Training Manual on

Conservation Agriculture for Climate Resilient Farming & Doubling Farmers' Income




Sponsored by

Education Division
Indian Council of Agricultural Research
New Delhi

(14-23 October, 2019)

भाकृअनुप
ICAR

ICAR Research Complex for Eastern Region

ICAR Parisar, P.O. : Bihar Veterinary College
Patna-800 014 (Bihar)

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JS Mishra, Rakesh Kumar, Kirti Saurabh and BP Bhatt

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Abstract

This book is a compilation of lectures delivered by the experts during the short course on conservation agriculture. The book describes various elements of conservation agriculture, highlights the impact of CA as a climate resilient farming in terms of agricultural production, environment and ecosystem services, livelihoods and other socio-economic factors. All the articles in this book convey the views of the respective authors and they are solely responsible for any advanced statements and opinions.

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Constant support extended by all the staff of this institute for the successful organization of the course is gratefully acknowledged. The support and contribution of the scientists, experts, speakers, ICAR-RCER officials and all who contributed in successful conduct of this programme are sincerely acknowledged. The cooperation of the participating organizations for deputation of their officials to participate in this training is also sincerely acknowledged. Special thanks are due to the Indian Council of Agricultural Research, New Delhi for sponsoring this training programme.

Preface

Before the inception of the Green Revolution in the mid-sixties, the country was not self-sufficient in food grain production, particularly cereals. But now in spite of tremendous growth in population, the country is able to feed its people and even we are exporting certain commodities. On the other hand, due to multiple and intensive cropping, changing climatic conditions as well as excessive and indiscriminate use of fertilizers and pesticides, soil health is deteriorating particularly in higher productive zone of India like Indo-Gangetic plains. The conventional agricultural system (excessive tillage, monocropping/cereal-cereal cropping, removal/burning of crop residues, etc.) has resulted in declining the factor productivity due to soil organic matter depletion, soil structural degradation, soil erosion, reduced water infiltration, surface crusting, soil compaction, etc. This situation is very alarming and warrants addition of organic matters in soil to improve soil health by restricting the use of chemical fertilizers and pesticides.

Planned adaptation is essential to increase the resilience of agricultural production to climate change. Several improved agricultural practices evolved over time for diverse agro-ecological regions in India have potential to enhance climate change adaptation, if deployed prudently. Conservation agriculture (CA) is being promoted as a solution to increase agricultural productivity and food security while at the same time preventing erosion and maximizing the ecological functions of the soil. CA is a package of technologies that includes minimum tillage, mulching and crop rotation. CA has potential to reduce labour needs for land preparation and improve soil fertility while also reducing water stress in crops. CA in the Eastern region is still in the initial phase. The major CA based technology being adopted is zero-till wheat in the rice-wheat system. In India, efforts to develop and spread conservation agriculture have been made through the combined efforts of several State Agricultural Universities, ICAR institutes and the Rice-Wheat Consortium for the Indo-Gangetic Plains. Spread of these technologies is taking place in the irrigated regions of the Indo-Gangetic plains where the rice-wheat cropping system dominates. The focus of developing and promoting conservation technologies has been on zero-till seed-cum fertilizer drill for sowing of wheat in rice-wheat system. Other interventions include raised-bed planting systems, laser equipment aided land leveling, residue management practices, alternatives to the rice-wheat system etc. Attempts have been made to integrate desirable features of CA research into the mainstream agricultural research so that technologies developed are relevant, client-oriented and location specific.

The training programme was organized by the ICAR Research Complex for Eastern Region, Patna to impart the knowledge about “Conservation Agriculture for

Climate Resilient Farming & Doubling Farmers' Income" to increase the livelihood of the resource poor farmers with limited land resources during 14-23 October 2019. This publication is the outcome of compilation of lecture notes of above training course. This book contains 32 chapters addressing the thematic areas of conservation agriculture strategies for adaptation and mitigation of adverse effect of climate change, resource conservation technologies practiced in eastern Indo- Gangetic plains (EIGP), constraints, issues and opportunities in CA in EIGP, role of CA in management of rice-fallows, prospects of organic farming for adaptation and mitigation of climate change, crop diversification, carbon sequestration, integrated farming system approach for climate resilient agriculture, impact of CA on soil properties, crop residue management, nutrient mineralization, farm mechanization and energy management, enhancing water productivity, strategies for developing climate smart rice/wheat genotypes, insect-pest, disease and weed management strategies under CA in changing climate, socio-economic impact and farmers' perception for CA, etc.

The publication of the Training Manual was made possible with the support and cooperation from all the contributors. Their deep understanding of the subject of conservation agriculture and critical analysis made the book a rich source of information on the various aspects of the subject. We appreciate their contributions. The assistance rendered by the staffs of ICAR-RCER, Patna in facilitating the course is heartily appreciated. Sincere thanks are also due to Administration and Finance & Accounts Sections of this Institute for providing timely support during the course. We firmly believe that this publication will be highly useful to the researchers, policy makers, students and other stakeholders.

(J S Mishra)
Course Director

Contents

Overview of Conservation Agriculture in Eastern Indo-Gangetic Plains

B.P. Bhatt and J.S. Mishra

ICAR-Research Complex for Eastern Region, Patna (Bihar)

Sustainable food production is at the stake due to over exploitation of the natural resources in many parts of India. Unsustainable use of land in tillage-based conventional agricultural system has resulted in declining the factor productivity due soil organic matter depletion, soil structural degradation, soil erosion, reduced water infiltration, surface crusting, soil compaction, etc. Most natural resources, i.e., land and water are shrinking at an alarming rate and prone to ever increasing diversion to non-agricultural use. Hence, a long term profitable and sustainable production of food, feed and fibre for meeting the human and livestock requirements can be made possible through conservation and judicious use of natural resources.

Conservation Agriculture (CA) as defined by FAO, is an approach to manage agro-ecosystems for improved and sustained productivity, increased profits and food security while preserving and enhancing the resource base and the environment. CA is based on the three linked principles of minimum mechanical disturbance of the soil, permanent organic cover of the soil surface, and crop diversification or association of crops, along with other complementary good agricultural practices of crop production (FAO 2014a). CA provides a number of advantages like sustainability, enhanced biodiversity, labour saving, improved soil health and environment, climate resilience, increased crop yields and profits, and reduced costs on global, regional, local and farm level. The global cropped area under CA was 180 m ha in 2015-16 corresponding to about 12.5% of the total global cropland (Kassam *et al*. 2018). Rice-wheat rotation covering nearly 14 million ha of land (10.5 m ha in India, 2.2 m ha in Pakistan, 0.8 m ha in Bangladesh and 0.5 m ha in Nepal) in Indo-Gangetic Plains (IGP) of South Asia is the major cropping system in the region (Gupta and Seth 2007, Saharawat *et al*. 2010, Alam *et al*. 2016). On an average, rice-wheat system provides 85% of the total cereal production and 52% of the total calorie intake in India (FAO 2007). There is a large adoption of no-till wheat with some 5.0 m ha in this region (Kassam *et al*. 2018), but only modest adoption of permanent no-till systems and full CA (Farooq and Siddique 2014). In India, no-till wheat is planted in nearly 1.5 m ha. In addition to wheat, the area under no-till system is increasing in crops such as maize, sorghum, cotton, pigeonpea, lentil, grass pea and chickpea with the availability of seeding service from service providers when locally produced CA equipment is available, and the Government policies.

Though India could achieve food security through Green Revolution, it led to over exploitation of natural resources coupled with indiscriminate use of inorganic fertilizers and pesticides, and thereby declining factor productivity, increasing soil salinity, loss of biodiversity, lowering of ground water table, environmental pollution, pest resurgence and land degradation are some of its consequences. Therefore, the advantages of the green revolution have now been masked by the problems posed by it. Though the Eastern region is rich in natural resources, its potential could not be harnessed in terms of improving agricultural productivity, poverty alleviation and livelihood improvement. Eastern region of India has been focused to user second Green Revolution so as to meet out the ever increasing demand of food in the country. However, it is possible only through improving the soil health, minimizing the impact of biotic stresses, increasing the water productivity, development of suitable varieties, and integrated approach of land use. Conservation agriculture, therefore, is need of the hour, particularly in Eastern IGP where rice-wheat cropping system is predominant.

Resource conservation technologies (RCTs) make use of natural resources more efficiently and save input for food production. Appropriate RCTS encompass innovative crop production systems that combine the objectives such as dramatic reductions in tillage with an ultimate goal to achieve zero till or controlled till seeding for all the crops in a cropping system if feasible, rational retention of adequate levels of crop residues on the soil surface to arrest run-off and control erosion, improve water infiltration and reduce evaporation, increase soil organic matter and other biological activity to enhance land and water productivity on sustainable basis, identification of suitable crop rotations in cropping system and crop diversification and intensification to boost food security, incomes and thereby provide the livelihood security to the people.

Relevance of CA in Eastern IGP-Bihar

Rice-wheat rotation is the most common cropping system in the Eastern-IGP. This system is characterized by two contrasting edaphic environments namely, puddling in rice and excessive ploughing in wheat. Although puddling is known to be beneficial for growing rice, it can adversely affect the growth and yield of a subsequent upland crop (e.g. wheat) because of its adverse effects on soil physical edaphic properties, which include poor soil structure, suboptimal permeability in the subsurface layer, poor soil aeration, and soil compaction (Kumar *et al*. 2008). In addition, intensive tillage and crop establishment methods require a large amount of labour and water, resulting in a rise in the cost of cultivation (Ladha *et al*. 2009). The excessive tillage in wheat results in late planting and, therefore, the yield is drastically reduced. Singh *et al.* (2002) had also reported a yield reduction of wheat by 44 per cent if the sowing is done after 23 December in south Bihar.

Conservation Agriculture has major relevance in the Eastern IGP. With an average yield of 2.34 t/ha, Bihar has the lowest wheat yields in the IGP. The State produces 4.73 million tons of wheat (2015-16). Coupled with the highest population growth rate in India and increasing per-capita wheat consumption, the gap between consumption and production is poised to widen in this densely populated State of 104 million people. The state imports wheat from North-western states of Punjab, Haryana and UP to meet out its domestic consumption. Delayed sowing of wheat has been identified as one of the major reasons for the low productivity of wheat in the State. The sowing is delayed due to delayed transplanting of rice due to late release of water in canals, and late harvesting (even up to mid-December) of long-duration rice varieties (Table 1). Delayed sowing of wheat leads to forced maturity due to high temperature stress at reproductive stage, resulting in poor grain setting, lower test weight and less yields (Table 2). Therefore, timely crop establishment must be brought forward as a basic strategy to improve the cropping system productivity. Once it is ensured, it will lead to range of associated technologies that help optimizing the cropping systems. These include, medium duration rice varieties including hybrids, machine transplant- ing of rice, healthy and young seedlings through creation of nursery enterprises, zero tillage technology and broad based mechanization from seed to harvest, and better bet agronomy. The productivity of rice-wheat cropping system is still low (4.7 tonnes/ ha) and the difference between Bihar and states like Punjab and Haryana is still large (> 8.0 tones/ha).

