing this potential would require investment in public infrastructure such as roads, electricity and communication that generate widespread benefits and encourage private investment in agro-processing, cold storages and refrigerated transportation that are critical for success of high-value agriculture. Besides, there is also a need to strengthen markets and institutions as to foster diversification.



## Technology innovation process and methodology for the last mile delivery of agronomic management practices

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Technology innovation is a process in which the problems are identified, solutions are found and tested, and thus, the target group adopts a technology or other type of innovation (Nina *et al.*, 2004). “Scaling up” is both horizontal and vertical; the former refers to adoption and the later to institutionalization. “Horizontal scaling up” is also known as “Scaling out”. Thus:

- Horizontal scaling up = scaling out = adoption
- Vertical scaling up = institutionalization = decision making at higher levels

Scaling out implies the geographical spread of an innovation through its replication and adaptation and is integrally linked to its perceived benefits over conventional methods of agricultural technology. Scaling up *requires* adaptation of innovations, *requires* understanding of underlying principles, *requires* capacity building, *requires* substantially greater investment (Menter *et al.*, 2004). The process of scaling up is taken up always at a higher organizational level.

There has been a shift from relatively easy-to-use technologies (e.g., seeds) to more knowledge- and management-intensive innovations, such as soil management or integrated pest management (IPM), or watershed management or integrated natural resource management or integrated soil fertility management (Ashby, 1986). Such integrated approach needs to be taken up with different components of the system, including

social, economic, biophysical, and policy dimensions. The farming systems research initiatives of the 1970s and 1980s introduced social science inputs and more recent participatory and gender approaches, to address both the complexity and equity perspectives (Collinson, 2000).

The key strategies for effective scaling up based on the participants’ experiences during various international workshops include i) Incorporating scaling up considerations into project planning, ii) Building capacity, iii) Information and learning, iv) Building linkages, v) Engaging in policy dialogue, and vi) Sustaining the process (funding) (Franzel *et al.*, 2001, Gonsalves, 2001, Gundel *et al.*, 2001 and IIRR, 2000). The term Scaling up is often used to refer to a combination of different processes. There are four different types of scaling up as Quantitative, Functional, Political and Organizational; the typology of which is described below:

Agricultural research has traditionally been undertaken on research stations where facilities for experimentation are usually available and accessibility to researchers is favorable. It was assumed long time that the best technology in research stations is also the best in farmers’ fields. However, especially in the developing countries of the humid tropics there is high variability between farmers’ fields and response to improved crop management is less favorable than that in the research stations. In the case of such technology performance inconsis-

**Table 1.** Typology of scaling up (Menter *et al.*, 2004)

Unwin’s terms <sup>a</sup>	Description	Alternative terms
Quantitative scaling up	‘Growth’ or ‘expansion’ in their basic meaning: increase the number of people involved through replications of activities, interventions, and experiences	Dissemination, replication
Functional scaling up	Projects and programmes to expand the types of activities (e.g., agricultural intervention, training, credit etc.)	Scaling out or horizontal scaling up (Unwin, 1995)
Political scaling up	Projects and programmes move beyond service delivery, and towards change in structural/institutional changes	Vertical scaling up (Gundel <i>et al.</i> , 2001)
Organizational scaling up	Organizations improve their efficiency and effectiveness to allow for growth and sustainability of interventions, achieved through increased financial resources, staff training, networking, etc.	Vertical scaling up (Gundel <i>et al.</i> , 2001) Institutional development

tencies the technology selection process should be done on-farm in comparison to the farmers' existing practice under the farmers' growing conditions (Gomez and Gomez, 1984).

### 1. Technology adaptation to micro-environment diversity

The method of on-farm testing of technology involves extensive farmer participation addressing two key requirements of adaptive research for small farm systems: (i) the need to improve information feedback about farm-level constraints and the potential acceptability of technologies between small farmers and researchers; and (ii) the need to develop methodologies for adaptive research which takes into account the diversity and micro-environment specificity that characterize small-farm conditions.

New organizational strategies for farm-level technology assessment are required to overcome these two fundamental limitations, first, the resource-poor farmers seldom have access to institutionalized channels, such as producer associations, for communicating with technology designers about their experience with recommended technologies, and second, the micro-environment diversity imposes severe limitations on the capacity of formal research systems to exhaustively screen new technology for its suitability to small farm conditions. The primary goal of on-farm research is to foster adoption, adaptation, and innovation by farmers, not to further the science of agriculture (Meertens, 2008).

An on-farm trial aims at testing a technology or a new idea in farmers' fields, under farmers' conditions and management, by using farmers' own practice as control. An on-farm-trial is not identical to a demonstration field, which aims at showing farmers a technology of which researchers and extension agents are sure that it works in the area (Jakar, RNC-RC, 2001).

On-farm experimentations are conducted with several different objectives which include i) the farmers and researchers working as partners in the technology development process, ii) evaluating the biophysical performance of a practice under

a wider range of conditions than is available on-station, iii) helping in obtaining realistic input-output data for financial analysis, and finally iv) providing important diagnostic information about farmers' problems. The types of on-farm trials depend on the critical information needed for determining the biophysical performance, profitability, and acceptability, *i.e.*, its adoption potential (Table 2) (Bellon and Reeves, 2002)

### 2. Methodology for participation of small farmers in design of on-farm trials

During 1982-84 a collaborative research effort of the International Fertilizer Development Center (IFDC) and the International Center for Tropical Agriculture (CIAT), investigated to what extent the agronomic potential of local phosphate materials, could be realized in the soils, climate and management conditions found on small farms in Colombia (Ashby, 1986).

The results showed that increased scope for farmer participation produced significant changes in the design of on-farm trials due to important insights into how farmers themselves would evaluate fertilizers, and raised basic research questions about improvements in the technology. It was concluded that farmer participation in experimental design for on-farm trials requires fewer resources and less time than diagnostic survey research while qualitatively improving feedback between scientists and farmers. Institutionalizing the development of a 'Farmer Design' into the diagnostic phase of on-farm research can be a rapid, low-cost improvement on the use of survey research, with the important function of building the missing link between formal research systems and farmer experimentation.

### 3. Reducing the R&D tag facilitating early flow of research benefits – case of ICARDA

ICARDA (International Center for Agricultural Research in the Dry Areas) has used decentralized-participatory barley (*Hordeum vulgare* L.) breeding since 1996 in Syria, Tunisia,

**Table 2.** The suitability of different types of trials for meeting specific objectives

Information types	Type 1	Type 2	Type 3
Biophysical response	H	M	L
Profitability	L	H	L
• Acceptability			
• Feasibility	L	M	H
• Farmers assessment of a particular prototype	L	H	M
• Farmers assessment of a practice other	L	M	H
• Identifying farmer innovations	0	L	H

- Type 1 = researcher designed, researcher managed; Type 2 = researcher designed, farmer managed; Type 3 = farmer designed, farmer managed.
- H = high, M = medium or variable, L = low, 0 = none.
- Prototypemeans a practice that is carefully defined, e.g. a prototype of improved fallows would include specific management options such as species, time of planting, spacing, etc.

Morocco, Yemen, Eritrea, Egypt, and Jordan; the key steps of which are as follows:

- Planting a large sample of barley lines on farmer's field in several locations as FIT (Farmer Initial Trial).
- The materials, selected by the farmers in FIT, are planted in second year in fields of several host farmers at each location, called FAT (Farmer Advance Trials).
- Material selected from FAT enters the FET (Farmer Elite Trials) in the third year.
- The breeders' role is to make the initial crosses, provide genetic material for the trials, and keep records about the agronomic characteristics of the lines.
- The farmers' role is to manage the trials, select, and record their selections. Breeders and farmers together discuss and decide what materials go to different trials.
- Thus Participatory Plant Breeding (PPB) itself has the potential to reduce the R&D lag, and so corresponds to an early flow of research benefits, and ultimately higher returns to research investment.
- In the Structure of PPB as Compared to Conventional Breeding at ICARDA, the first two years of research structure are the same.
- ICARDA's PPB takes the lines to farmer selection in year 3, whereas on-farm testing in conventional breeding takes place 3 years later, in year 6.
- This means that decentralized participatory research has potentially a 3-year reduction research.
- The conventional breeding research lag is 8 years at the minimum.
- After 8 years, 2 more years of large-scale testing follow before a variety can be released. If single plant selections are made, then the pedigree method adds at least 3 more years because materials are not bulked until year 5.

One of the most robust findings of the economic theory of innovation diffusion is that the technology adoption follows an s-shaped curve (Mansfield, 1979). When the technology first becomes available, usually a small group of farmers will adopt immediately, or after short experimentation. These are known as "early adopters". As time passes, a much larger group of farmers will adopt, and they can be called "mainstream adopters". Lastly, a few farmers are always very slow to take advantage of new and emerging technologies, and often wait until the technologies are "mature".

Under the conventional breeding program the speed of barley adoption has been 3% per year, and the adoption ceiling has been 25% of the barley area (Aw-Hassan *et al.*, 2004). A 2001 survey trials (Lilja and Aw-Hassan, 2002) indicates that the participating farmers expect a 26% yield increase of the new barley over their local variety; being quite high over the breeders' moderate estimate of a 10% yield advantage, and estimate that they will plant 69% of their total barley area in the new barley lines, after their own initial 2-year experimenting period. This 69% represents the adoption ceiling, and

it is 44% higher than the 25% ceiling rate of the varieties developed by the conventional breeding program. The participating farmers were also willing to pay a 24% premium on the new barley seed over the locally available seed.

#### **4. Three-year participatory varietal selection (PVS) expediting diffusion**

By 1996, WARDA (West Africa Rice Development Association) made significant and breakthrough advances in plant breeding by developing interspecific hybrid rice (NERICA, New Rice for Africa) by crossing Asian varieties (*Oryza sativa* L.) with traditional African rice (*Oryza glaberrima* Steud.). The WARDA researchers developed a 3-year participatory varietal selection (PVS) and breeding approach, which it implemented in its 17-member, national agricultural research systems (NARS) programs.