Table 1. Sowing time variability in wheat in different zones of Bihar

Sowing Dates	Zone I	Zone IIIA	Zone IIIB
up to 30 Nov	75%	50%	40%
01 Dec to 15 Dec	20%	30%	20%
16 Dec to 31 Dec	5%	15%	30%
By 2nd week Jan	-	5%	10%

Table 2. Effect of sowing time on wheat yield (n=3410)

Sowing dates	Average wheat yield (t/ha)	Decrease in yield
15 Nov to 30 Nov	4.53	-
01 Dec to 15 Dec	4.17	8%
16 Dec to 31 Dec	3.47	17%
15 Nov to 30 Nov	2.96	15%

Promising CA Technologies for the Region

No-tillage or Zero tillage in wheat in rice-wheat cropping system has been the most promising technology being adopted by the farmers during last one decade. This technology is also spreading in other winter crops like lentil, chickpea, field pea and maize. Zero tillage (ZT) with and without residue retention ('conservation agriculture' implies ZT with residue retention) has demonstrated considerable agronomic and economic benefits, while improving the environmental footprint of agriculture by reducing energy costs and improving soil and water quality. Zero tillage proves better for direct-seeded rice, maize, soybean, cotton, pigeonpea, moonbean, cluster bean, pearmillet during *kharif* season and wheat, barley, chickpea, mustard and lentil during *rabi* season. Wheat sowing after rice can be advanced by 10-12 days by adopting this technique compared to conventionally tilled wheat, and wheat yield reduction caused by late sowing can be avoided. In ZT wheat, agronomic factors leading to productivity advantages are related to (i) time savings in crop establishment, allowing earlier sow- ing and, hence, reducing risks of terminal heat stress during the grain-filling phase;

(ii) better control of weeds, such as *Phalaris minor*; (iii) better nutrient management; and (iv) water savings. In Bihar ZT to facilitate an advancement of wheat sowing can be exploited in well-drained areas. An impact assessment of zero tillage technology in improving wheat productivity in rice-wheat system in 6 districts of Bihar has been done by Keil *et al*. (2015). They reported that the ZT technology in wheat provided an average yield gain of 200 kg/ha (7.6%), seed saving of 13 kg/ha and reduction in cost of crop establishment of Rs 1540/ha as compared to conventional till wheat sowing. National Agricultural Research System (NARS) is at the forefront of this work and because it is implemented in participatory mode, adoption is accelerated. Rice -Wheat Consortium, CIMMYT and IRRI encouraged the State Agricultural Universities, State Governments, NGOs, the private sector and extension agencies to test and adapt these approaches and feature them in rural development strategies. The state governments were convinced for subsidy on RCTS machines and service providers were trained. The policies influenced the State Governments, and emergence of service providers for RCTs adoption/sustainability was also achieved. In addition to zero tillage, following technologies were also tested, evaluated and up-scaled in EIGP (Khan *et al*. 2011):

- Zero-till direct-seeded rice (ZTDSR)
- System of Rice Intensification (SRI)
- Direct sowing of rice in puddled field through drum seeder
- Unpuddled transplanting
- Use of Leaf Colour Chart (LCC) for nitrogen management
- Brown manuring of *Sesbania* in rice
- Bed planting in rice and wheat
- Use of second generation RCTS and refinement in sowing techniques
- Double Zero Tillage in rice-wheat (RW) system
- Surface seeding of rice and wheat
- Residue management for improving soil health
- Bed planted maize
- ZT lentil/chiclpea
- Crop diversification

– Extra early (ICPL 88039-150 days) ,
– Bed planting of potato + maize,
– Bed planting of sugarcane + vegetables,
– ZT moong/cowpea,
– Relay moong in RW cropping system,
– Spring maize through reduced tillage,
– Inclusion of summer pulses after RW for crop intensification, and
– Laser aided land levelling for increasing land and water productivity.

Status of CA in Eastern IGP

Conservation Agriculture in the Eastern Indo-Gangetic Plains comprising states of eastern Uttar Pradesh, Bihar and West Bengal is still in the initial phase. The major CA based technologies (also known as Resource Conservation Technologies-RCTs) being adopted is zero-till (ZT) wheat in the rice-wheat (RW) system. Over the past few years, adoption rate of ZT is very fast, and the area under ZT wheat in Bihar has increased from 18,000 ha in 2004-05 (RWC 2004) to around 3.0 lakh hectare in 2016-17. There are few pockets in the State where other crops like lathyrus, lentil and wheat are grown as *utera/para* cropping/surface seeding (broadcasting seeds in the standing crop of rice 10-15 days before rice harvest). As the land holding size of the farmers is less (<0.40 ha) and land is fragmented, and livestock population is more, most of the crops are harvested manually from the ground level, leaving no crop residue on the soil surface. In such cases, ZT sowing is done without residue retention. But still there are areas, where rice is harvested through combine machine leaving at least 30% anchored crop residue. In these areas farmers mostly burn the crop residues fully/ partially before sowing of the next crop by ZT machine. However, there has been a rapid increase in another type of tillage system using a tractor drawn rotavator. The rotavator incorporates crop residue and pulverize the soil in a single pass. This may be treated as reduced tillage system. Overall, the conventional agriculture based crop management systems in the State are gradually undergoing a paradigm shift from intensive tillage to reduced/zero-tillage operations.

Farmers' Perception about CA Technologies

A study conducted by Singh *et al*. (2011) in Eastern IGP at farmer-field level, 'zero tillage' and 'bed planting' taken as resource conservation technologies, which were widely prevalent in the region. The comparative study on adopters and non-adopters of RCTs in the rice-wheat cropping system (Table 3) has clearly indicated the superiority of RCT over conventional practices in terms of cost saving and more efficient use of inputs.

Another study, comparing various tillage practices, crop establishment and residue management in a systems' perspective in a rice–wheat rotation of Eastern IGP was conducted by the Borlaug Institute of South Asia (BISA), Samastipur, Bhar. Seven years of data from this research trial showed that however during the initial 2–3 years, the benefits of CA based rice production system are not prominent but consequently it became more productive and profitable than CT based system. Yield and economical benefit of CA based production systems in case of wheat were deceptive right from initial years. Moreover, the wheat yields were constrained by conventional tillage based management in preceding rice crop. At system level, CA based production systems (i.e. ZTDSR–ZTW with and without residue retention) yielded more than CT based production systems after 2–3 years of experimentation. Moreover, system productivity decreased where at least one of the crops involved intensive tillage, after 2–4 years of experimentation indicating the disadvantageous effect of tillage for a crop to the subsequent crop (Jat *et al*. 2014). Laxmi and Mishra (2007) observed that most of the farmers were of the view that adoption of ZT leads to increased yield, saving in cost of cultivation, irrigation water saving, and reduction in weed (especially *Phalaris minor*).

Table 3. Differential in cost, yield and returns from rice and wheat cultivation in Bihar- RCT adopters *vs* non-adopters (per hectare)

Particulars	Rice		Wheat	
	Adopters	Non-Adopters	Adopters	Non-Adopters
Total input cost (Rs)	13367 (-9.10)	14706	12634 (-11.17)	14223
Grain yield (tonnes)	4.0 (3.25)	3.9	2.84 (1.79)	279
By-product yield (tonnes)	-	-	2.82 (2.55)	275
Grain price (Rs)	573 (0.02)	573	638.33 (1.07)	631.57
Grain revenue (Rs)	22946 (3.27)	22196	18129 (2.88)	17621
By-product revenue (Rs)	1350 (19.33)	1089	3074 (1.43)	3031
Total returns (Rs)	24297 (4.16)	23285	21202 (2.67)	20651
Return over cost (Rs)	10929 (27.39)	8579	8568 (33.29)	6428
Return/cost	1.89 (14.79)	1.58	1.68 (23.44)	1.45

*Figures within parentheses indicate the percentage change in particulars experienced by adopters over non-adopters in Bihar.

Additional advantage was reported for timely sowing of wheat. The main reason for not adopting the ZT was unavailability of ZT machine in time. In Bihar, scarcity of ZT machine and absence of market for hiring services were reported.

Success Stories

Sri Sunil Kumar Singh, Village Pardeshia, Block Sheohar, Distt. Sheohar

Mr. Singh owns 8 acres of land. He was growing wheat in 4 acres with pro- ductivity of 8q/acre. He has one tractor, cultivator, pumping set and thresher. In order to reduce the cost of cultivation and timely sowing KVK, Sheohar suggested him to purchase zero till drill machine.

During *Rabi* season 2015-16 he used zero- till machine (ZTM) for sowing wheat in his 4 acres area. Latter he outsourced it in about 55 acres @ Rs 650/ acre in other farmers. In traditional method for sowing of wheat the cost of seed bed preparation and sowing was Rs. 2200/ acre whereas by zero till drill it was only Rs 650/acre. Thus, Rs. 1550/acre was saved. He reported that in the field sown by ZTM labour requirement for harvesting wheat was 5 labours/acre whereas in traditional method 8 labours are required. Thus, the saving from harvesting was about Rs. 600/ acre (@ Rs. 200/ labours). The average yield obtained in the field sown by ZT machine was 16 q/ acre whereas in the fields bours/acre whereas in traditional method 8 labours are required. Thus, the saving from harvesting was about Rs. 600/ acre (@ Rs. 200/ labours). The average yield obtained in the field sown by ZT machine was 16 q/ acre whereas in the fields sown by traditional method it was 8q/ acre. Thus the income from excess yield was Rs. 12000/ acre.

It can be said that by use of zero till drill machine his income from 4 acres land increased by Rs. 56,600/-. Last year from custom hiring of zero tillage machines he earned Rs 35,750/-. Now he has become an icon for other farmers in his block and is well skilled in application of zero till drill and imparts trainings to other farmers also in how to best use this machine.

His income is uplifted due to adoption and diffusion of zero tillage technique.

Zero tillage sowing of wheat in Buxar district

Rice-wheat cropping system is dominant cropping system of Buxar district and covers 90,000 ha area. Farmers of the district growing long duration rice va- rieties (MTU 7029) and semi-medium duration variety (BPT 5204). Transplanting of rice started end of June and completed up to first fortnight of August. Late harvesting of rice leads to delayed sowing of wheat. Advancing the sowing date of wheat crop by using zero tillage machines, KVK started front line demonstra- tion in several part of district in 2012 and continuously giving more emphasis on zero tillage technology (ZTT). Different project of KVK *viz.* Farmers Participatory Action Research Programme (FPARP), National Innovation on Climate Resilient Agriculture (NICRA), Improved Rice Based Rainfed Agricultural System (IRRAS) and Cereal System Initiative for South Asia (CSISA) also involved in promotion of wheat sowing by zero tillage.