- First Year: a centralized village plot is identified with local farmers, where a rice garden is established with about 60 upland or lowland rice varieties. Men and women farmers are invited to visit the plot as frequently as possible, but formal plant evaluations are held at three stages during the season.
- Second Year: each farmer receives the varieties s/he selected in the first year, and thus a new diversity of varieties enters the locality. Observers visit the field to record performance indicators and farmer appreciation of the varieties.
- Third and Final Year: the farmers' willingness to pay for seed varieties is elicited in order to derive an estimate of technology demand. Farmer input confirmed that their breeding goals were already consistent with farmers' needs

#### **5. Mother-baby trial model**

ICRISAT (International Crops Research Institute for the Semi-Arid Tropics) initiated Mother-Baby (MB) trial model as a methodology designed to improve the flow of information between farmers and researchers (Snapp, 1999). The methodology was initially developed and implemented to test legume-based soil fertility management technologies in Malawi in 1997. While, a Mother Trial is researcher-designed, a Baby Trial consists of a single replicate of one or more technologies from the mother trial and is managed by single farmers on his or her own land. Many people reported visiting the baby trials rather than the mother trials, which suggests that this methodology may be more effective than a traditional test or demonstration plot in disseminating information about new technologies.

The MB approach was successful in quickly "discarding" the technologies that were not acceptable to farmers. In order to appreciate this result, one needs to consider the costs avoided as a "benefit" from discarding technologies that have a low probability of succeeding.

## 6. Facilitating adoption of more complex technology

The project changed its focus from integrated pest management (IPM) to integrated crop management (ICM). The expansion from IPM to ICM resulted in:

- Increased number of people for which the technology is relevant. The farmers who attended the improved FFS benefited.
- Participation of six sweet potato ICM FFSs, there was 44% higher net returns/hectare.
- The farmer-researchers who developed the FFS curricula benefited significantly from their participation in the research project; by forming strong bonds with the other farmers, and continued to maintain them after the project ended.
- The researchers' roles also changed, to officials such as extension agents.
- The project increased human capital impact of participatory research, a consequence of existing modes of social interaction (Johnson *et al.*, 2000).

## 7. Hardware and software aspects of new technologies

It is useful to make use of distinction between the *hardware* and the *software* aspects of new technologies, hardware being the object that embodies the technology, and the software being the information needed to use it effectively (Rogers, 1995). Part of the difficulty in reaching the last mile, in addition to the human and financial constraints and lack of infrastructure, is that interventions and services are not designed or equipped to reach these unique environments. In order for last mile solutions to be sustainable, they must address challenges specific to low-resource settings.

### 8. Dealing with portfolio of interventions

Climate Resilient Agriculture requires a portfolio of interventions aiming at sustainably increase productivity and income, build resilience to climate change, reduce greenhouse gas emissions and enhance achievement of national food security and development goals (Aggarwal *et al.*, 2013). The Climate-Smart Villages are the sites where researchers, local partners, and farmers are to collaborate to evaluate and maximize synergies across a portfolio of climate-smart agricultural interventions. The aim is to improve farmers' income and resilience to climatic risks and boost their ability to adapt to climate change. There is no fixed package of interventions or a one-size-fits-all approach. The emphasis is on tailoring a portfolio of interventions that complement one another and that suit the local conditions, out of 8 important areas of climate smart technologies as Cropping System Smart, Weather Smart, Water Smart, Carbon Smart, Nitrogen Smart, Energy Smart, Knowledge Smart and Sensor Smart.

## 9. Inadequate focus on Africa's major crops

Why did Africa not take advantage of the research breakthroughs in high-yielding varieties developed in the international agricultural research centers? Why does Africa have

only 7 per cent of its area sown with high-yielding varieties compared to 17 per cent in the Near East, 30 per cent in Latin America, and up to 72 per cent in Asia, allowing these continents to increase their production at rates of up to 4 per cent annually (FAO, 1988). The important reasons are i) the type of commodities CGIAR concentrated is of marginal interest in Africa, and ii) the most national agricultural research programs in Africa do not have the capacity to absorb research results that could be useful to their circumstances.

The major crops in Africa are in the Sahelian zone, millet and sorghum representing 40 per cent and 18 per cent of world production, and in the tropical zone, yam, plantain and cassava which represent 95 per cent, 70 per cent, and 44 per cent of world production. Neither rice nor wheat, which spearheaded the Green Revolution, is of importance to Africa. Besides, the available rice technology which was mainly developed for irrigated land, does not suit African conditions where upland, deep-flooded and mangrove swamp rice are prevalent. It could be added that nearly all research was made on *Oryza sativa*, instead of *Oryza glaberrima* which used to be traditionally cultivated in Africa.

## 10. Characterizing and measuring the effects of incorporating stakeholder participation in natural resource management research

The Working Document on CGIAR System wide Program on Participatory Research and Gender Analysis (Johnson *et al.*, 2000) assessed the impacts of incorporating user participation and gender analysis in natural resource management research and summarized as i) Impacts on technology and adoption where the farmer input influenced the technology development process, especially when the input came early in the research process or when technology testing was done in a collaborative (empowering) way; and ii) Feedback to formal research, in which some of the feedback was technical in nature and influenced institutional research priorities, most was methodological, such as information about barriers to adoption, which is likely to benefit future research and extension efforts. By analyzing three research/development projects that used participatory methods in applied research on NRM, this study aimed to improve our understanding of the costs and benefits of using participatory research (Nina *et al.*, 2004).

## CONCLUSION

The paper dealt with some specific conclusions about the role of participatory research in scaling out and up the impact of agricultural research. There is also example of how "conventional" research and participatory research complement each other, and how participatory approaches can add significant value to conventional research processes. Some of the useful methodologies for overcoming the difficulties of last mile connectivity and scaling up and scaling out have been explained for increased adoption and diffusion of agriculture technology.

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## Enhancing farmers prosperity in the irrigated agriculture

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Agricultural production is a biological process and irrigation water is the pivot to it. Historically, civilizations were settled and farming was started being practised on the embankments of rivers and canals where water was available for both humans and plants. Consequently, agriculture developed relatively more in the regions where water was available from rains and/or surface/groundwater sources as compared to those regions where water availability from these sources was scanty. Green revolution technology also revolved around availability of water and was more successful in irrigated regions than un-irrigated regions. Combination of high yielding seeds of various crops especially wheat and rice, irrigation water and chemical fertilizers along with farm mechanization, rural infrastructure development, agricultural input-output prices and marketing ushered in the era of substantial gains in the productivity of important crops especially cereals. Green revolution technology was deliberately promoted for enhancing food grain production to meet the challenge of food security at the national level. Recognising the importance of irrigation, public investments in surface irrigation were made to create irrigation potential at the national level under five year plans over time. On the other hand, private investments were encouraged in tapping tubewell irrigation through easy and cheap availability of credit. This strategy paid off and Indian not only became food self sufficient over time but started exporting grains to other countries. The food grain production which was only 72 million tons in 1965-66 reached the level of 265 million tons in 2013-14. Irrigation played pivotal role in this accomplishment. The irrigated area increased from 19% of the cultivated area in 1965-66 to 45% in 2012-13. However, still there is lot of difference in the percent irrigated area among different states of the country and so is the agricultural productivity and agricultural incomes.

Punjab state remained on the forefront in reaping the benefits of green revolution technology based on irrigation. Agricultural policy facilitated this process because country needed food grains. On the other hand, those states where irrigation facilities did not progress, could not develop concomitantly and are still standing low on the pedestal of agricultural productivity and incomes. However, there is other side of the story of this nexus also between agricultural growth and irrigation water. It was not a win-win situation for the ir-

rigated regions like Punjab. In quest for harvesting higher and higher productivity and supported by the State policies to produce and procure grains from such areas for food security needs, farmers started over-exploiting its water resources. This was especially more true for underground water resources. Traditional crops were replaced by the new crops which required more water but at the same time gave higher profits and were more stable. This paper examines the relationship of agricultural productivity with irrigation water and how over the years water resources were misused/over-exploited by adopting irrational crop patterns/farm practices by the farmers for productivity and income gains and how policies promoted such crop choices and practices without any regard to economic rationality and logic.

### Agricultural productivity and water in India

As discussed earlier, availability of assured irrigation helped farmers to follow intensive agricultural practices in the irrigated regions because of less degree of risk in the production process. High yielding seeds were more responsive to higher use of nutrient in attaining better productivity. Consequently, use of chemical fertilizers as well as other agrochemical as plant protection measures went up in these area. Table 1 shows the productivity of important crops and extent of irrigated area out of the total area under that crop, among important states growing such crops.

It was seen that the rice and wheat productivity was the highest in Punjab/Haryana states where almost the entire area was irrigated. The productivity declined as the level of irrigation decreased among the states. [Rainfall is also an important source of water in some states (eastern states) in determining productivity, which we have not discussed in this paper]. The rice productivity was less than half in Bihar, Odisha, Madhya Pradesh and Gujarat where irrigation was available only between 26-61% of area as compared with Punjab where almost all the rice area was irrigated. The relationship between productivity and irrigation was less strong in wheat crop because it is grown in winter season and requires less water. Even one or two life saving irrigations helps in obtaining good yield. In some north-eastern states its productivity also depends upon rainfall and not fully explained by irrigation facility because these areas receive relatively higher degree of rainfall. Yet,

**Table 1.** Productivity and irrigated area of rice and wheat, 2013–14

State	Rice		Wheat	
	Yield (kg/ha)	Irrigated area (%)	Yield (kg/ha)	Irrigated area (%)
Punjab	3952	99.5	4848	98.9
Haryana	3256	99.9	4722	99.5
AP	2891	97.1	-	-
West Bengal	2786	48.2	-	-
Bihar	1774	61.1	2251	94.1
Odisha	1815	33.2	-	-
Madhya Pradesh	1891	26.1	2405	89.3
Gujarat	2003	61.5	2703	90.8

Source: Agricultural statistics at a glance, various issues

certainty of availability of water at certain important crop stages prevents the farmers from adopting intensive input use cultivation practices due to which even their productivity remains lower than assured irrigation areas.

Stability in productivity is also directly linked with irrigation water. The productivity gets severely affected during the period of low rainfall in the states where irrigation potential is less developed. A typical phenomenon of higher productivity during less rainfall years has been observed in the Punjab state which is cent percent irrigated state. This happens because the incidence of pests and diseases is lower during drought years. Instability in crop yield was examined by working out the ratio of maximum to minimum productivity during 2000-01 to 2013-14 for rice and wheat in states with different levels of irrigation. It was estimated that in rice, this ratio was low at 1.15 in Punjab and was as high as 2.56 in Madhya Pradesh, 2.81 in Chattisgarh and 2.88 in Bihar. In case of wheat ratio of maximum to minimum productivity was 1.19 in Punjab and 1.60 in Gujarat. These ratios clearly indicate higher degree of instability in agricultural productivity and production in less irrigated regions.

### Depletion of water resources in Punjab

More than 98% cultivated area of the Punjab state is irrigated, out of which 27.5% is irrigated by surface sources (canal water) and 72.5% by groundwater (tubewells). HYVs-irrigation-fertilizers ushered green revolution in the state resulting in shifts in the crop pattern in favour of rice and wheat (while all other crops relegated to negligible position), higher use of fertilizers, higher use of farm machinery and the annual productivity increased to more than three times and food grain production to about nine times during 1965-66 to 2013-14 (Table 2).