Mr. Sanjeev Kumar, a 48 years old farmer's achievement can encourage to depict how a person's diligence, honesty and desire can bring success in life. Previ- ously, Sanjeev kumar was cultivating his land traditionally with minimum applica- tion of modern technologies and as a result, he was not getting optimum income from his farming what he should get. He came in contact with the CIMMYT – BISA institute and climate change agriculture and food security program from where he came to know about conservation agriculture technologies. Then he became active participant in the trails conducted by CIMMYT-BISA. The engagement of Sanjeev Kumar in the BISA activities has exposed him to various improved technologies of conservation agriculture like zero tillage, bed planting, combine harvester etc., which increased his knowledge and skill and made him confident to apply those technologies in his field effectively and efficiently. Now, he is cultivating success- fully through applying these conservation agriculture technologies, which, accord- ing to him, has brought about several benefits like reduction in cost of produc- tion, labor and irrigation water, as well as it ensures timely farming with help of machineries. With all these advantages, he significantly improved his income and livelihood. For instance, his net profit has increased from Rs. 11,000 to Rs. 14,300 per acre by adopting zero tillage technology. Now, he was strongly motivated to continue these technologies in their farming. His success also inspiring the other farmers of his society as they witness the success of the new technologies.

He is actively involved in out scaling the latest technologies to fellow farmers and strong impact have been observed in Neerpur and nearby villages of Vaish- ali District. Today he is providing service for modern agriculture machines like; Zero-till seed drill, Laser Land Leveler, Multi-Crop Planter, Reaper cum Binder, Mechanical Sprayer, and Green Seekar. Through its extension mode, he has laser leveled the fields of hundreds of farmers in nearby villages at nominal charges and also sown hundreds of acres wheat by zero till acting as single window service provider. Since 2016, Mr. Sanjeev continuously demonstrated Direct Seeded Rice technology in nearby villages. Area under ZT wheat in Neerpur was only 20 acres in *Rabi* 2016-17 which has increased to 140 acres in 2017-18. More and more farm- ers have been attracted towards this technology and they are willing to adopt this environment friendly, resource conserving and economically viable technology. Maize on bed as well as in flat bed sown by multi crop planter followed by wheat on on his farm has encouraged fellow farmers also to adopt this technology. The concept of climate smart agriculture has been extensively popularized among the farmers to mitigate the effects of climate change on agriculture. Farmers were educated on all six smart strategies; Weather Smart, Water Smart, Carbon Smart, Nutrient Smart, Energy Smart & Knowledge Smart agriculture. Such extension activities have also proved helpful in out scaling the new technologies. After wit- nessing the of his success, large number of farmers from other pockets of the State is also approaching for adopting CA based agriculture production system in their respective areas.

Constraints in adoption of CA-based Technologies

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 (Sharma *et al*. 2017). In addition to these, there are several other factors restricting the adoption of CA technologies, such as the following:

Operational constraints

- Small and fragmented land holding size.
- Lack of availability of CA machinery, especially for small and marginal farmers.
- Higher costs of CA machineries and non-availability of CA machinery parts in local market.
- Requirement of high power tractor for running the machine (seed drill).
- Appropriate moisture at the time of sowing.
- Widespread use of crop residues for livestock feed due to higher animal population.
- Burning of crop residues (especially after combine harvest of rice) for timely sowing of the next crop.
- Lack of extension services, mainly regarding new technologies.
- Lack of skilled and scientific manpower, and old mind set of the farmers about necessity of tillage operations. Convincing the farmers that good crop can be produced even without tillage is a major hurdle in promoting CA on a large scale (Bhan and Behera 2014).

Technical constraints

- Non-availability of quality seed drills.
- Non-availability of machine on custom hiring basis.
- Lack of trained mechanic for repairing the machines.
- Lack of awareness, training / capacity building.
- Spare parts are not available locally.
- Lack of local manufacturers of machines.
- Problems in operation under unleveled field/small size of holding.
- Extension related constraints

- Lack of extension support from State agriculture agencies.
- Lack of attention by mass media/authorities/policy maker.
- Lack of knowledge of extension agencies regarding new technologies.
- Inadequate extension facility at disposal of input agencies.
- Lack of cooperation among fellow farmers.

Socio-economic constraints

- Old mind set /social fear among farmers that CA technologies may results in lower crop yields.
- Poor economic condition of farmers (farmers' income of Bihar is the lowest in the country).
- Lack of credit facilities.
- Lack of money to buy new machines and inputs.
- High cost of Zero-till seed-drill/Happy seeder.

In eastern IGP, the adoption of resource conservation technologies, especially zero tillage in wheat in rice-wheat cropping system is increasing. Apart from long- term benefits, immediate time & cost-savings as compared to conventional tillage is making the technology attractive to farmers. Adoption of conservation agriculture in totality is however very difficult as farmers will continue to puddle the field and transplant rice during rainy season. Further, the adoption of zero tillage may be suc- cessfully implemented in other winter season crops through making farmers aware of the technology, the timely availability of machines, developing markets/custom hiring centers for hired services and proper policy interventions. The government policies to improve human resource in the form of training and awareness are beneficial for the adoption of RCTs. For promoting RCTs, the availability and accessibility of credit need to be ensured.

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Conservation agriculture for sustainable rice-wheat production

J.S. Mishra
ICAR Research Complex for Eastern Region, Patna

Unsustainable exploitation of natural resources has lead to widespread degradation of land, soil nutrient mining and soil carbon loss, and resulted in to serious implications for food security and ecological integrity. Conservation Agriculture is a response to sustainable land management, environmental protection and climate change adaptation and mitigation. FAO (2014) has defined Conservation agriculture (CA) as "an approach to managing agro-ecosystems for improved and sustained productivity, increased profits and food security while preserving and enhancing the resource base and the environment". Sometimes it is also referred to as "agricultural environmental management". CA based on three key elements of ***minimizing soil disturbance*** (no-tillage/minimum tillage), ***maintaining soil cover*** (organic soil mulch cover by crop residues and cover crops), and ***crop rotation*** (diversification of crop species in sequence or associations), enhances biodiversity and natural biological processes above and below the ground surface, which contribute to increased water and nutrient use efficiency and to improved and sustained crop production. The overall goal of conservation agriculture is to make better use of agricultural resources (than does conventional agriculture) through the integrated management of available soil, water and biological resources such that external inputs can be minimized.

The CA system has been adopted on over 180 million hectares globally (Table 1) (Kassam *et al*. 2018). In India, CA system has been partially practiced in form of zero tillage in winter crops, mainly in wheat in rice-wheat cropping system of Indo-Gangetic Plains. Conservation tillage is a major component of Conservation Agriculture (CA), which has been widely advocated worldwide in present day agriculture. The U.S Soil Conservation Service defines conservation tillage (CT) as any tillage system that leaves at least 30% of the surface covered by plant residues for control of soil erosion. Conservation tillage is a tillage system that conserves soil, water and energy resources through the reduction of tillage intensity and retention of crop residue. It involves the planting, growing and harvesting of crops with limited disturbance to the soil surface. Conservation tillage includes many types of tillage and residue management systems (Reicosky and Allmaras, 2003). Zero tillage/no tillage, reduced tillage; strip-tillage, ridge-tillage and mulch-tillage are various forms of conservation tillage.

Table 1. Extent of adoption of CA worldwide

S. No.	**Country**	**CA area '000ha (2015/16)**
1	USA	40,204
2	Brazil	32,000
3	Argentina	31,028
4	Australia	22,299
5	Canada	19,936
6	China	9,000
7	Russia	5,000
8	Paraguay	3,000
9	Kazakhstan	2,500
10	India	1,500
11	Uruguay	1,260
12	Others	9,712
13	Total	**1,80,439**

Rice - wheat (RW) cropping system, the largest cropping systems in the world, occupies an area of approximately 24 million hectares (m ha) spread over Asia and 13.5 m ha in South Asia. Indian portion of IGP contributes 33% to the total cereals production of India (Chauhan *et al*. 2012). North-western IGP has played a vital role in the food security of India by contributing about 40% of wheat and 30% of rice to the central grain stock every year during the last four decades (Hira and Khera 2000). Under conventional system, puddling and transplanting of rice seedlings is done in rice fields; while after rice harvest, wheat is sown in well-pulverized soil. Although, puddling helps in reducing water loss through percolation, and weed management, it led to a number of problems in post-rice crops, threatening sustainability of the system. These are:

(i) Erratic stand establishment of post-rice crops owing to poor contact of seed with soil
(ii) Delayed sowing of wheat due to late harvesting of long-duration transplant rice, resulting in low wheat yield
(iii) Overexploitation of groundwater
(iv) Soil compaction with a consequent increase in bulk density resulting in restricted root growth
(v) Weed shift and development of herbicide resistant weeds
(vi) Sharp decline in soil organic matter
(vii) Multi-nutrient deficiencies

To counteract some of these problems, conservation agriculture (CA) is now being promoted which involves minimum soil disturbance, providing a soil cover through crop residues or other cover crops and crop rotations for achieving higher productivity. Conservation agriculture offers a pragmatic option to resolve the edaphic conflict in the conventional rice-wheat system. Conservation rice production systems, like aerobic culture/direct-seeded rice, alternate wetting and drying, SRI method of rice establishment, use of leaf colour chart (LCC) for efficient nitrogen management, etc. may help in resolving the edaphic conflict in the rice. Similarly in wheat, zero tillage, ridge and furrow method of sowing, crop residue retention, etc., are the major practices.
Different crop establishment practices were also evaluated in rice-wheat-greengram cropping system to find out the effect of CA practices on crop productivity, water-use efficiency and weed dynamics. After three years, results revealed that the population of *Trianthema portulacastrum* (horse purslane) in complete CA system (ZTDSR-ZTwheat-ZT greengram) was drastically reduced to 11/m^2 as compared to 120/m^2 in conventional DSR (Mishra *et al*. 2017) (Photo 1).

Photo 1. Effect of rice establishment method on population of *T. portulacastrum*

Relevance of CA in Bihar

Conservation Agriculture has major relevance in the States like Bihar. With an average yield of 2.34 t/ha, Bihar has the lowest wheat yields in the IGP. The State produces 4.73 million tons of wheat (2015-16).Coupled with the highest population growth rate in India and increasing per-capita wheat consumption, the gap between consumption and production is poised to widen in this densely populated State of 104 million people. The State imports wheat from Northwestern State of Punjab, Haryana and UP to meet out its domestic consumption. Delayed sowing of wheat has been identified as one of the major reasons for the low productivity of wheat in the State. The sowing is delayed due to delayed transplanting of rice due to late release of water in canals, and late harvesting (even up to mid December) of long-duration rice varieties (Table 2). Delayed sowing of wheat leads to forced maturity due to high temperature stress at reproductive stage, resulting in poor grain setting, lower test weight and less yields (Table 3). Therefore, timely crop establishment must be brought forward as a basic strategy to improve the cropping system productivity. Once it is ensured, it will lead to range of associated technologies that help optimizing the cropping systems. These include, medium duration rice varieties including hybrids, machine transplanting of rice, healthy and young seedlings through creation of nursery enterprises, zero tillage technology and broad based mechanization from seed to harvest, and better bet agronomy. The productivity of rice-wheat cropping system is still low (4.7 tones/ha) and the difference between Bihar and States like Punjab and Haryana is still large (> 8.0 tones/ha).