However, the dependence on groundwater for agriculture increased immensely during this period. Agricultural policies also favoured this process, more particularly the cultivation of rice crop in the state. Rice was not a traditional crop of the state but was adopted by the farmers due to its higher profitability and assured marketing, which was ensured through input subsidies (fertilizers and power), increase in MSP and

**Table 2.** Agricultural productivity and inputs use in Punjab

Parameter	Before Green Revolution (1965–66)	Current status (2013–14)
Cropping intensity (%)	126	191
Irrigated area (%)	54	99
Through surface water (%)	45	27.5
Through ground water (%)	55	72.5
NPK usage (kg/crop- ha)	9.4	224
Area under paddy-wheat (%)	38.7	77
Tractors ('000)	5 (1970-71)	488
Productivity/annum of paddy & wheat (q/ha)	33	107
Foodgrain production (million tonnes)	3.4	29.5

Source: Statistical Abstract of Punjab, various issues

public procurement by the government agencies. Consequently, the groundwater resources started being irrationally overused. Power to agriculture sector was made free of cost and electric operated tubewell connections were granted to farmers in large numbers. Rice was planted in almost all the area which had groundwater fit for irrigation, especially the central Punjab. All this caused unsustainable use of groundwater resources and water table started declining at an alarming rate. The current demand for water is 4.45 million ha meter while supply is 3.04 million ha meter and the remaining deficit is met by pumping out groundwater. Table 3 shows the rate of decline in groundwater in central Punjab over the years. The rate of fall increased as the area under rice increased and additional tubewells were dug to meet the increasing requirement of water. The rate of fall was also influenced by the rainfall; it was little lower in those years, when precipitation was higher than normal, and was higher when precipitation was less than normal long run average. The rate of decline was as high as 90 cm/annum during the period of 2000-05 and 75 cm/annum during 2005-08. Consequently, 96% of the development blocks in central Punjab are over-exploited and are regarded as 'dark blocks'. But the phenomenon is still continuing, however the rate of decline in recent years has been

**Table 3.** Fall in water table in central Punjab

Period	Average decline (cm/year)	Average rainfall (cm)	Additional tubewells (Lakh)
1990-2000	-25	64	1.53
2000-05	-90	37	2.58
2005-08	-75	41	0.92
2008-13	-45	53	1.2
2013-15	-55	36	0.31

*Source:* Annual Reports of Central Groundwater Board Reports, various issues

lowered down due to the enactment of 'Preservation of sub-soil water act 2009, which prohibits farmers from transplanting paddy before 15<sup>th</sup> June, while before this act, about two-third of farmers used to transplant paddy from the end of May to 15<sup>th</sup> June. Yet, free electricity to agriculture (Rs 47 billion in the year 2015-16) is encouraging the farmers to use water in an irrational manner. The crop is irrigated even if it does not require water as water and electricity are free and the marginal cost of application of irrigation water is zero. Some water saving technologies/practices such as direct seeded rice,

irrigation scheduling with the help of tensiometer, early duration rice varieties, irrigation two days after the water is drained, etc. are available but these are not being adopted in the absence of any economic incentives. Similarly, crop diversification towards less water using crops such as maize, pulses, oilseeds, etc. is not happening because rice remains the most profitable crop with assured price and marketing and free power and free water without any regulation on the quantities to be pumped out.

Under such situation, there are many lessons to be learned for the states which are following similar growth pattern and policies. Power subsidies need to be rationalized and incentivised in such a manner that water is used optimally and sustainably. Further, input-output price structure must give signals for the promotion of those crops which use less water keeping in view the criticality of the emerging scenario in states like Punjab where water resources are being over-exploited. Further, adoption of water saving technologies, practices and varieties need to be promoted by incentivising those in the form of capital subsidies, law, bonus, assured marketing, etc. Above all, the farmers must be educated about the necessity of sustainability of water resources for future not only for agriculture but for the human race also.



**Symposium 11**  
**Emerging Challenges for**  
**Agronomic Education**





## Privatization of agronomy education for professionalism

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Water resources management is one of the most important policy issues of the 21<sup>st</sup> century for planners of the developed as well as developing countries. Global population continues to increase and it is expected to increase by another 3 billion people between now and 2050. This will add increasing pressure on the world's finite supply of freshwater for drinking, sanitation, agriculture, and industry. Water quality and availability of freshwater supplies are the two most important water issues facing the global society today. Declining water supplies, pollution of existing water supplies, uneven spatial distribution of available water, climate change, and lack of financial resources in many developed and developing countries are creating serious water management problems that are both challenging and need urgent attention. In many developing countries, women walk several miles a day to obtain water to meet their daily domestic drinking water needs which in most cases is of poor quality. A very large proportion of the world's population does not have access to clean and safe drinking water. Sanitation systems for rural women in many countries of south Asia are desperately lacking. It is estimated that about five million people die each year from water borne

diseases and poor sanitation conditions.

Rainwater harvesting offers an excellent hope of creating additional sources of surface water supplies meet the drinking water and irrigation needs of growing population and could be one of the best strategies of groundwater recharge. Rain water is largely a clean source of water in many non-industrialized countries. If simple and low cost water harvesting techniques and technologies can be promoted and implemented in rural areas, adequate drinking water supplies and irrigation water needs can be assured for large proportion of the population in the world. Soil is still the best water filter to remove water contaminants and through the use of locally sustainable water harvesting technologies, clean water for human consumption can be made available for masses. This paper will present some of the rainwater harvesting technologies that are already being used successfully at different scales, both at village and watershed levels. This paper will also present some of the most important local water quality and policy issues that need to be addressed for supplying clean water for drinking, sanitation, and irrigation to communities on a sustained basis.



## Changing phase of Agronomy education

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Today, Agronomy has left behind its classical definition that was explained by the Greek words AGROS (Field) and NOMOS (Management). Agronomy and its education today is being identified with advanced science and technology, business practices and industry as well social and economic parameters, hence Agronomy education has become a multidisciplinary subject.

In recent times, new global developments like environmental degradation and climate change have impacted Agronomy and its education to a great extent, Agronomy education particularly, therefore, is not an education for education sake but it is rather identified with livelihood, food security and other socioeconomic parameters; further Agronomy education is a live subject and has a dynamism of its own, that way it is different than the classical type of education of arts and other social science subjects. Being a live subject Agronomy education keeps changing with time with a change in its internal and external factors.

### Development of Agronomy education

The Agronomy education at under-graduate and post-graduate levels till 1950's revolve around study of various crops, their production technology and soil and water management studies, all this was happening within the college boundaries and the attached farms. This trend prevailed in south and south-east Asian colleges of agriculture till early 1960's.

1960 was the epoch making year when the first State Agriculture University (SAU) India was established at Pantnagar in Uttar Pradesh, India (now in Uttarakhand) with the US assistance, a series of SAU's followed at Ludhiana in Punjab, Hissar in Haryana, Coimbatore in Tamil Nadu, Jabalpur in Madhya Pradesh, and in several other states of the country. As of today, there are about 45 SAU's all over the country, some of the Central Agriculture Universities also came up with the assistance of Indian Council of Agriculture Research (ICAR). Some of the Central Institutes of ICAR like IARI, IVRI and NDRI also became deemed universities, this brought a revolutionary change in the system of agricultural education as this pattern was based on US system of education and it provided more flexibility in courses option across the disciplines. Other Asian countries like Philippines, Thailand and Pakistan also

have started similar system of agricultural education in their countries.

### Factors affecting Agronomy education

Both natural and physical factors influence Agronomy education. Climate change, soil and water management systems, type and extent of forestry and bio-diversity are major natural factors affecting agricultural education in general and Agronomy education in particular. Among physical factors, extent of economic development, market demand, volume and spread of market available to farmers, infrastructural facilities and farmers connectivity and approach with domestic and international market are the major physical factors that influence the nature and content of Agronomy education. World Trade Organization (WTO) regulations have also started affecting agricultural trade as well education component. These regulations affect the agricultural situation in developed and developing countries in different manner.

### New phase of Agronomy education

Agronomy is entering a new phase of modernity through adoption of latest scientific technologies closing at maximum precision. Precision has become the password in all operations of farm management, all resources, whether natural or physical are limited and expensive, their use has to be with maximum efficiency and turn-over. The whole idea is zero waste of energy and material with maximum turn-over and profitability. Computerization of all farm operations has facilitated the process of precision. In this context an important change has come up in the form of polyhousing and polyculture, the best example being South Korea, Japan, Israel and other countries.

Field and laboratory facilities in universities have to be re-designed on modern lines with a suitable linkage with farm and corporate sectors. An interactive relationship has to be maintained between the Agronomy under-graduate and post-graduate students on one side and those working on related fields on the other side. Agriculture in Asian countries is fast becoming an essential component of business and industrial chain there is need to introduce new package of business management courses in Agronomy curriculum along with courses on climate change, modern resource management and



the precision technology involved. There have to be different packages of courses with high tech leading farm managers, high tech farm advisory personals, researchers, teachers or those graduating students who have to enter modern food processing industry which is worth 39.7 billion US dollars with a growth rate 11% per year in India. Special care has to be taken for small and marginal farmers who are resource poor.

### **Climate change effects on Indian farming**

Climate change effects have started appearing all over the globe. Its effects can be clearly noted in the Indian subcontinent. Winter maize has started replacing wheat in eastern U.P and Bihar due to temperature rise, and summer (monsoon) maize has replaced rice in southern states of India due to receding monsoon rains. Summer Bajra has occupied large areas in western and central U.P. as a new crop, again due to rising temperature. The most significant climate change is appearing in Thar desert area where last 50 years average annual rainfall has shown an increasing trend. These developments call for a need to include climate change courses in Agronomy curriculum.

### **Market reforms and agriculture**

Some of the important market reforms have been introduced in India such as the introduction of Goods and Services Tax (GST), digitization process and through food security law

2013. Agronomy students need to understand these changes as their future preparation.

### **CONCLUSION**

Modern Agronomy education has to cater to the needs of business and industry oriented Agronomy with high monetary stakes. Agronomy education therefore, should be capable to generate technology for higher and profitable production of such crop varieties that are preferred by the food processing industry as well as for consumption by the people universally. Agronomists should be qualified enough to deal with the environmental and climate change challenges under field conditions. The modern Agronomy presents immense opportunity for development of high tech farm Advisory Services network in south and south-east Asian countries. Special courses are required to meet this new demand. Besides the above mentioned developments in Agronomy education, the greatest challenge for agronomists particularly in Southern hemisphere is to produce enough nutritious food and to satisfy hunger of more than a billion people all over the world and to make them secured, whose food security is under peril.

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## Capacity building and competency enhancement for addressing challenges of Agronomy education in India

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India has come a long way from the situation of “living from ship to mouth” to “food self-sufficiency”. Agriculture is the pivotal sector for ensuring food and nutritional security, sustainable development and for alleviation of poverty in India. It is the key sector for generating employment opportunities for most of the population, even today it is providing employment to half of the Indian population. Indian agriculture contributes to 8% global agricultural gross domestic product (GDP) to support 18% of world population on only 9% of world’s arable land and 2.3% of geographical area. The country has 142 million ha net cultivated and 60 million ha net irrigated area with 138% cropping intensity. The agricultural sector contributes 13.9% to the India’s GDP. Nearly one-fourth of the country’s population lives below poverty line, and about 80% of our land mass is highly vulnerable to drought, floods and cyclones. On the brighter side, India possesses substantial biodiversity, nearly 8% of the world’s documented animal and plant species are found in India.

The Indian Council of Agricultural Research (ICAR) is an apex body of the National Agricultural Research and Education System (NARES) of the country with 109 ICAR-Institutes and 73 Agricultural Universities spread across the country. ICAR has played a pioneering role in ushering Green Revolution and subsequent developments in agriculture in India through its scientific research and technology development that has enabled the country to increase the production of foodgrains by 5 times with an all-time high of 264.77 million tonnes in 2013, horticultural crops by 9.5 times, fish by 12.5 times, milk by 7.8 times and eggs by 39 times since 1951 to 2014, thus making a visible impact on the national food and nutritional security. But it envisions challenges that agriculture sector is facing, especially for ensuring food, nutritional, environmental and livelihood securities.

Recent literature (Ahluwalia, 2011; Desai *et al.*, 2011; Chand and Parappathu, 2012, and Lele *et al.*, 2012) have indicated that the agricultural sector has gone through different phases of growth, embracing a wide variety of institutional interventions, and technological and policy regimes. The bottom line is that India will be facing serious challenges to achieve a target growth rate of 4% in agriculture sector to re-

duce poverty at a fast rate. Moreover, the agricultural sector is getting more complex due to globalization, impact of climate change, entry of corporate sector in agricultural value-chain, diversification of agriculture towards high value commodities, expanding demand for processed food, and need for post-harvest technology.

Modern Agronomy has the capacity to find practical solutions for most of the challenges that the Indian agriculture is facing. However, there is a need to reorient present agronomy education and training in India to enhance the competency level of students who can be groomed as Scientists, Teachers and Technical personnel having the capacity to develop new agronomy to generate cost effective and sustainable technologies to address the present and future challenges of agriculture in the country. Therefore, India needs rich human capital of highly qualified, motivated, and well trained agricultural scientist/teacher and technical human resources. It is the primary responsibility of the NARES to provide such human resources. State Agricultural Universities (SAUs) are governed by the State Governments and agriculture being a state subject with major responsibility of agricultural education, research and extension as per Act and Statutes. At the centre, ICAR is the apex body responsible for promoting and coordinating agricultural education in the country. Agronomy being a major discipline, traditionally deals with the principles and practices of crop production, soil and water management. In changing scenario, the horizon of agronomy needs to be widened to include various new courses like hi-tech agronomy, environment/ecological agronomy, cost effective agronomy, precision farming, protected agriculture, alternate land use systems, quality production of crops and marketing for global competitiveness, value additions, and integrated approaches for management of biotic and abiotic stresses. Because of the central role of Agronomy in many environmental and agricultural issues, the study of Agronomy in SAUs is of paramount importance accounting for about 16% of the total credit hours at UG level.

In the advent of globalization, technological and information revolution, it has become imperative for the Organizations to have a well-trained and well-informed staff in order

to meet the ever-increasing demands of the stakeholders. Training and capacity building programmes should be initiated based on the competency approach which is dependent on the principle of "Right Person in the Right Job." Competency Approach enables us to define the right Knowledge, Skills, Behavior and personal characteristics required for a job, prepare the person to hold the job through training, place the person with right competencies in that job so that he/she can perform the job well. It is very important to develop capacity building of Agronomists based on competency mapping to face the current and future challenges of Agronomy education and research in India.

### **Agricultural scenario and performance in India**

Indian economy has undergone structural transition over the years. There has been continuous increase in real GDP growth over each decade since Independence. Despite of the fact that the GDP from agriculture in total GDP has grown continuously and significantly in absolute terms but the per cent share has declined continuously due to relatively higher increase registered in other sectors. As on 2013, agricultural sector including forestry and fishing has accounted for about 13.9% of the GDP (Planning Commission, 2014).

The production of foodgrains has made more than 5 times growth since 1950 i.e. 50.82 million tonnes in 1950-51 to 264.77 million tonnes in 2013-14 (Department of Agriculture and Cooperation, 2015). The major contribution comes from rice and wheat that too with the advent of Green Revolution on account of significant increase in the productivity mainly due to availability of improved dwarf varieties and seeds, improved agronomic package of practices coupled with irrigation water, fertilizers and pesticides. The productivity gains were also significant in case of coarse cereals to boost their production significantly, while such gains were relatively sluggish in case of pulses even though pulse production enhanced by 1.3 times in 2013-14 over 1950-51, particularly growth picked up since 2001-02.

As far as oilseeds are concerned, the production increased by about 5.4 times in 2013-14 over 1950-51 due to scientific and technological innovations along with input supply and policy interventions. Since, the domestic production of pulses and oilseeds is inadequate to meet the domestic demand; therefore, India depends on imports for bulk of the domestic demand for pulses and edible oil.

### **Challenges of Indian agriculture**

Agriculture sector in India has been confronted with numerous challenges like declining average size of land holding as about 85% farmers are small and marginal; 60% rainfed cultivation influenced by vagaries of monsoon; shrinking and degradation of natural resources; yield plateau in most of the crops; multi-nutrient deficiency; poor total factor productivity; regional imbalances in agricultural productivity; rising input costs; stagnating/declining profitability; increased risks

in the face of changing climate; poor resourcefulness of majority of farmers; globalization of trade and commerce; vulnerable markets; weakened technology transfer system and about 5-25% food losses in the entire supply-chain besides slower growth in the agriculture sector causing concerns for the future food and nutritional security of the country. Moreover, the demand for food and processed commodities is increasing due to growing population and rising per capita income.

### **Role of agronomy**

In recent times, Agronomy has come to encompass work in the areas of plant genetics, plant physiology, meteorology and soil science beside conventional scientific crop, soil and water management. It is the application of a combination of sciences like biology, chemistry, physics, economics, ecology, earth science, and genetics. In many American Universities, Department of Agronomy consists of Soil Scientists, Plant Breeders and Crop Production Scientists. This indicates that the science of Agronomy is more broad based than simply associated with scientific and practical aspects of crop production. Due to prevalence of various agricultural problems under the changing circumstances, we need to intensify our effort, not only to diversify crop production but also to reorient crop production system models to sustain agriculture production, soil health and productivity which in turn bring income security to the farming community and also to reduce the cost of production to compete in the international market. In this regard, Agronomists have a crucial role to play. Human Resource Development in Agronomy in the light of changing scenario of Indian agriculture would go a long way in meeting the challenges like:

- Attaining food grains demand of 398.6 million tonnes in 2035 requiring to produce additional 6 to 7 million tonnes/year
- Managing climate change/variability for food production systems for food security as about 80% of country's land mass is highly vulnerable to drought, floods and cyclones.
- Making small holdings economically viable as operational holdings increased to 121 million and the average size of the holdings expected to be mere 0.68 hectare in 2020 and as low as 0.32 hectare in 2030.
- Restricting or reversing land and water degradation—a key constraint in augmenting agricultural production. About 120.72 million hectares suffer from soil erosion and 8.4 million hectares have soil salinity/water logging problem
- Improving soil quality as it is poor with multiple nutrient deficiencies and low carbon content.
- Improving total factor productivity
- Improving critical water table and effective use of poor quality water
- Developing Integrated Farming System models for

varied agro-ecological regions and resourcefulness of farmers to achieve sustainable production of agricultural produce with enhanced net returns.

- Achieving effective farm mechanization particularly for small and marginal farmers
- Improving cost-effectiveness of production and farm profitability
- Preventing post-harvest losses

In order to address the present and future challenges, agronomy must enable development of technology to exploit the following aspects for attaining the desired productivity and sustainability to break the unwanted alliance of hunger, poverty, and environmental degradation:

- i. Achieving and retaining the yield gains, bridging yield gaps, and enhancing productivity levels, including value addition, processing and prevention of post-harvest losses.
- ii. Enhancing focus on increasing convergence across Bio-, Nano- and Info- technologies along with robotics and atomization.
- iii. Effective exploitation of immense potential and possibilities in hydroponics, aquaponics and vertical farming.
- iv. Practising precision agronomy through combination of systems-research tools relating to information technology, geographic information systems (GIS), global positioning systems (GPS), remote sensing; and climate smart resource management technologies for improving efficiency and competitiveness. Smart sensors and new delivery systems i.e. variable applicators will help in site specific nutrient, water, weed and pest management.
- v. Efficient management of natural resources including land, water and biodiversity with conservation and sustained, efficient, and equitable use through an integrated and participatory approach.
- vi. Refinement of cost effective technologies, diversification and proper management of resource base and inputs to achieve food, nutrition, health, environment and livelihood securities.
- vii. Mechanization of farm operations through energy-efficient and environment-friendly devices to compensate the growing shortage of farm labour.
- viii. Addressing environmental and climate-change concerns and minimizing adverse impacts of natural disasters based on decision-support systems and technology packages along with effective environmental monitoring and preparedness.
- ix. Effective trade management must ensure linking farmers to markets and strengthening value chain.

### **Agronomy education**

Though, the history of agronomy education in India dates back to as early as 1905 with the start of 06 Agricultural Col-

leges and organized courses in agriculture with diploma programme, but the formal agronomy education started with the degree programme in agriculture in early 1920s, further by late 1940s. This programme was offered in 17 Colleges of Agriculture which were under the umbrella of State Department of Agriculture and Animal Husbandry. Subsequently, the agricultural education was strengthened with the reorganization of Indian Council of Agricultural Research (ICAR) and creation of Department of Agricultural Research and Education (DARE) under the Ministry of Agriculture, GoI, and also with the establishments of State Agricultural Universities (SAUs) from 1960 onwards.