Table 2. Sowing time variability in wheat in different zones of Bihar

Sowing Dates	Zone I	Zone IIIA	Zone IIIB
up to 30 Nov	75%	50%	40%
01 Dec to 15 Dec	20%	30%	20%
16 Dec to 31 Dec	5%	15%	30%
By 2nd week Jan	-	5%	10%

Table 3. Effect of sowing time on wheat yield (n=3410)

Sowing Dates	Average Wheat Yield (t/ha)	Decrease in Yield
15 Nov to 30 Nov	4.53	-
01 Dec to 15 Dec	4.17	8%
16 Dec to 31 Dec	3.47	17%
15 Nov to 30 Nov	2.96	15%

Zero tillage (ZT) with and without residue retention (‘conservation agriculture’ implies ZT with residue retention) has demonstrated considerable agronomic and economic benefits, while improving the environmental footprint of agriculture by reducing energy costs and improving soil and water quality. Zero tillage proves better for direct-seeded rice, maize, soybean, cotton, pigeonpea, moonbean, cluster bean, pearl millet during *kharif* season and wheat, barley, chickpea, mustard and lentil during *rabi* season. Wheat sowing after rice can be advanced by 10-12 days by adopting this technique compared to conventionally tilled wheat, and wheat yield reduction caused by late sowing can be avoided. In ZT wheat, agronomic factors leading to productivity advantages are related to (i) time savings in crop establishment, allowing earlier sowing and, hence, reducing risks of terminal heat stress during the grain-filling phase; (ii) better control of weeds, such as *Phalaris minor*; (iii) better nutrient management; and (iv) water savings. In Bihar ZT to facilitate an advancement of wheat sowing can be exploited in well-drained areas. An impact assessment of zero tillage technology in improving wheat productivity in rice-wheat system in 6 districts of Bihar has been done by Keil *et al.* (2015). They reported that the ZT technology in wheat provided an average yield gain of 200 kg/ha (7.6%), seed saving of 13 kg/ha and reduction in cost of crop establishment of Rs. 1540/ha as compared to conventional till wheat sowing.

Impact

The ZT wheat sowing is one of the fast growing technologies in the State. The technology has been adopted in more than 3.0 lakh hectare area during last 5 years. Spread of this technology even in 50% wheat growing area (10.6 lakh ha) by 2022 will result in an additional production of 2.12 lakh tonnes of wheat besides net savings of 13,800 tonnes of seed and Rs. 1632.4 million on crop establishment. Besides, the technology is spreading fast in other winter crops like lentil and chickpea (Table 4).

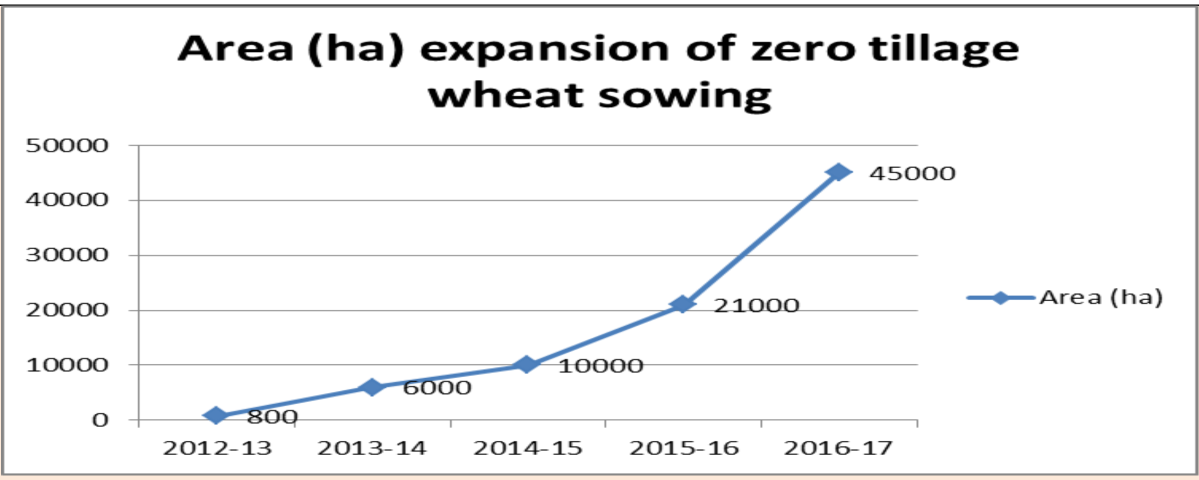
Table 4. Effect of ZT in wheat on yield and economics

Zone	**Yield (t/ha)**	**Seed rate (kg/ha)**	**Cost of crop establishment (Rs/ha)**	**B:C ratio**
Zone I (Vaishali, Samastipur, Begusarai)				
CT(N=394)	2.85	129	4111	1.03
ZT (N=70)	3.20	96	1230	3.08
Zone IIIA (Lakhisarai)				
CT (N=77)	2.17	141	2240	2.58
ZT (N=47)	2.32	128	1480	6.14
Zone IIIB (Bhojpur, Buxar)				
CT (N=550)	2.52	151	2970	1.39
ZT (N=317)	2.81	140	1990	1.92
Average				
CT (N=1021)	2.62	141	3350	1.34
ZT (N=434)	2.82	128	1810	2.56

Source: Keil *et al.* (2015)

Zero tillage sowing of wheat in Buxar district of Bihar: A case study

Rice-wheat cropping system is dominant cropping system of Buxar district and covers 90,000 ha area. Farmers of the district growing long duration rice varieties (MTU 7029) and semi-medium duration variety (BPT 5204). Transplanting of rice started end of June and completed up to first fortnight of August. Late harvesting of rice leads to delayed sowing of wheat. Advancing the sowing date of wheat crop by using zero tillage machines, KVK started front line demonstration in several parts of district in 2012 and continuously giving more emphasis on zero tillage technology (ZTT). Different project of KVK viz. Farmers Participatory Action Research Programme (FPARP), National Innovation on Climate Resilient Agriculture (NICRA), Improved Rice Based Rainfed Agricultural System (IRRAS) and Cereal System Initiative for South Asia (CSISA) also involved in promotion of wheat sowing by zero tillage.



Economics of Zero tillage demonstration

Year	Average yield (t/ha)	Cost of cultivation (Rs/ha)	Gross returns (Rs/ha)	Net returns (Rs/ha)	Cost benefit ratio
2012-13	4.1	21500	55350	33850	2.57
2013-14	4.3	23200	60200	37000	2.59
2014-15	3.9	24800	56550	31750	2.28
2015-16	4.6	25100	70150	45050	2.79
2016-17	5.1	25700	82875	57175	3.22

Minimum Support Price of per quintal wheat grain: 2012-13: Rs 1350, 2013-14: Rs 1400, 2014-15:Rs 1450, 2015-16:Rs 1525, 2016-17:Rs 1625

Benefits

- Significant reduction in cost of production (~2500 rupees/ha). This reduction in cost is attributed to savings on account of fuel, labour and input costs, particularly herbicides.
- Increase yield by 5-15% over conventional system due to advanced sowing date, enhanced seed germination (due to better seed-soil contact) and plant stand over traditional sowing.
- Improvement in soil health in terms of physico-chemical and biological conditions.
- Reduction in incidence of weeds, such as *Phalaris minor* and *Chenopodium album* because of less soil disturbance.
- Reduction in air pollution and Green House Gases emission to the environment with proper management of surface crop residues in ZT.
- Improvement in nutrient and water-use efficiency.
- Offers crop diversification opportunities.
- Less traction wear and tear maintenance costs
- In zero-till, use of surface residues as mulch moderates soil temperature, reduces soil moisture evaporation, promotes the population of beneficial insects, and promotes biological activities in soil.
- No-till mean less carbon oxidation during ploughing and possibly some carbon sequestration especially if residue management is good.
- Advancement in sowing time over conventional system.
- Increased soil moisture retention due to reduced evaporation and runoff.
- Reduction in soil temperature near the soil surface.
- Hydraulic conductivity is increased
- Higher stability of soil aggregates due to accumulation of more organic matter

- Organic carbon concentration near the soil surface is increased.
- Reduction in soil pH due to nitrification and higher CEC of the surface soil.
- Higher accumulation of phosphorus and potassium in upper soil layer.
- Increased population of earthworm and beneficial insects and predators

Limitations

- Small and fragmented land holding size.
- Lack of availability of CA machinery, especially for small and marginal farmers.
- Higher costs of CA machineries and non-availability of CA machinery parts in local market.
- Widespread use of crop residues for livestock feed due to higher animal population.
- Burning of crop residues (specially after combine harvest of rice) for timely sowing of the next crop.
- Lack of extension services, mainly regarding new technologies.
- Lack of skilled and scientific manpower, and old mind set of the farmers about necessity of tillage operations. Convincing the farmers that good crop can be produced even without tillage is a major hurdle in promoting CA on a large scale (Bhan and Behera 2014).

Constraints in adoption of CA-based technologies

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 (Sharma *et al*. 2017). In addition to these, there are several other factors restricting the adoption of CA technologies, such as the following:

Operational constraints

- Small and fragmented land holding size.
- Lack of availability of CA machinery, especially for small and marginal farmers.
- Higher costs of CA machineries and non-availability of CA machinery parts in local market.
- Requirement of high power tractor for running the machine (seed drill).
- Appropriate moisture at the time of sowing.
- Widespread use of crop residues for livestock feed due to higher animal population.
- Burning of crop residues (especially after combine harvest of rice) for timely sowing of the next crop.
- Lack of extension services, mainly regarding new technologies.
- Lack of skilled and scientific manpower, and old mind set of the farmers about necessity of tillage operations. Convincing the farmers that good crop can be produced even without tillage is a major hurdle in promoting CA on a large scale (Bhan and Behera 2014).

Technical constraints

- Non-availability of quality seed drills.
- Non-availability of machine on custom hiring basis.
- Lack of trained mechanic for repairing the machines.
- Lack of awareness, training / capacity building.
- Spare parts are not available locally.
- Lack of local manufacturers of machines.
- Problems in operation under unleveled field/small size of holding.

Extension related constraints

- Lack of extension support from State agriculture agencies.
- Lack of attention by mass media/authorities/policy maker.
- Lack of knowledge of extension agencies regarding new technologies.
- Inadequate extension facility at disposal of input agencies.
- Lack of cooperation among fellow farmers.

Socio-economic constraints

- Old mind set /social fear among farmers that CA technologies may results in lower crop yields.
- Poor economic condition of farmers (farmers' income of Bihar is the lowest in the country).
- Lack of credit facilities.
- Lack of money to buy new machines and inputs.
- High cost of Zero-till seed-drill/Happy Seeder.

Conclusion

Adoption of resource conservation technologies (RCTs), especially zero tillage in wheat in rice-wheat cropping system is increasing. Apart from long-term benefits, immediate time & cost-savings as compared to conventional tillage is making the technology attractive to farmers. Adoption of conservation agriculture in totality is however very difficult as farmers will continue to puddle the field and transplant rice during rainy season. Further, the adoption of zero tillage may be successfully implemented in other winter season crops through making farmers aware of the technology, the timely availability of machines, developing markets/custom hiring centers for hired services and proper policy interventions. The government policies to improve human resource in the form of training and awareness are beneficial for the adoption of RCTs. For promoting RCTs, the availability and accessibility of credit should be ensured.