Presently, there are 73 Agricultural Universities (AU) including State Agricultural Universities (SAU) Central Agricultural Universities (CAU), Deemed Universities (DU) and Central University with Agricultural Faculty. Out of which, there are 56 AUs where agronomy education is imparted at UG and/or PG level. In addition to this, large no. of Private Colleges has been established to impart agricultural education at UG and/or PG level. The course curricula are almost common for these AUs with slight variations in number of credit hours load at UG and PG levels. At SKNAU, Jobner (Jaipur), presently 165 credits load is offered at UG programme, out of that in agronomy, being major discipline bears the load of 25 credits. The PG programme is comprised of 60 credits out of which 45 credits are allotted for course work. Similarly, Ph.D. degree programme having 70 credit loads include 40 credits for course work. The ICAR has introduced new curriculum by adding advanced and modern courses at UG and PG level. The existence of Agronomy education is questioned as the nutrient management, fertilizer management, soil management research and education are being dealt in Soil Science and Agricultural Chemistry; irrigation water management, education and research are included in the syllabus of Agricultural Engineering, Irrigation and Drainage Department; Crop Production is partly covered in Plant Physiology. Now, only weed science research and education besides management of crop, labour and land are left over in Agronomy.

Irony is that the Agronomy discipline known for integration of knowledge and practices of sustainable crop production, has been encroached and disintegrated by other related disciplines. In India, it is unfortunate scenario that the major discipline is being treated as subsidiary branch of Agriculture while, subsidiary and supportive branches have taken the major role and focus. Besides, agronomy education is facing several challenges like declining education standard, dismal performance of graduates in competitive platform (Sheelavantar, 2004). In reality, the country is looking to agronomy education and research to find practical, sustainable and cost effective solutions for the agricultural challenges before the country and the farmers.

The present situation demands a renewed thrust for enhanced quality and relevance of higher agricultural education to facilitate and undertake human capacity building for devel-

oping self-motivated professionals and entrepreneurs in view the changing scenario of globalization of education, emergence of new areas of specialization such as IPRs, other WTO-related areas, techno-legal specialties etc., and the cutting-edge technologies and alternative sources of energy, nanotechnology, etc. The graduates are required to possess professional capabilities to deal with the concerns of sustainable development (productive, profitable and stable) of agriculture in all its aspects. Modern developments like social media, open educational resources, knowledge access through internet video formats, and open access to electronic learning based courses in educational streams like engineering, agriculture have taken place during the last decade. In view of the present and futuristic scenario of agriculture in India, there is a need for reorientation of Agronomy education.

### **Approaches for meeting the challenges of agronomic education**

- Curriculum upgradation considering current and new emerging challenges
- Strengthening RAWE programme
- Capacity building and competency enhancement of faculty, technical staff and farmers and their families by including soft skill development through technical and vocational courses
- Produce graduates with entrepreneurship skills who are job providers and not job seekers
- More practical orientation of students
- Interdisciplinary approach in teaching courses
- Effective assessment and evaluation system
- Encourage research oriented focused agronomy education
- Promoting inter-institutional agronomy education for better exposure of students in understanding advance research
- Multidisciplinary student consortia for enhanced learning through i) Group discussion involving relevant disciplines like Soil Science, Crop Physiology, Agro-meteorology, Other related disciplines ii) Better understanding of issue based research
- Reorientation of crop production courses at PG level to avoid repetition with the UG curriculum

### **Evolving agronomy education**

There is need to evolve agronomy education in tune with fast changing national and international scenario. There is also need to bring innovations in the education system and exposing faculty, technical staff and students to new science and technological advancements like climate change/variability - adaptation and mitigation; location specific integrated farming systems; sustainable intensification; enhancing water productivity; modelling; application of nanotechnology and geospatial technologies (remote sensing, GIS and GPS); developing and promoting market oriented competitive agricul-

ture; Carbon sequestration and clean development mechanism, etc.

Today, there is a growing trend in private agronomic research, globally and even in India. It is becoming imperative to explore collaborative agronomy education and research programmes at national and international levels in public and private sectors and as well as in a Public- Private Partnership mode. It is the time that AUs to further strengthen excellence and futuristic agronomic education, particularly research by collaborating with the ICAR Institutes, ISRO, CSIR, DST etc. and also with CGIAR institutes like CIMMYT, IRRI, ICRISAT, ICRAF, ICARDA, etc. To meet the emerging demands, there is also need to innovatively develop academic and professional programme for agronomy discipline as given below:

- Collaborative Graduate Training programmes
- Professional degree programmes in Agronomy and Watershed Management
- Agricultural Polytechnic Diploma specialization in Agronomy and Watershed management
- Certified Crop Adviser (CCA)
- Certified Professional Agronomist (CPA)
- Updated Agronomy Education
- Distance Agronomy Education

### **Capacity building and competency enhancement**

Human Resource Development is critical for sustaining, diversifying and realizing the potentials of agriculture and addressing the challenges posed. Agricultural human resource development is a continuous process being undertaken through partnership and efforts of NARES. India will need rich human capital of highly qualified, motivated, and well trained agricultural scientists to meet the challenges of 21<sup>st</sup> Century. It is the responsibility of the NARES to provide such human resources. Besides, continuous Training and Capacity Building is a very important for any organization. Training and Capacity Building is a proactive and systematic learning event and its objective is to methodically impart required knowledge, skills and behavior to the employees to bridge their competency gaps, so that it results in an improvement of the overall performance and service delivery of the organization. Training and Capacity Building has been proved to be vital for an organization for the following reasons:

- In the ever-changing environment, Organizations need to update themselves continuously to continue to meet their ever-increasing customer demands. This continuous updating requires a lot of training.
- Technological revolution is waging a continuous war on the Organization's learning capacity. Those who adapt and welcome new technologies and achievements faster will emerge as market leaders and those who are slow in change will lag behind. Organizations can achieve this through continuous training.

People need to manage their work, interpersonal relation-

ships and when the need arises, manage others, organizations and institutions. For this, they need to build their competencies and capacities, and improve their knowledge, skills and attitude/behavior. To manage their work efficiently and effectively, they need to develop their technical abilities, human capacities as well as conceptual capabilities. Their education prepares them mostly with the technical work skills, however, it is on the job management training that lays a foundation of human and conceptual capacities. Continued technical and managerial development through periodic training is necessary to sharpen the saw from time to time to excel at the cutting edge of performance. The Training Policy of NARES should aim to actualize this philosophy and prepare a road map to work on this important area effectively.

A competency may be defined as 'an appropriate mix of knowledge, skills, behavior and personal characteristics required for carrying out a task effectively', which is required in an individual for effectively performing the functions of a post/job. Competencies may be broadly divided into those that are core skills which scientist and technical staff of agronomy would need to possess with different levels of proficiency for different functions or levels. Some of these competencies pertain to leadership, financial management, people management, information technology, project management and communication. The other set of competencies relate to the professional or specialized skills, which are relevant for specialized functions such as conducting research, teaching, extension, etc. in the areas of agronomy and natural resources management, social and basic sciences, etc.

It would be apt to switch over from qualification - based to competency-based framework in the NARES. As we always see that scientists or technical staff with same qualification tremendously vary in their performance and contributions. This so happens due to lot of variations exist in their competency to do the job despite of having similar qualifications. Therefore, the country demands to develop competency framework for enhanced efficiency and effectiveness of agronomy scientist and technical staff. A fundamental principle of the competency framework is that each job should be performed by a person who has the required competencies for that job. Competency approach is widely dependent on the principle of 'Right Person in the Right job.' Competency approach enables us to define the right knowledge, skills and behavior required for a job, prepare the person to hold the job, prepare the person to hold the job through training, place the person with right competencies in that job so that he/she can perform the job well. Further, their competencies need to be enhanced constantly to meet the ever-changing demands, and expectations of the citizens to achieve and sustain public satisfaction. Continuous enhancement of relevant competencies in the Government workforce is possible by imbibing Competency Approach into training functions of the Government.

Training has usually been based on the duties that are to be performed in a particular post. There has been no comprehensive

review or classification of all the posts in accordance with functions that are to be performed and the competencies required thereto. Thus, the issue of whether an individual has the necessary competencies to be able to perform the functions of a post has not been addressed. For moving to a competency-based approach, it would be necessary to classify the distinct types of posts (research, teaching, extension or a combination of two or three) and to indicate the competencies required for performing work in such posts. Once the competencies are laid down for each post and individual, an individual's development can be more objectively linked to the competencies needed for addressing current or future jobs and challenges in agriculture. Career progression and placement need to be based on matching the individual's competencies to those required for a post. The training plan of the NARES (ICAR and AUs) needs to address the gap between the existing and the required competencies and provide opportunities to the Agronomy scientists and technical staff to develop their competencies. This would require development of infrastructure at each Institution to do competency mapping studies of not only each position, but also for each individual agronomist and technical staff assisting. This would need creation of Institutionalized structure to do competency mapping on periodic basis. The HRD/training cell at the Institutions/ Colleges must take-up this responsibility.

### Benefits of competency approach

- Training needs can be holistically identified based on a systematic competency mapping.
- Training modules will be comprehensive as their design and development will address not only knowledge part but also the associated skill and behaviours.
- Learning out of these modules will be higher and holistic as the module will be designed based on the trainee's role and the competencies required thereof.
- Training evaluation will be realistic.
- Training can become more comprehensive as both the core competencies and specialized competencies are addressed in the training.

### Competency based training process

Application of competency-based approach to training involves following key processes:

- Mapping of employees' services and cadres
  - √ Identification of staff services in the Department
  - √ Mapping of different cadres in the staff services
- Mapping of employee roles and responsibilities
  - √ Identification of employee roles
  - √ Mapping of responsibilities and roles
- Mapping of competencies of the roles
  - √ Competency mapping workshops
  - √ Finalization of competencies of the roles
- Competency-based training needs analysis
- Competency-based module design and development

- Organisation of competency-based trainings
- Competency-based training evaluation

In order to boost teaching and learning in the emerging themes of science and technology, teachers need continuous encouragement and assistance to improve their competence in relevant subject areas. Two types of training of teachers, in India and abroad, to be considered (i) relatively of longer duration (3 to 6 months) in priority theme areas and (ii) continuing life-long learning in the form of refresher courses of shorter duration (20 to 30 days) in educational technology and the subject domain of a teacher's expertise. There shall be compulsory provision of Induction and Orientation Programmes for newly recruited faculty in NARES; Faculty training in specific areas; Faculty recognition and awards including Young Faculty awards; International Faculty visit for capacity building in NARES; Attracting Talent to NARES to help capacity building in new emerging areas; Establishment of more Centres of Excellence in competitive mode; Faculty Movement/Exchange and linkages with public and private R&D institutions; Collaborations with International Centres/Institutions for Faculty Development; Promoting Niche Areas of Excellence. Besides, there is need to promote Centres of Advanced Students/Advanced Faculty Training (CAS/CAFT); Summer/Winter Schools and short courses; Preparation of quality study/instructional material including e-resources in general for web-based teaching learning and fellowship programmes in Human Resources and Institutional Capacity Building, cutting-edge areas of science and technology, etc.

### CONCLUSION

Indian agriculture plays an important role in the economy of the country by providing employment to half of the Indian population and contributes to 8% global agricultural gross domestic product (GDP) to support 18% of world population on only 9% of world's arable land and 2.3% of geographical area. The agricultural sector contributes 13.9% to national GDP. Nearly one-fourth of the country's population lives below poverty line. India is facing serious challenges to achieve a target growth rate of 4% in agriculture sector to reduce poverty at a fast rate. The present situation demands a renewed thrust for enhanced quality and relevance of higher agricultural education so as to facilitate and undertake human capacity building for developing self-motivated professionals and entrepreneurs in view the changing scenario of globalization of education, emergence of new areas of specialization such

as IPRs, other WTO-related areas, techno-legal specialties etc., and the cutting-edge technologies and alternative sources of energy, nanotechnology, etc. It is the modern Agronomy which has the capacity to find practical solutions for most of the challenges the Indian agriculture is facing.

In the era of changing crop production demand, nutritional security, depleting resource base and climate vulnerability, there is need to reorient present agronomy education in India to enhance the competency level of students who can be groomed as Scientists, Teachers and Technical personnel having the capacity to develop new agronomy to generate cost effective and sustainable technologies to address the present and future challenges of agriculture/agronomy in the country. Continued technical and managerial development through periodic Training and Capacity Building is necessary to sharpen the saw from time to time to excel at the cutting edge of performance. It would be apt to switch over from qualification - based to competency-based framework in the NARES. The country demands to develop competency framework for enhanced efficiency and effectiveness of agronomy scientist and technical staff in terms of right knowledge, Skills and Behavior required for the assigned job.

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## New dimensions in Agronomic research for food security

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Food, *per se*, means carbohydrates, proteins, lipids, vitamins and minerals. But, it is a paradox in the scientific community that only cereals and pulses are considered for computing the statistics on food crops. Many oilseeds provide lipids (fat), which is an essential requirement under food, besides, oilseed crops contain large quantity of proteins (peanut and soybean) and even carbohydrates. Excluding them from food by ignoring protein/ carbohydrates in them wrongly accounts the actual consumption. I am of the strong opinion that food production of any country/ state should include cereals, pulses and oilseeds.

Solutions to food security of our vast country have always been complex, considering the fast increasing population on one side and challenges posed to increase agricultural production on the other. Agronomic research has addressed to the problems of increasing the crop production very effectively in earlier decades and pivotal in reaching the present food production to the level of 268 million tonnes, which was around 50 m. tons at the time of independence. The food production in India is expected to be 400 m. tons by 2050. At global level, the cereal production is expected to increase up to 3000 million tonnes from the present 2200 million tonnes (FAO, 2015). However, considering the complex issues of food security- including energy and nutritional security, and taking cognizance of challenges of climate change, agronomic research needs a kind of metamorphosis to include new dimensions. In the last decade, many new fields have been added to agronomic research to strengthen the cause of food production. Many multidisciplinary issues are integrated with food production and it is necessary to take stock of new dimensions with due importance to fundamental issues of resource management and sustainability in agriculture. Agronomic research is strengthened by new inventions in various fields like biotechnology, satellite technology, nanotechnology, automation, organic farming, climate resilient studies as well as computer technology. Each one of them have added a new dimension for agronomic research and posed new challenges on the field to achieve quantitative improvements in food production. These inventions, themselves, may not achieve an increase in food production but provide necessary impetus to the agronomic research for up scaling under field conditions.

But, the fundamental roots of agronomic research lie in advances in crop physiology. Hence, all new dimensions need to consider the latest inventions in the field of crop physiology and blend them with new paradigms and to evolve a utilizable technology for improvements in food production. These dimensions may also include quality improvement of food, as food security need to include nutritional security also. At this crucial moment, it is absolutely essential to browse the available new dimensions, which would change the directions of future agronomic research.

### Source- sink relationship

One of the conventional barriers of increasing the crop production has been imbalance in source to sink relations of different crops. The physiological potential of crop production based on photosynthetic efficiency of many crops is not even partially harvested due to sink limitations. For example, it is estimated based on photosynthetic carbon fixation, a production of 383 t/ha of potato could be possible. But, to translate this into reality, agronomic measures need to be standardised. Similarly, vast sink capacities have not matched with limited source capacities. This has been observed in many crops. These observations made about two decades back in many crops have been addressed with new dimensions. Many genetic, physiological and environmental factors responsible for sink limitations in sunflower were identified, which led to identifying the yield limitations of sunflower, despite having good source characters like higher N uptake better light interception, high specific leaf nitrogen than corn (Massignam *et al.*, 2009), which has higher sink capacity. Genetic factors like protandrous nature and self-incompatibility represent sink limitations in sunflower, which may be accentuated by abiotic stress like moisture/nutrient limitations. Source- sink relationships need to get more focussed research in many crops like cowpea, pigeon pea, gram, rice, sorghum, cotton, peanut etc.

### Photosynthetic pathway

An important new dimension directing the new age agronomic research is conversion of C<sub>3</sub> crops into C<sub>4</sub> crops, particularly rice and wheat. It is well understood physiological



phenomenon that  $C_4$  crop like maize adopts Hatch- Slack pathway besides Calvin's cycle to produce four carbon molecules (maleate/aspartate) and function efficiently even at low  $CO_2$  concentration ( $<10$  ppm) (Fig 1) while crops like rice and wheat adopt Calvin's cycle to produce three carbon molecules (PGA) and function at higher concentration of  $CO_2$ . As a result,  $C_3$  crop loses more energy and photosynthates by way of photorespiration, but  $C_4$  crop can achieve more positive balance in catabolic and anabolic reactions (photosynthesis and respiration). Hence,  $C_4$  crop can perform better with higher biomass and yield in response to higher concentration of  $CO_2$  (low compensation point). In addition,  $C_4$  plants have an advantage of Kranz' leaf anatomy (shorter gaps between veins, with higher vein density). This traditional finding has been transformed into a new dimension research about the possibility of converting  $C_3$  plants into  $C_4$  plants (Dionara, 2008) at IIRI, based on findings of Sage *et al* (2012), who developed strategies for a directed evolution of new species in rice by induced evolutionary trends.

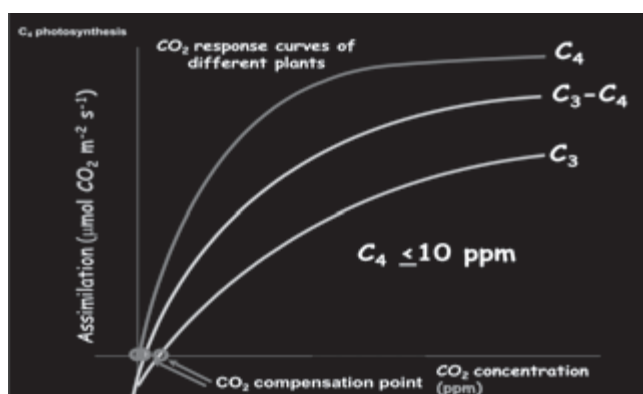


Fig 1.  $CO_2$  compensation points in  $C_3$  and  $C_4$  plants

Sage *et al.* (2012) were inspired by earlier observations on evolution of crops from grasses by Kellogg (2001). They identified that  $C_4$  characters found in maize represent an evolutionary trend from  $C_3$  grass like *Aegilops*. The genera *Pennisetum*, *elusine*, *Oryza* and *Triticum* fall in consecutively lower levels of evolution. *Sorghum*, exhibiting higher vein density is nearer to corn than *Triticum*.

Anatomical changes to achieve Kranz' leaf anatomy of higher vein density could be achieved through genetic modifications- which leads to biochemical changes (Fig 2). Many wild species of rice with higher vein density area identified with large number of accessions, justifying the evolutionary trends in achieving higher vein densities. Many researchers have observed that many wild species of *Oryza* had higher vein density up to 18/mm in *O. brachyntha* much nearer to  $C_3$ - $C_4$  intermediate plant like *Pennisetum*. The challenges before Agronomists would be to devise new research programmes to deal with  $C_4$  rice and  $C_4$  wheat crops, which

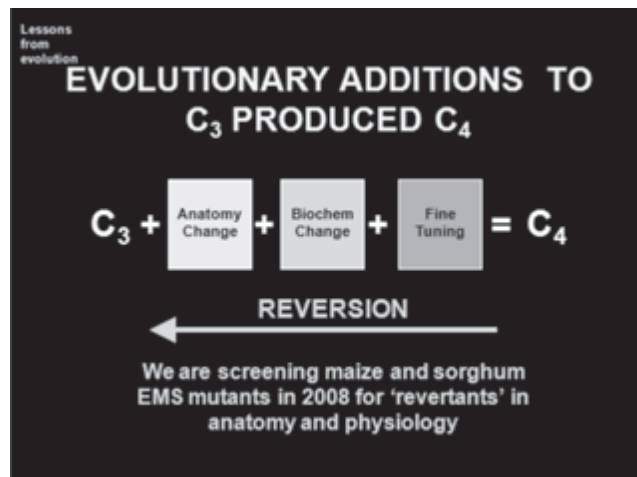


Fig 2. Evolution of  $C_4$  plants from  $C_3$  plants

are traditional  $C_3$  crops. New photosynthetic efficiency of rice crop would be boon to the world, under new set of management conditions. It is for new age agronomists to evolve such a new set of management practices for rice and wheat, which can produce photosynthates even under higher  $CO_2$  concentrations. This new efficiency could be harnessed, only if new varieties are developed with characters of ideal ideotype.

### Ideotype concept

The new age rice crop may require specific ideotype, to be developed and may need different set of nutrient/ water management, besides strategies for improved carbon management techniques. The new ideotype for high yielding rice may include characters like root survival during ripening, improved nutrient mobilisation during ripening, increased spikelet viability and higher lodging resistance (Fig. 3). Such redesigned rice crop may yield more than double the productivity by present varieties.