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High yielding rice varieties for drought prone-ecology of Eastern India

Santosh Kumar, S.K. Dwivedi, Surajit Mondal, A. K. Dubey and Manisha Tamta
ICAR Research Complex for Eastern region, Patna-800014

Rice being one of the most important staple food crops in the world after wheat and is the primary source of calories for about half of mankind. It provides around 27 per cent of dietary energy, 15 per cent of dietary protein and 3 percent of dietary fat to global population. The area under its cultivation is 167 million hectares producing 770 million tons and a productivity of 4.60 tons/ha in the world (FAOSTAT, 2017). It is cultivated under diverse ecologies ranging from irrigated to rainfed upland to rainfed lowland to deep water. Drought is the most widespread and damaging of all environmental stresses, affecting 23 million hectares of rainfed rice in South and Southeast Asia alone. The frequent occurrence of drought has been identified as the key to the low productivity of rice in rainfed ecosystems, particularly in eastern region of India (Kumar et al., 2008; Verulkar et al., 2010). In India, out of the total 20.7 mha rainfed rice area, approximately 16.2 mha are in eastern India (Singh and Singh, 2000). About 6.3 and 7.3 million ha of upland and lowland areas of eastern India, respectively, are frequently affected by drought (Pandey and Bhandari, 2008). Moreover, a recent estimate on climate change predicts the water deficit to deteriorate further in years to come and the intensity and frequency of drought are predicted to become worse (Bates *et al.*, 2008). Eastern states of India accounting for 27.26 million ha rice area, out of which 16.2 million ha is rainfed and nearly 4.28 million ha area is prone to frequent drought (IRRI, 2013). Drought stress can develop at any stage of the crop in unbunded or bunded upper fields upon the cessation of rainfall for a few consecutive days, often resulting in a severe yield reduction. Bunded lower fields can also be affected by drought stress following the failure of rains for three or more consecutive weeks. Severe drought in the wet season not only had an adverse effect on rice production but also reduced the area sown under wheat, pulses, and oilseeds in the subsequent dry season because of the unavailability of sufficient moisture in the soil, thereby reducing the production of these crops and creating food insecurity in the country.

Generally, drought is induced at one specific stage to select tolerant genotypes. However, in rainfed conditions, the occurrence of drought is not stage specific it can occur at any developmental stage of rice (seedling, vegetative and reproductive) due to greater temporal variability and long break between showers. In rainfed areas, upon failure of rain or a long-spell between two rains, drought stress can occur at the seedling, vegetative, and reproductive stages of the rice, it can be intermittent drought depending upon the rainfall pattern and distribution (Kumar, 2011). Among all these, drought at the reproductive stage has been identified as the most detrimental to grain yield. Moreover, in most rainfed regions, the probability of occurrence of terminal reproductive-stage drought is high due to the early withdrawal of monsoon rains (Kumar *et al.*, 2008). Rice productivity in these drought prone areas is poor and unstable; emphasis is shifting towards drought prone rainfed rice areas which offer a great potential in enhancing rice production and productivity.

Most of the current high-yielding rice varieties [Swarna (MTU 7029), Sambha Mahsuri (BPT 5204), IR 64, IR 36, MTU 1010, MTU 1001, Rajendra Sweta, Rajendra Bhagwati, Rajendra Mahsuri, Sarjoo 52, Savitri and Naveen] are being grown in drought-prone areas of eastern India; which were originally developed for irrigated ecology, and they are extremely sensitive to drought at any crop growth stage. Several earlier studies also reported that high yield loss of those varieties in mild to moderate drought conditions; many of these even failed to flower and form grain under severe drought which happens nearly every five years (Pandey and Bhandari, 2008). Keeping this fact in view, there is an urgent need to develop, identify, disseminate and adopt high yielding drought tolerant varieties to achieve food self-sufficiency at regional as well as national level.

Drought prone rice areas in eastern states of India

The eastern region comprises of Bihar, Eastern Uttar Pradesh, Odisha, West Bengal Jharkhand, Chhattisgarh and plains of Assam, represents 21.85% geographical area of the country and supports to 33.64% of country's production (Bhatt *et.al*, 2011). Though the region is endowed with rich natural resources but the production level remained low. In eastern India, rice production is directly correlated with regional and national food security. The challenge of growing water scarcity and frequent occurrence of drought threatening the food security in the eastern region. Eastern India accounting for 71.84 million ha geographical area, and 27.26 million ha rice area, of which nearly 4.28 million ha rice area is prone to frequent drought (Table 1).

Table 1: Drought prone rice areas in eastern states of India

States	Geographical areas (mha)	Rice area (mha)	Drought prone rice area (mha)	% Rice drought prone area
Bihar	9.41	3.20	0.725	23
Eastern UP	8.64	5.92	0.985	17
West Bengal	8.87	5.94	0.956	16
Assam	7.84	2.50	0.221	9
Odisha	15.57	4.35	0.631	14
Jharkhand	7.97	1.67	0.243	15
Chhattisgarh	13.51	3.66	0.521	14
Eastern India	71.84	27.26	4.281	16

Source: IRRI (2013)

Present status of drought tolerant rice varieties

Despite the importance of drought as a constraint, little effort has been devoted to developing drought-tolerant rice cultivars. Most of the high-yielding varieties *viz;* IR64, Swarna, Sambha Mahsuri, MTU 1010, MTU 1001, Sarjoo 52, Rajendra Sweta, Rajendra Mahsuri, Rajendra Bhagwati, Lalat and Naveen grown in rainfed areas are bred for irrigated ecosystems and they were never selected for drought tolerance. In drought years, these varieties inflict high yield losses, leading to a sudden decline in the country's rice production. Because of the absence of high-yielding, good-quality drought-tolerant varieties, farmers in the rainfed ecosystem continue to grow these varieties. Farmers of drought-prone areas require varieties that provide them with high yield in years of good rainfall and sustainable good yield in years with drought. By employing direct selection for grain yield under drought, several promising breeding lines for rainfed lowlands and uplands have been identified recently. Similarly, some drought tolerant varieties (Sahbhagi Dhan, Swarna Shreya, Shusk Samrat, DRR 42, CR Dhan 40, Anjali, Vandana, NDR 97, NDR118, Hazaridhan, and Indira Barani Dhan) are already released for different states of eastern India (Table 2). Cultivation of these drought tolerant varieties will be helpful for sustaining food security in eastern states. Details of some of these drought tolerant rice varieties are as follows:

Sahbhagi Dhan

This variety was developed by Central Rainfed Upland Rice Research Station (CRURRS), Hazaribagh in collaboration with International Rice research Institute (IRRI), Manilla, Philippines. It has been released and notified in 2009 and 2010, respectively. It is highly drought tolerant variety and recommended for cultivation in rainfed upland and lowland areas of eastern states, particularly in Jharkhand, Bihar, UP and Odisha. Sahbhagi dhan is maturing in 105-110 days in plain areas and 110-115 days in upland. On the basis of soil type and availability of moisture, it can be established either transplanted or direct seeding. Direct seeding of Sahbhagi Dhan can be done through zero tillage or seed drill machine or manually. Seed of Sahbhagi dhan is long and bold, having intermediate amylose content and high head rice recovery (HRR). Sahbhagi dhan is highly resistant to leaf blast and moderately resistant to brown spot and sheath blight. Productivity of Sahbhagi dhan is 2.0-2.5 t/ha under drought and 3.8-4.5 t/ha without stress.

Swarna Shreya

This variety was developed by ICAR Research Complex for Eastern Region, Patna in collaboration with IRRI, Philippines. It has been released and notified in 2016. Swarna Shreya is drought tolerant aerobic rice variety and recommended for cultivation under aerobic situation in rainfed medium lowland and poorly irrigated areas of Chhattisgarh, Madhya Pradesh and Bihar. Swarna Shreya is a semi-dwarf (105-110 cm) variety which flowers in about 85 days and matures in 115-120 days. Direct seeding of Swarna Shreya can be done through zero tillage or seed drill machine or manually. Seed of Swarna Shreya is long and bold, having intermediate amylose content. Swarna Shreya is resistant to leaf blast and moderately resistant to neck, blast, brown spot, RTD and sheath rot. It also showed moderately resistant against stem borer (dead heart), leaf folder, gall midge (Biotype 1) and whorl maggot under natural screening. Quality wise, this variety possesses high hulling recovery (77.5%), milling (69.2%), head rice recovery (56.2%) with desirable intermediate amylose content (21.87%) and alkali spreading value (ASV=4.0). It has high GC (65.5 mm) with very occasionally chalky indicating good cooking quality. Productivity of Swarna Shreya is 2.0-2.5 t/ha under drought and 4.0-4.5 t/ha without stress.

Shusk Samrat

Rice variety ‘Shusk Samrat’ was developed by Narendra Dev University of Agriculture and Technology, Faizabad for drought prone rainfed upland and lowland areas of eastern Uttar Pradesh, Bihar and Chhattisgarh. Besides drought tolerant ability, it also shows tolerance for low fertilizer stress and responsive to favorable conditions. Shusk Samrat having semi dwarf (95-100 cm) stature, with 8-10 panicle bearing tillers $plant^{-1}$, early maturity (110-115 days), high yielding ability and good grain quality. Shusk Samrat performed well under aerobic conditions too. It is moderately resistant to major insects and pests such as stem borers, gall midge, leaf folders, and whorl maggots. It is also resistant to sheath rot and brown spot and moderately resistant to sheath blight.

DRR 42 (IR64 Drt 1)

This variety was developed by Directorate of Rice Research (DRR), Hyderabad in collaboration with Birsa Agricultural University (BAU), Ranchi and IRRI, Philippines. It has been released and notified in 2015 and recommended for cultivation in rainfed midland and lowland areas of Tamil Nadu, Andhra Pradesh, Telangana, Madhya Pradesh, Chhattisgarh & Jharkhand. It is maturing in 115-120 days. DRR 42 is the improved version of the popular rice variety IR 64. Along with drought tolerant potential, it has an added advantage of high yield production. This variety is tolerant to drought, especially at flowering and grain filling stage. Seed of DRR 42 is long and slender, having intermediate amylose content and high head rice recovery (HRR). It is resistant to blast, moderately resistant to bacterial leaf blight and brown spot.

CR Dhan 40

This variety was developed by CRURRS, Hazaribag for drought prone upland areas of Jharkhand, Bihar and Maharashtra. CR Dhan 40 is drought tolerant, medium-tall (115-120 cm) and early maturing (95-100 days) variety. Grain type of this variety is short bold, having high HRR. Yield potential of CR dhan is 3.0 and 4.0 t ha^{-1} under direct seeded and transplanted condition, respectively. It is moderately resistant to brown spot and leaf blast.