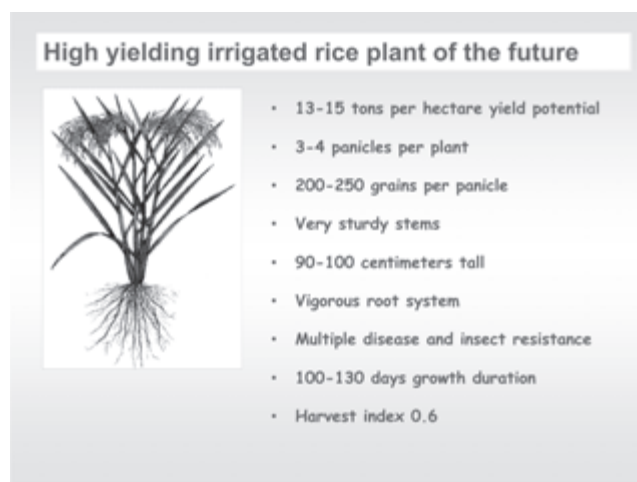


Fig 3. Ideotype of high yielding rice

## Nano technology

Positive response by new high yielding crops will certainly need higher nutrient uptake, which necessitates better nutrient use efficiency than application of higher level of nutrients. Increasing the dosages with poor nutrient efficiency not only results in wastage but in environmental hazards. The new dimension in improving nutrient use efficiency is the use of nano particles. Nano technology has spread not only to nano nutrients, but nano pesticides. Nano technology has been defined as “The design, characterization, production and application of structures, devices, systems by controlling shape and size at nanometer scale ( $10^{-9}$ nm). Kuzma (2005) have rightly recognized that nano technology has potential to revolutionize agriculture and food systems, besides saving inputs. Nano technology is essentially 56 year old technology used in various fields. In agriculture, the use of nano particles and nano techniques to improve the traditional approaches / techniques is of recent origin. In India, the use of nano techniques for agricultural applications is still in infancy, although large number of agricultural fields have been recognised for using these techniques. But, nano technology has already been used widely in the fields like pharmaceuticals, electronics, metallurgy, health care and water purification systems in India. Some agricultural applications of nano technology in agriculture include nano fertilizers for improved nutrient use efficiency, nanocides (pesticides encapsulated in nano particles), different nano particles for soil conservation, soil quality assessment, nano particles for water management, nano magnets for purifications of soil and water, nano based sensors for precise management of resources under precision farming, nano technologies for gene transfer in breeding new varieties. In the last 8-10 years, some nano pesticides and nano fertilizers have also appeared in the market. All these technologies need agronomic interference to upscale them to large area in the near future. Preliminary studies at GKVK, Bangalore using nano boron and nano zinc have indicated the advantages of better root growth and stem elongation.

## Climate change

Climate change is threatening agriculture in many respects. Shift in the season, delay/ preponement in onset and withdrawal of monsoon, increasing flood/drought incidences in most parts of country, change in temperatures- causing change in pest cycles, heavy rainfall in unexpected locations etc have posed greater challenges to crop production. Nationwide efforts are continuing in crop-weather modelling, assisted by automatic real time weather forecasting facilities in most states. National Initiative on climate resilient agriculture (NICRA) has introduced large scale adoption of climate predictive models of crop production in cluster of villages to ensure the drought mitigation. However, fine tuning of these efforts is necessary by further screening crops/ varieties to suit specific climatic model in each agro climatic zone. Imposition

of crop choice or a variety of a crop in such weather predicted crop planning is one of the greatest challenges in Indian agriculture. Although many encouraging results in such ORP type studies have been recorded, up scaling them to larger area is a herculean task. Specific crop choice, specific cultural operation - based on weather forecasting has certainly recorded encouraging results. The efforts of IIHR and UAS Bangalore in this regard are worth emulating.

## Precision farming

Agronomists have another emerging challenge in the form of precision farming- a worldwide phenomenon for efficient and precise/ directed use of inputs not only to save the inputs but to protect environment from hazards of pollution and at the same time enhance the production. The essence of precision farming lies in identifying and documenting ‘within field’ variations in soil characters, crop stand and pest/ disease incidences and suitably remedying them adopting ‘variable rate technologies (VRT)’ as against considering the entire field as uniform and adopting uniform rate technologies (URT). The use of satellite assisted sensor data is an integral part of precision farming, with the availability of high precision sensors to sense minute details even at 1M X 1M space. Precision farming deals with using VRTs in field conditions by specialised machineries to achieve variable application based on the ‘within field’ variations. Although India has been leader in launching satellites and offering satellite launching services to other countries, satellites are still not used intensively for direct agricultural operations, although extensive meteorological observations through satellite have helped agriculture. Even ‘cartosat’ applications are used for water shed programmes- but they are still short of precision farming. Future agronomists have a great role to play in developing Indian version of precision farming metamorphosed from Preire’s original model of precision farming, because Indian tenurial system, combined with laws pertaining to inheritance of landed property has subdivided the lands into such small pieces, where precision farming in its original sense is difficult to adopt.

## Biofortification/ biopriming

One more new dimension of agronomic research is bio fortification and other approaches to achieve nutritional security. Increasing the food production alone without regard to nutritional security cannot achieve fundamental objective of food security to provide better health to human beings. Vitamin/mineral deficiency and protein deficiency are two principal sectors of nutritional insecurity. Vitamin/iron deficiency has been addressed globally by bio-fortification strategy- transgenic introduction of gene responsible for production of vitamin and concentrating iron density by conventional breeding. But, genetic biofortification has been successful for vitamin A and iron, particularly in case of golden rice. Other vitamins and minerals also need to be tackled in future.

Protein deficiency is a major nutritional disorder of major proportion widespread in Indian population, with lower per capita income. Future agronomic research will have to concentrate on strategies to tackle protein malnutrition by different steps like strengthening pulse production, besides improving the protein status of existing pulses- by more rational nitrogen management approaches.

### Bio fertilizers

Effectiveness of bio fertilizers in pulses is one of the challenge not fully addressed, after decades of introduction of bio fertilizers. Recent introduction of liquid bio fertilizers as well as number of other constraints for effectiveness of bio fertilizers need new direction research in future preferably in the 'consortium' approach. Liquid inoculants with a distinct advantage of longer shelf life (12-24 months) (Brahma Prakash and Sahu, 2012), reduced dosages ( due to their high enzymatic activity) containing consortia of micro organisms can promote cell to improve the vigour of crops besides imparting better resistance against pathogens. The consortium of bio fertilizers in liquid form pose new set of challenges to agronomist in the form of method of application, crop suitability, time of application, while consortium can take care of multiple nutrients in a single application. Effectiveness of liquid bio fertilizers with drip irrigation needs a special consideration. Use of efficient inoculants consortia is considered as an important strategy for sustainable management of soil fertility by reducing the reliance on chemical fertilizers ( Hungria *et al.*, 2013). Use of Pink Pigmented Facultative Methylophilic bacteria (PPFM) for crop growth promotion can improve the growth and yield of crops ( Sundaram *et al.*, 2002). Development of dual purpose liquid formulations for crop protection and production is tried in tomato and radish (Agrawal *et al.*, 2014). Agronomic research has to be focussed not only on development of several combinations of microbial cultures for improving the crop productivity and crop protection. These consortia could be evaluated in different agro ecological situations across different season/ years to test their efficacy on sustainable basis.

### Management of greenhouse gases

Methane emission from rice fields is estimated to be 60-

150 Tg/ yr , accounting to 15-20 per cent of world's total anthropogenic methane emission. Total emission of methane from East, south east and south Asia is estimated at 25.1 Tg/ yr, of which 7.67 Tg from China and 5.88 Tg from India . Among the mitigation options available, adoption of aerobic rice (Jayadeva and Prabhakara Setty, 2011), intermittent irrigation Wei *et al.* (2010), reduced tillage ( David *et al.*, 2009) and use of sulphate containing fertilizers are note worthy. New dimensions are added to agronomic research in each of these options (Table 1).

### Water management

In general, poor water use efficiency due to various technical and management factors is of great concern both in rainfed and irrigated situations. While major policies of water management should be more stringently implemented to improve the water use efficiency, new dimensions in the field of water management may need to use modern innovations in the field of electronics (high precision sensors), space technology ( satellite based underground water status) or computers based automation (software for automatic control of irrigation systems or even drone based technologies (for effective surveillance of irrigation systems).

The new challenges in weed management include herbicide resistance in weeds, persisting problems posed by parasitic weeds in many crops (*Orobanchaceae*, *Convolvulaceae*, *Santalaceae*, *Lauraceae* and *Loranthaceae* families), environmental pollution caused by continued use of herbicideps. Continued research may have to be taken up through integrated weed management system since weeds cause greater yield reductions than insect pests and diseases, combined together.

### CONCLUSION

Land and water are the natural resources, which have to be used judiciously since they are finite and inelastic. The population is ever increasing and to meet its food needs, new dimensions in agronomic research have to be focussed on several novel approaches such as source- sink relation, conversion of photosynthetic pathway from C<sub>3</sub> to C<sub>4</sub>, nano technology, input use efficiency and ideotype concept. The paper deals extensively on new dimensions ion agronomic research to attain food security

**Table 1.** Effects of fertilization and irrigation on emissions of CH<sub>4</sub> and N<sub>2</sub>O

Treatment	Average CH <sub>4</sub> Flux (mg/m <sup>2</sup> .h)	Emission amount (g/m <sup>2</sup> )	Average N <sub>2</sub> O Flux (mg/m <sup>2</sup> .h)	Emission amount (g/m <sup>2</sup> )	Yield (q/ha)
Flooded with slow-releasing urea	0.96c	2.89c	7.58a	0.02a	63.76a
Flooded with Urea	0.83b	2.48b	18.51b	0.06b	63.33b
Intermittent irrigation with urea	0.56a	1.68a	25.92c	0.08c	63.20c

Wei *et al.* (2010)

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## Challenges and opportunities in weed science research, education and extension

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Weeds are ubiquitous and are a problem virtually in all ecosystems including agriculture, plantation crops, grasslands, forestry, sanctuaries, water bodies, wastelands, public amenity areas, etc. Weeds therefore impact everyone including non-farmers and city dwellers. The loss caused by weeds in agriculture is enormous. They contribute as much as 37% of the total loss caused by all the agricultural pests. At a conservation estimate, 10-15 % of the crop production is lost every year due to weeds amounting to well over Rs 100,000 crores.

### Current status

- The loss caused by weeds goes unnoticed as the effect is mostly unseen. Because of this, the farmer develops a fatalistic attitude towards weeds and gives them the last priority when it comes to their management.
- Manual and mechanical removal is the most predominant method of weed management in India, although they are ineffective, particularly under adverse soil and weather conditions.
- Manual weeding is highly labour-intensive, involves a lot of drudgery and is unfortunately mostly done by women.
- Currently the farming is being predominantly practiced by old men and women with youth simply taking no interest. Perhaps modernization of agriculture involving use of chemicals, machinery and other modern technologies may halt his trend.
- Increasingly more and more farmers are opting for herbicides mainly due to increased labour cost and their unavailability. Many pro-poor welfare schemes such as MNREGA have aggravated the situation.
- Globally herbicides are the leading group of pesticides with 44% of the total consumption compared to mere 18% in India. Its share is expected to rise faster in the years to come. In fact non-selective herbicides are now being used on the highways, railways, municipalities, and also on the borders for clearance of unwanted vegetation.
- Herbicide application is more common in crops like wheat (44%), rice (31%), plantation crops like tea (10%) and soybean (4%). Their use in other crops including pulses, oilseeds, vegetables, spice is on the rise.
- Unlike other pesticides, herbicides by and large have lower toxicity (higher LD50 values) and reported to leave no or very low levels of residues in the soil, crop produce and ground water.
- There are however, concerns of residual effect of herbicides on susceptible intercrops or succeeding crops and development of herbicide resistance in weeds.
- It is well documented that integrated weed management approach involving different methods- specifically the cultural methods is more sustainable. However, it is not being adopted by majority of the farmers for a variety of reasons.
- Weed management has traditionally been a part of agronomy. In the recent past, however, weed science has grown into a discipline of its own, drawing knowledge from varied disciplines such as botany, entomology, pathology, microbiology, soil science, biotechnology, engineering etc. which is needed to address the problem of weeds in a holistic way.

### Research priorities

- Much of the research done in the country is on evaluation of herbicides and optimising the dose and time of application in individual crops. More research on herbicide application, herbicide mixtures, and integration with other methods of weed control are needed based on a cropping systems approach. Such investigations would help in increasing the weed control efficacy, reducing herbicide load in the environment and development of herbicide resistance in weeds.
- Research efforts must be focused on the basic study on ecology and biology of weeds. In-depth studies should be carried out on biological attributes that are closely associated with successful establishment, survival and multiplication of weeds under different methods of weed management.
- Correct application of herbicides using the right spray equipment and following the right technique is critical for safe and effective weed control. However, this is often not followed strictly. This is in direct contrast to the advances made in the field of herbicide application in developed countries. Sensor-based site-specific application, use of robots and unmanned aircrafts are

some of the recent technologies to name a few.

- Research on integrated weed management (IWM) must broaden beyond herbicide-centred weed management. A recent analysis of the research papers published in IJWS during 1992 to 2009 suggested that over 90 % of the articles were herbicide-centric.
- To overcome the lack of effective herbicides and herbicide resistance, farmers will have to adopt IWM practices. In IWM, direct weed control methods other than chemical control should be used wherever feasible. Besides this, preventive and cultural methods are an integral part of the overall weed management strategy and herbicides can also be integrated judiciously with IWM.
- Most research studies are done with the sole objective of weed control without realizing that other resources including soil, water, nutrients (fertilizer), energy (tillage) etc. influence weed control efficiency and vice-versa. Therefore, the studies should focus on resource-use efficiency as a whole involving interaction of weed, water, nutrients, tillage etc.
- Management of weeds is a major issue in conservation agriculture system where, weed infestation is likely to be more particularly the perennials. Presence of crop residues on soil surface precludes mechanical weeding and interferes with the activity of herbicides applied as pre-emergence. Long-term studies on weed seedbank and innovative ways of herbicide application will be helpful.
- There is hardly any work on the application of modelling in weed management. Successful modeling provides a clear picture about weed seedbank dynamics, emergence patterns, replacement trends, competitiveness, canopy architecture, and possible yield losses. Influence of different variables such as soil conditions, environmental factors, crop husbandry practices, and mechanization on weed emergence, distribution, and competition patterns is identified and measured with the help of decision-making tools and models. Thus, modeling approach is very beneficial for the implementation of precision weed management.
- Host resistance is an important component in integrated pest management. In weed management, however, to develop a crops /cultivars resistant to weeds is almost impossible to accomplish. Limited research has shown that few crops/cultivars exhibit inhibitory effect on some weeds through allelopathic effect. Despite considerable research in allelopathy not much headway has been made. However, it is an exciting area. What is needed is focused in-depth research and not merry-go-round type research in this field.
- Biological control of weeds is the deliberate use of natural enemies to suppress growth or reduce the populations of weed species. Despite its early gain, this field has not gained as much success as it should be and is still struggling regarding inventions or launching products. Currently, eight bioherbicides have been registered and are being commercialized in developed countries on a limited scale. Considering its unique advantages, the research must be continued, but we need to prioritise the work and focus on promising candidates.
- Biological control of aquatic weed *Salvinia* by use of introduced biocontrol agent has been a good success in Kerala. But biological control of water hyacinth and *Parthenium* is not that consistent. It is time we think of better candidates. *Parthenium* has been under satisfactory control in Australia, mainly due to the strict domestic quarantine and use of as many as five biocontrol agents, each with a different mode/mechanism of action. Other invasive weeds such as *Chromolaena odorata*, *Mikania micrantha* and *Ageratum hausotnium* need immediate attention.
- Climate is changing fast and this will impact crop-weed competition and the currently followed weed management practices. Research is needed to study the effect of increasing CO<sub>2</sub>, temperature and other variables in an integrated manner on crop-weed associations, herbicide efficacy, biocontrol agents and soil micro flora.
- With increasing herbicide use by the Indian farmers, there is required to be a strong back-up support in terms of environmental impact of herbicides including food chain and non-targeted beneficial organisms. Herbicide residue research needs to be strengthened to allay fears in the minds of anti-chemicals campaigners.
- Conventionally agronomic research in India is done in small plots (15-25 m<sup>2</sup>) with mostly manual / hand-based operations. These findings are often at variance with the actual farming situations. Therefore, field-oriented on-station agronomic research in general and weed science research in particular must be carried out in large plots (>100 m<sup>2</sup>) employing use of suitable farm machinery and other resources as available at the farmers level.
- Cropping systems research in India is mostly done in relation to tillage, nutrient or water management but rarely with respect to weed management. Long-term effect of weed management practices including herbicides on weed dynamics, herbicide residues, soil health etc. is needed following cropping systems approach.
- Integrated pest management (IPM) modules largely emphasize on insect and disease control, and virtually ignore weeds which otherwise cause more harm than other pests. It is essential that weed management should form an integral component of the overall IPM strategy in crop production.
- Invasive alien weeds are a big threat to the country as they impact our agriculture and environment negatively. We have an effective quarantine system in place in accordance with guidelines of the International Plant Protection Convention (IPPC) of FAO and the Agreement

on the application of Sanitary and Phyto sanitary measures (the SPS Agreement). Under the WTO regime, an alien weed has to be subjected to a systematic Pest Risk Analysis (PRA) before declaring it as a quarantine pest. Only then the entry of such a weed could be stopped. This requires collection of large amount of data on biology and ecology of potential quarantine weeds. Such database is also needed for all domestic weeds in all crops and cropping systems and under all agro climatic conditions to facilitate exports. This calls for DPPQS working in close partnership with ICAR-DWR and strong networking with all concerned agencies around the world.

- A national repository containing weed herbarium, weed seed collection, high resolution pictures of weeds and weed seeds is required to be created and strengthened with competent human resource for speedy identification of weed species in question.
- Some weed species have assumed serious proportions in our country, threatening biodiversity, and food and environmental security. There is a need for more effective coordinated research efforts to contain their menace and ensure livelihood security.
- Genetically modified crops (also referred to as biotech crops), since their first introduction in 1995, are currently being cultivated on over 180 mha in 31 countries—thus making it the fastest adopted crop technology in the history of modern agriculture. Herbicide tolerant crops contribute well over 80% of the total area. In the US, 94% of soybean, 89% of cotton, and 89% of corn area was planted with glyphosate-resistant (GR) cultivars in 2015. Globally, 82% of soybean, 68% of cotton, and 30% of corn area was planted with GR cultivars in 2014.
- HTCs offer more efficient, convenient and cost effective management of weeds, eliminate the use of cocktail of herbicides often more toxic and applied sequentially, offer environmental benefits by promoting conservation agriculture – based technologies involving zero tillage and residue recycling.
- The research done in India has also proved the merits of HTC technology. While the technology is awaiting the approval of the Government for its commercialization, the issue has been debated and discussed threadbare in several scientific platforms and future course of action has been drawn up. Meanwhile, more research is needed to address the issues related to environmental safety of the technology.

### Education and training

- In the Fifth Dean's committee report under core courses for undergraduate programme, weed management has been clubbed with agronomy. However, there is a separate course on weed management under electives. It is

suggested that there should be separate course on weed management under core courses too.

- Higher education in weed science must be given greater emphasis in view of the emerging challenges posed by climate change, globalization and environmental hazards. Realizing that weeds cause more harm than other pests, there is a need to consider weed science as distinct discipline drawing expertise from all related sciences on the lines of biotechnology and environmental science.
- It may sound preposterous to suggest that every teacher/scientist who would be engaged in weed science should undergo a minimum of 30-day training at ICAR-DWR. But this will go a long way in improving the quality of research and teaching in weed science as this will give them a holistic view of the problem of weeds and their management.

### Extension

- The herbicides are different as compared to other pesticides, and the extension personnel need to know this so that farmers use these effectively and safely. There should be regular capacity building programmes for the extension staff. As face-to-face trainings are difficult to meet the demand, developing on-line courses and making them compulsory is recommended.
- Despite recommendations by the authorised agencies, it is the retailer/pesticide dealer who plays a critical role in prescribing farmers the 'right' herbicide often resulting in misuse and crop failures. The government has woken up to the problem and has recently taken a decision that only agricultural graduates would be issued licenses for the sale of pesticides.
- Weed infestations are highly variable and location-specific, and also keep changing with cultivation practices and the environment. On-station research in weed science must be effectively complemented with on-farm research. There is required to be a greater emphasis on problem-solving output-oriented weed research rather than routine herbicide screening for bioefficacy.
- On-farm research in weed science is generally lacking, and therefore, it must form an integral part of the overall strategy of weed management in collaboration with KVKs, state agriculture department and other stakeholders. Promising solutions to the local problems need to be demonstrated in the farmers' fields to convince them of the benefits of new technology. This is now being laid greater emphasis by the ICAR under various programmes like MGMG, Farmers FIRST, ARYA etc.
- A strong public awareness programme on alien invasive weeds is urgently required to prevent their further spread and to prevent introduction and establishment of new weeds in both cropped and non-cropped areas.