Vandana

Rice variety Vandana was developed by CRURRS, Hazaribag for drought prone rainfed upland areas of Jharkhand, Bihar, Odisha and Chhattisgarh. It was released in year 1992. It is drought tolerant, tall (100-110 cm) and early maturing (90-95 days) and deep rooted variety. Grain type of this variety is long bold. Yield potential of Vandana is 2.5-3.0 and 3.5-4.5 t ha^{-1} under direct seeded and transplanted condition, respectively. Besides drought tolerant, it is also weed competitive variety. It is moderately resistant to brown spot and blast.

Anjali

This variety was released by CRURRS, Hazaribag for drought prone upland areas of Bihar, Jharkhand, Odisha, Assom and Chhattigarh states of eastern region in 2002. It is drought tolerant, semi-tall (85-90 cm) and early maturing (95-95 days) variety. Grain type of this variety is short bold. Its yield potential is 3.0 and 4.0 t ha^{-1} under direct seeded and transplanted condition, respectively. It is highly resistant to brown spot & gall midge biotype 5 and 1and moderately resistant to leaf blast.

Drought effect on rice growth, physiology and yield

Rice plants respond to drought through alternation in morphological, physiological and metabolic traits. Understanding of physiological and biochemical mechanism that enable plants to adapt to water deficit and maintain growth and productivity during stress period could help in screening and selection of tolerant genotypes and using these traits in breeding programme. Variation in maintaining internal plant water status at flowering was associated with grain yield under drought condition. Drought impacts include alterations in growth, yield, membrane integrity, pigment content, osmotic adjustment, water relation and photosynthetic activities (Praba et al., 2009; Kumar et al., 2014). Several studies showed that drought caused negative influence on rice plant in terms of less tiller number, reduced plant biomass, reduced leaf area, lower plant water status, severe membrane injury, loss of chlorophyll content and dysfunction of photosynthesis system. Drought also causes lowering test weight, spikelet fertility and grain yield. Kumar et al. (2014) reported that drought stress at reproductive stage in rice cause reduction in physiological and biochemical traits, viz. leaf area index (LAI), relative water content (RWC), membrane stability index (MSI), TBARS content, total soluble sugar, starch and proline contents.

Characters for drought tolerant variety

- High yield under normal situation
- Good yield under drought condition
- Tolerance to drought at seedling, vegetative and reproductive stage
- Tolerant to majour diseases (blast and brown spot) and insect pest (stem borer, grasshopper and termite)
- Ability to withstand delayed transplanting conditions
- Ability to give yield well under low-moderate fertilizer management
- Ability to be grown under direct seeded situation in case of unavailability of water for transplanting
- Good grain quality/quality maintenance under drought
- High farmers' preference

Table 2: Rice varieties for drought prone areas of eastern states of India.

Varieties	Duration (days)	Yield (t ha^{-1})		Grain type	Favorable land for cultivation	Recommended states
		Drought	Non-stress			
Sahbhagi Dhan	110-115	2.5-3.0	4.0-4.5	Long –bold	Rainfed upland & medium lowland	Odisha, Bihar, Jharkhand, eastern UP and West Bengal
Shushk Samrat	110-115	2.5-3.0	3.5-4.0	Long –slender	Rainfed upland & medium lowland	Eastern UP, Bihar, Jharkhand and Odisha
Swarna Shreya	115-120	2.5-3.0	4.0-4.5	Long –bold	Rainfed medium lowland (aerobic condition)	Chhattisgarh, Madhya Pradesh and Bihar.
DRR 42 (IR 64 Drt 1)	115-120	2.5-3.0	4.5-5.0	Long –slender	Medium or upland	Tamil Nadu, Andhra Pradesh, Telangana, MP, Chhattisgarh & Jharkhand.
CR Dhan 40	95-100	2.5-3.0	3.5-4.0	Short-bold	Rainfed upland (direct seeded)	Jharkhand & Bihar
Narendra Dhan 97	95-100	2.0-2.5	3.0-4.0	Long –slender	Rainfed upland & medium lowland	UP, west Bengal, Bihar and Chhattisgarh
Narendra Dhan 118	90-95	2.0-2.5	3.0-3.5	Medium slender	Rainfed upland & medium lowland	Uttar Pradesh & Bihar
Anjali	90-95	2.5-3.0	3.5-4.0	Short-bold	Rainfed upland	Bihar, Odisha, Jharkhand, Assom & Chatishgarh
Vandana	95-100	2.5-3.0	3.5-4.5	Long –bold	Rainfed upland	Jharkhand, Bihar, Odisha & Chatishgarh
Hazaridhan	115-120	2.0-2.5	3.5-4.5	Long-slender	Rainfed upland & lowland	Jharkhand & Bihar
Indira Barani Dhan	110-115	2.5-3.0	4.0-4.5	Long-slender	Rainfed upland & medium lowland	Chhattisgarh & MP

Identification of drought tolerant rice genotypes

The ability of crop cultivars to perform reasonably well in drought stressed environments is paramount for stability of production. The relative yield performance of genotypes in drought stress and non–stress environments can be used as an indicator to identify drought resistant varieties for drought prone environments. Several drought indices [Drought Susceptibility Index (DSI), stress tolerance index (STI), stress tolerance level (TOL), Yield index (YI), stress susceptibility index (SSI)] have been suggested on the basis of a mathematical relationship between yield under drought conditions and non-stressed conditions. These indices are based on either drought resistance or drought susceptibility of genotypes (Raman et al. 2012). Various physiological traits like membrane stability index (MSI), relative water content (RWC), chlorophyll content, proline accumulation, photosynthetic rate and stomatal conductance have been reported as the marker traits to differentiate drought tolerant and susceptible rice genotypes. Kumar et al. (2014) suggested that selection based on drought tolerance indices DTE, SSI, STI and TOL will results in the identification of drought tolerant genotypes with significantly superior and stable performance of yield and yield attributes physiological and biochemical traits over current cultivated varieties under water stress condition in rainfed lowland drought prone ecosystem

Potential morpho-physiological traits used for screening rice genotypes for drought tolerance

1. Grains per panicle
2. Spikelet fertility (%)
3. Effective tillers/m^2
4. Test weight (1000 grain weight)
5. Grain yield
6. Pollen viability
7. Leaf curling and tip drying
8. Flag leaf area
9. Relative water content (RWC)
10. Membrane stability index (MSI)
11. Photosynthetic rate (P_N rate)
12. Leaf chlorophyll content
13. Stomatal conductance
14. Stem carbohydrate re-mobilization
15. Root length and root weight

Conclusion

The challenge of growing water scarcity and frequent occurrence of drought has been identified as the key to low rice productivity in rainfed ecosystems of eastern region, threatening food security. Because of absence of high yielding, good quality drought tolerant varieties, farmers in rainfed ecosystem continue to grow traditional varieties, leads to high yield losses. Adoption of high yielding drought tolerant rice varieties like Sahbhagi Dhan, Swarna Shreya, DRR 42, Shusk Samrat, NDR 97, NDR 118, CR Dhan 40, Vandana, Hazari Dhan and Anjali will play pro-active and decisive role in developing sustainable food production and lead for food security among farm families in the drought prone areas.

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Impact of Conservation Agriculture on mitigating the adverse effect of Climate Change

Manisha Tamta, Rakesh Kumar, Santosh Kumar, Kumari Shubha and Abhishek Kumar Dubey

ICAR-Research Complex for Eastern Region, Patna (Bihar)

The United Nations Framework Convention on Climate Change (UNFCCC) has defined climate change as "a change of climate which attributed directly or indirectly to human activity that alters the composition of the global atmosphere and which is in addition to natural climate variability observed over comparable time periods" **(Kumar and Agarwal, 2011)**. The Intergovernmental Panel on Climate Change (IPCC) in its fifth assessment report **(IPCC, 2013)** had stated that "warming of the climate system is unequivocal, and since the 1950s, many of the observed changes are unprecedented over decades to millennia", global land and ocean surface temperature has warmed by 0.85 (0.65-1.06) °C, frequency of heat waves has increased in large parts of Europe, Asia and Australia, global mean sea level rose by 0.19 (0.17- 0.21) m and Green House Gas (GHG) concentration for carbon dioxide (CO_2), methane (CH_4), and nitrous oxide (N_2O) has increased by 40%, 150%, and 20%, respectively compared to pre-industrial levels. Total radiative forcing is positive which has led to an uptake of energy by the climate system by the maximum contribution of carbon dioxide (CO_2). GHGs present in the atmosphere beyond their natural levels have been ascribed as the major cause for climate change **(Harikumar, 2016).**

One person emits nearly 20 tons of CO_2 per year and combustion of most carbon containing substances produce CO_2. Though this gas makes up just 0.035 % of the gases present in the atmosphere, but it is the most abundant gas among the GHGs **(Kargari and Ravanchi, 2015).** Global Warming Potential (GWP) of major GHGS is shown in **Table 1**, which expresses extent of the global warming effect caused by each greenhouse gas relative to the global warming effect caused by a similar mass of carbon dioxide. CO_2 concentration in Earth's atmosphere has increased from its pre-industrial level of ~280 ppm to 317 ppm in 1960 and 390 ppm in 2010 as measured at ground level in Mauna Loa, Hawaii **(Tans and Keeling, 2011)**. On the other side CH_4 concentration has also increased from 1151 ppb in 1985 to 1355 ppb in 2008 as observed in the lower stratosphere **(Rinsland *et al*., 2009).** Possibly due to this increase in methane concentration, stratospheric water vapour has also increased by ~2 ppmv from 1945 to 2000, with its present level of ~4-6 ppmv **(Hurst *et al*., 2011).** This increased level of GHGs in the atmosphere has led to a remarkable decrease in total ozone concentration level from ~375 Dobson units (DU) in 1970 to ~325 DU in 2000 as measured in Switzerland, which is much higher over the polar regions **(Solomon, 1999)** Intensity and frequency of extreme weather events such as droughts, floods and cyclone is expected to be more in coming years thus, adversely affecting agriculture, water resources, forest ecosystem, energy, infrastructure and human as well as animal health. Based on the suite of climate models, by 2070-2099, the average temperatures across seasons are likely to range between 2.5-5°C and winter temperatures are likely to be significantly higher ranging between 3.75- 4.85 °C whereas South-West monsoon precipitation with a much higher uncertainty is likely to increase between 9-27 % across the regions of India **(Kavi, 2016)**.

Table 1: Global Warming Potential of GHGs

GHG	Chemical formula	Lifetime up to (years)	Radiative efficiency ($Wm^{-2}ppb^{-1}$)	Global Warming potential	Contribution to global warming
Carbon dioxide	CO_2	100	1.4×10^{-5}	1	76 %
Methane	CH_4	12	3.7×10^{-4}	23	12 %
Nitrous Oxide	N_2O	114	3.03×10^{-3}	310	11 %

(*Source:* Sejian and Naqvi, 2015; Kargari and Ravanchi, 2015)

Climate change and Agriculture

There are three ways in which climate change may affect crop production firstly; increased atmospheric CO_2 concentrations can have direct effect on the growth rate of crop plants and weeds, secondly; CO_2 induced changes in climate may change temperature, rainfall and sunshine, all of which can influence plant growth and finally; rises in sea level may lead to loss of farmland by inundation and to increasing salinity of groundwater in coastal areas. There are very good chances of decrease in rice yield up to 5 % for every 1°C rise in temperature above 32 °C (IPCC, 2007) and there will be decline in world agricultural productivity by 3-16 % by 2080s (FAO, 2010). Furthermore, the global temperature is expected to increase by 3 to 5 °C by the end of this century (IPCC, 2014). In current context of climate change the abiotic stresses are major factor that limits crop productivity, causing series of changes in terms of morphological, physiological, biochemical and molecular parameters that adversely affect plant growth and productivity. It has been estimated that drought stress can cause an average loss of 17 to 70% in grain yield (Nouri-Ganbalani *et al*., 2009).

Besides industrialization it is agriculture and livestock sector to be blamed for GHG emissions. Rice cultivation is considered as a contributor of methane gas (CH_4) due to anaerobic conditions maintained during growing season of crop and livestock is considered to contribute in production of methane (CH_4) and nitrous oxide (N_2O) gases into atmosphere. Climate change is expected to influence crop and livestock production, hydrologic and energy balance on the earth as well as input supplies and other components of the agricultural system (Singh and Pathak, 2014). Climate change can also change the frequency, occurrence and types of many crop and livestock related diseases and pests along with the availability and timing required to irrigate crop fields and the level of soil erosion. Literature shows that, high temperatures (30/20 °C day/night) during the growing season can reduce the cropping potential (thermodormancy) in everbearing strawberry varieties, due to the effects on pollen germination and pollen tube (Karapatzak *et al*., 2012) leading to flower abortion post anthesis. Sultan *et al*. (2013) found contrasting results for the Sudanian and Sahelian regions, with crop yields in the former region (sorghum and millet) strongly sensitive to high temperatures and those in latter region primarily responsive to changes in rainfall. Knox *et al*. (2012) provided evidence of consistent yield losses by 2050 for the major regional and local crops across Africa (wheat, maize, sorghum and millet) and South Asia (maize and sorghum) caused mainly by higher temperatures. Hence, coping with the projected changes in climatic conditions will require development of spatially differentiated strategies to mitigate negative trends and to take advantage of positive trends in crop and livestock productivity.

Impact of Conservation Agriculture

Food and Agriculture Organization (FAO) has defined Conservation Agriculture (CA) as an approach to manage agro-ecosystems for improved and sustained productivity, increased profits and food security while preserving and enhancing the resource base and the environment. It is based on the three main principles of; minimum mechanical disturbance of the soil, permanent organic cover of the soil surface and crop diversification or association of crops, along with other complementary good agricultural practices of crop production (FAO, 2014). It is mainly promoted for resource conservation and agricultural sustainability and has a potential to improve crop productivity, enhance resource use efficiency and also helps in coping with some weather extremes. A number of advantages are linked with CA like sustainability, enhanced biodiversity, labour saving, improved soil health and environment, climate resilience, increased crop yields and profits, and reduced costs on global, regional, local and farm level (Bhatt and Mishra, 2018). CA can help in mitigating atmospheric GHG by reducing existing emission sources and sequestering net carbon. This widely tested and proven technology has a remarkable impact in dealing with the adverse effects of changing climate in agriculture, such as:

- Conventional rice-wheat system is a well-known contributor of methane and nitrous oxide in the atmosphere and CA based rice-wheat system reduces such emissions by creating more aerobic soil environment.
- CA based system through its principal of residue retention reduces GHG and other pollutant emission to the atmosphere as burning of rice straw in conventional system leads to emission of 70% CO_2, 7% CO, 0.66% CH_4, and 2.09% N_2O (Gupta *et al*., 2004).
- Organic covers and residue retained on soil surface helps in maintaining soil tempeture and moisture under favourable ranges in root zone and crop canopy thereby enhancing plant growth and soil microbial population.
- CA-based system substantially reduces the cost of production (by 23 %) along with producing almost equal or even higher than conventional system and thereby increasing the economic profitability of production system.
- This system is capable in moderating the effect of high temperature (reducing canopy temperature by 1-4°C) and increasing irrigation water productivity (by 66-100%) compared to traditional production systems, thus well adapting to heat and water stress situations arose a result of gradual climate change in past years.
- CA based rice-wheat systems emit 10-15 % less GHG than conventional systems (Sapkota *et al*., 2015).
- Laser-aided land leveling, zero or reduced tillage (ZT or RT), crop residue retention on the soil surface and crop diversification resulted in positive benefits in terms of enhanced productivity and reduced production cost when evaluated as an alternative against conventional practices in a range of agro-ecological regions (Laik *et al*., 2014).
- Conversion of all croplands to conservation tillage globally could sequester 25 Gt C over the next 50 years which is equivalent to 1,833 Mt CO_2-eq/yr, making conservation tillage among the most significant opportunities from all sectors for stabilizing global GHG concentrations (Baker *et al*., 2007).
- No-till farming reduces unnecessary rapid oxidation of soil organic matter to CO_2 which is generally induced by the tillage (Nelson *et al*., 2009).
- CA systems leads to greater soil moisture-holding capacity and thus crops perform better than those under conventional tillage (Stewart, 2007).

- Nitrogen leaching and runoff losses are also minimized under CA systems and thereby reducing the need for mineral N by 30–50 % in the longer run (Crabtree, 2010) and has potential to lower N_2O emissions as well.
- Switching from conventional tillage to either no-till or to conservation agriculture would positively increase the net C sequestration potential for agricultural lands (Eagle *et al*., 2010).
- Using cover crops and/ or adding leguminous crops into the rotation increases potential for N cycling and for higher N-use efficiencies that results in reducing the need for fertilizer inputs and contribution to lower N_2O emissions.
- CA practices improves soil porosity which has two beneficial effects, a greater proportion of incident rainfall enters into the soil and a greater proportion of this incident rainfall reaches to plant available tension zone due to better distribution of pore-spaces of optimum sizes (Shaxson, 2006). Thus, even after facing a rainless period, the plants can continue growth towards harvest.

Conclusion

Conservation agriculture practices provide alternative management strategies to the farmers that can help them to deal with negative effects of changing climate (e.g., droughts or other extreme weather events). It is capable to contribute significantly in sequestration of atmospheric C, reduction of GHG, and reduction of fossil fuel consumption in agriculture systems. The three main principles of conservation agriculture shows how management factors interact with and contribute to soil C which is primary determinant of soil quality. Minimum soil disturbance requires less fossil fuel energy to be consumed by the system and less direct C emissions from the soil. Crop diversification or Crop rotations play a major role in mitigation of climate change and can be used as tools to increase nitrogen use efficiency, improve soil and water quality, and sequestration of atmospheric C. Most of the agricultural crop residues are 40- 50% C on a dry weight basis, their presence and management on the soil surface holds a key role in minimizing soil loss (by water, wind, and tillage) and increasing soil quality, soil organic C, and soil fauna activity. In totality, CA systems are proven to have a better impact in mitigating climate change.

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Conservation Agriculture: A potential approach for carbon sequestration and climate resilient farming

Sushanta Kumar Naik

ICAR-RCER, Farming System Research Centre for Hill and Plateau Region, Plandu, Ranchi

Conservation agriculture helps in sequestering atmospheric carbon in soil-plant system through change in agricultural operations and management practices. Conservation tillage along with efficient management of inputs, viz. irrigation, fertilizer and pesticides facilitates carbon sequestration in soil-plant system. Land use change and conventional agricultural practices are major contributors to global annual emission of CO_2. Conservation agriculture and recommended management practices (RMPs) collectively are to offset part of the emissions due to unscientific agricultural practices. In India, agriculture contributes about 17 per cent of the country's total GHGs emission. An intensive agricultural practice during the post-green revolution era without caring for the environment has supposedly played a major role towards enhancement of the greenhouse gases. Due to increase in demand for food production the farmers have started growing more than one crop a year through repeated tillage operations using conventional agricultural practices. Increase in carbon emission is the major concern, which is well addressed in kyoto protocol. Nowadays, more emphasis has been given for promotion of conservation agriculture to mitigate the impact of climate change.

Carbon sequestration may be defined as the long-term storage of carbon in oceans, soils, vegetation and geologic formations. Carbon exists in many forms, predominately as plant biomass, soil organic matter, and as carbon dioxide (CO_2) gas in the atmosphere and dissolved in seawater. Through the process of photosynthesis, plants assimilate carbon and return some of it to the atmosphere through respiration. The carbon that remains as plant tissue is then consumed by animals or added to the soil as litter when plants die and decompose. The primary way by which carbon is stored in the soil is as soil organic matter (SOM). SOM is a complex mixture of carbon compounds, consisting of decomposing plant and animal tissue, various microbes and carbon associated with soil minerals. Carbon can remain stored in soils for millennia, or be quickly released back into the atmosphere. Climatic conditions, natural vegetation, soil texture, and drainage, all affect the amount and length of time carbon is stored.

Carbon sequestration builds soil fertility, improves soil quality, improves agronomic productivity, protect soil from compaction and nurture soil biodiversity. Increased organic matter in soil, improves soil aggregation, which in turn improves soil aeration, soil water storage, reduces soil erosion, improves infiltration, and generally improves surface and groundwater quality. This enhanced soil health, facilitates use of agricultural inputs in an efficient manner and helps in sustaining agricultural productivity at higher level. It is also helpful in the protection of streams, lakes, and rivers from sediment, runoff from agricultural fields, and enhanced wildlife habitat. Besides these, it has major roles in mitigating GHG gas emissions and tackling the effects of climate change.

2. Carbon sequestration under Conservation agriculture

Principle of conservation agriculture follows the three main processes as described by FAO.

1. Minimal soil disturbance: disturbed area must be less than 15 cm wide or 25% of cropped area (whichever is lower). No periodic tillage that disturbs a greater area then aforementioned limits.
2. Soil cover: Ground cover must be more than 30%.
3. Crop rotation: Rotation should involve at least three different crops. However, monocropping is not an exclusion facto.

Forms of conservation agriculture

Major forms of conservation agriculture includes

- Minimum, reduced or no tillage
- Crop and pasture rotation
- Contour farming and strip cropping
- Cover and green manure cropping
- Fertility management
- Erosion control
- Agro-forestry and alley cropping
- Organic and biodynamic farming
- Stubble mulching
- Integrated nutrient management (INM)
- Integrated pest management (IPM)
- Irrigation management

The carbon sequestration under conservation agriculture is possible either by maximizing the carbon input or by minimizing the soil carbon loss. Carbon sequestration rate varies with plant characteristics, rotation sequence, type and frequency of tillage, fertilizer management in terms of rate, timing and placement of fertilizers in the soils and integrated management of pest and nutrients, crop and livestock etc.

Gifford (1984) has classified agricultural practices into primary, secondary and tertiary sources with reference to their C emission capacity. Primary sources of C emissions are either due to mobile operations (e g tillage, sowing, intercultural, harvesting and transport) or stationary operations (e g pumping water, grain drying and milling). Secondary sources of C emission comprise manufacturing, packaging and storing fertilizers and pesticides. Tertiary sources of C emission include acquisition of raw materials and fabrication of equipment and farm buildings, etc. Emissions of CO2 from agriculture are generated from three sources: machinery used for cultivating the land, production and application of fertilizers and pesticides, and the SOC that is oxidized following soil disturbance (Lal 2004).

Large-scale development and utilization of groundwater in various parts of India has caused depletion of groundwater resources resulting in increase of gray and dark areas in the country. Groundwater irrigation is a very C intensive practice. Pumping of water from aquifers requires lot of energy for lifting the water. Agrochemicals include nitrogenous, phosphoric and potasic fertilizers including many micro-nutrients (plant growth regulators) required for plant growth and chemicals in the form of herbicides, insecticides, fungicides. The production, packaging, storage and transportation of these agrochemicals require energy and thus they contribute to GHG emissions (Bhat *et al.* 1994).

Carbon levels in soil are determined by the balance of inputs, as crop residues and organic amendments, and C losses through organic matter decomposition. Management to build up SOC requires increasing the C input, decreasing decomposition, or both (Paustian *et al.*, 1997). Decomposition may be slowed by altering tillage practices or including crops with slowly decomposing residue in the rotation. The C input may be increased by intensifying crop rotations, including perennial forages and reducing bare fallow, by reducing tillage and retaining crop residues, and by optimizing agronomic inputs such as fertilizer, irrigation, pesticides, and liming.

2.1 Conservation tillage and carbon sequestration

Several studies compare soil organic carbon (SOC) in conventional and conservation tillage systems. The results from analysis suggest that switching from conventional cultivation to zero till would clearly reduce on-farm emissions.
In India, zero-till drills, strip till drills, roto till drills are used for direct drilling of wheat after paddy. Comparative study of zero till, strip trill and roto-till was carried out and their performance was compared with conventional tillage (Routray, 2003). In no-till plots, fuel consumption was found to be 11.30 l/ha as compared to 34.62 l/ha by conventional method resulting in fuel saving of 24 l/ha. There was 67 % saving in fuel due to no-tillage as compared to conventional method. Jat (2008) for rice-wheat system reported that the crop yield was comparable under flat bed and raised bed sown wheat and paddy and was equal to the yield obtained by conventional method.

Varvel and Wilhelm (2011) conducted a long-term experiment under rainfed conditions with six primary tillage systems (chisel, disk, plow, NT, ridge-till and sub till) and three cropping systems (continuous corn, continuous soybean, and soybean–corn). They reported that soil N and SOC were sequestered deeper in the profile and were protected against mineralization or erosion. Practising of primary, secondary and tertiary tillage resulted in loss of C of 12.0, 6.7 and 3.9 kg C ha^{-1} (Lal, 2004). In general, C emission is more in CT than NT due to a higher use of Diesel.

2.2 Impact of tillage and crop rotations on carbon sequestration

Crop rotations with combination of tillage sequestered more soil carbon compared to monocropping under different climatic conditions. Evidences from research suggest that inclusion of legume in cereal–cereal rotation enhance soil quality and raises organic carbon level in soil (Ghosh et al. 2012). It greatly enhances SOC status of soil when adopted along with CA practice. The legume cover crops, which contain carbon compounds likely more resistant to microbial metabolism, could also increase the complexity and diversity of soil carbon, making it more stable. Growing cover crop like summer mung bean (*Vigna radiata*) during intervening period (period from wheat harvesting to sowing/transplanting of rice) has tremendous capacity to improve land and water productivity through in-situ soil moisture conservation (Bhatt et al. 2016).

Conservation agriculture can increase the possibility for crop intensification due to a faster turnaround time between harvest and planting. Crops can be planted earlier and in a more appropriate planting time.

A long term field experiment was conducted during 2009–2016 taking four crop scenarios with conservation agriculture (CA), crop intensification and diversified cropping as intervening technology aiming to evaluate the sustainability of the rice-wheat systems in IGP (Samal et al. 2017). The S3 scenario (legume crop was taken along with rice and wheat with CA) registered highest total organic carbon (TOC) stock of 47.71 Mg C ha^{-1} and resulted in significant increase of 14.57% over S1 (Farmer's practice) in 0–30 cm soil depth after 7 years of field trial. The S4 scenario (Conventional RWCS was replaced with rice-potato +maize-cowpea cropping system with partial CA) having intensified cropping systems recorded lowest TOC of 39.33 Mg C ha^{-1} and resulted in significant depletion of 17.56% in C stock with respect to S3 in 0–30 cm soil depth.

2.3 *Impact of RMPs on carbon sequestration*

Conversion to restorative land uses (e g afforestation, improved pastures) and adoption of recommended management practices (RMP) can enhance SOC and improve soil quality. Important RMP for enhancing SOC include conservation tillage, mulch farming, cover crops, and integrated nutrient management including use of manure and compost, and agro-forestry.

Agro-forestry has importance as a carbon sequestration strategy because of carbon storage potential in its multiple plant species and soil as well as its applicability in agricultural lands and in reforestation.

Average carbon storage by agroforestry practices has been estimated as 9, 21, 50, and 63 Mg C/ha in semiarid, subhumid, humid, and temperate regions. For smallholder agro-forestry systems in the tropics, potential C sequestration rates range from 1.5 to 3.5 Mg C/ha/yr (Montagnini and Nair, 2004).

2.4 Impact of tillage and crop residues on carbon sequestration

Conservation agriculture, based on the use of crop residue mulch and no till farming can sequester more SOC through conserving water, reducing soil erosion, improving soil structure, enhancing SOC concentration, and reducing the rate of enrichment of atmospheric CO2 (Lal 2004a). Franzluebbers (2008) reported that greater soil organic C accumulation under pastures than under annual crops due to longer growing periods, more extensive root system, and less soil disturbance. Ghimire *et al.* (2008) reported that SOC sequestration could be increased with minimum tillage and surface application of crop residue and SOC sequestration was highest in top 0-5 cm soil depth irrespective of the tillage and crop residue management practices. Crop residue served as a source of carbon for these soils especially in upper soil depths. No-tillage practice minimizes exposure of SOC from oxidation, ensuring higher SOC sequestration in surface soils of no-tillage with crop residue application.

Soil aggregate formation generally increased with added residue amount, but the proportion of residues occluded within aggregates decreased with increasing addition level. The occlusion of residues from aboveground biomass was more reduced with addition level than that of roots. Residue mineralization increased with the addition level, but this increase was less for roots compared to stalks and leaves. With increasing levels of residue incorporation the increase of SOM per unit of input may decrease 1) due to a shift from recalcitrant below to labile aboveground input, 2) by a lower proportion of fresh residues protected within aggregates or 3) by inducing positive priming of SOM. Aboveground crop residues (e.g. leaves and stems) are considered high quality compared with belowground residues, which are relatively recalcitrant to decomposition e.g. roots

Leaf litter from plants, particularly trees, is a major source of organic matter and energy to soil and is important for nutrient cycling in an ecosystem. Substantial amounts of nutrients and organic matter produced by plants are returned to the soil through litterfall. Litter also reduces bulk density, increase water holding and cation- exchange capacity of the soil and serves as reserve store of plant nutrient. Leaf litter decomposition is a critical step in nutrient cycling and providing nutrients to plants. Litter on the orchard floor acts as input–output system of nutrient while litter on the soil surface intercepts and stores a certain amount of precipitation, thus reduces run-off and soil erosion. Mango and guava leaf litter constitute comparatively readily available sources of nutrients and they could be suitable for short-term nutrient correction and sustainability of soil fertility. However, leaf litter from litchi caused noticeable slow decay rate and is worthy to be used for organic matter build up in hot and dry sub-humid climate under CA (Naik et al. 2018).

Naik et al. (2017) observed that the maximum total SOC in 0-0.60 m depth was 62.47 Mg ha^{-1} in mango orchard and resulted in 17.2 % increase over control in eastern plateau and hill region of India. Similarly, the guava and litchi orchard recorded higher total SOC with 12.6 and 11 % increase over control, respectively. The higher SOC in mango orchard may be attributed to the different quantities and qualities of organic matter input through fresh litterfall, living organisms and root activity.

Conclusions

A healthy soil is fundamental for sustained agricultural productivity and the maintenance of vital ecosystem processes. Arable lands are prone to severe soil degradation. Thus, crops require ever-increasing input to maintain yields, even in high-yielding areas where soils are moderately degraded. Therefore, agriculture should not only be high yielding but also sustainable. Conservation agriculture involving continuous minimum mechanical, oil disturbance, permanent organic soil cover and diversified crop rotations provides opportunities for mitigating greenhouse gas emission and climate change adaptation. CA has the capacity for short-term maximization of crop production as well as the potential for long-term sustainability i.e., C storage. Soil C sink capacity depends on several factors including climate, soil type, crops and vegetation cover, and management practices. Recycling organic resources containing polyphenols and lignin may affect the long-term decomposition dynamics and contribute to the buildup of SOC. Hence, it is important to explore a wide range of adaptation strategies, which could reduce the vulnerability of agriculture to climate change. A wide adoption of CA will reduce the cost of labor, fuel, and machinery, while conserving water, reducing erosion, and sequestering C.

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Sustainable interventions for improving water productivity in rice fallow areas

Santosh S Mali, Bikas Das, AK Singh

ICAR-RCER, Farming System Research Centre for Hill and Plateau Region, Plandu, Ranchi

Agricultural production in India emanates from variety of agro-ecologies spanning over wide range of climatic conditions that vary from tropical to temperate. The agro-ecologies of eastern India are characterised with low productivities and marginal annual returns per unit of land. Although a major contributor to the national agricultural production, the level of agricultural development in the eastern region is much less than it's potential. This has led to limited employment in the agriculture sector and a large proportion of the population still remains below the poverty. The eastern region covers the states of Eastern UP, Bihar, Jharkhand, West Bengal, Assam, Orissa, and Chhattisgarh. It occupies about 28% of the country's geographical area with food grain production of 58 million tonnes (34.6% of the total), is inhabited by about 35% of the country's population.

Rainfed transplanted rice is the main *kharif* (monsoon) season crop of the Eastern Plateau Region of India. It is mostly mono-cropped in a rice-fallow system. Rice is cultivated across the length and breadth of the country occupying 43.86 million hectares (DAC, 2016). The crop is grown in both irrigated and rainfed agro-ecosystems under diverse cropping systems. Although, most of the cropped area is covered with rice during kharif, major portion of it remains uncropped during succeeding seasons. These fallow lands are referred as rice fallows. Rice fallows imply to those lands which are put to paddy cultivation during kharif season (July to October) but remain uncropped during *rabi* (November - February) and summer (March-June) seasons. There is enormous scope to improve the production potential of eastern region through bringing its vast rice-fallow areas under cultivation. This need social and technical interventions and large scale demonstration and extension of suitable technologies and best management practices across the region.

India accounts for 88.3% (12.0 million ha) of the total rice fallows of South Asia (22.3 million ha) (Gumma et al., 2016). The stare wise estimates of rice fallow areas as provided by the national crop forecast centre, DAC & FW, New Delhi and reported in the annual report of DPD (DPD, 2017) are presented in Table 1. In India, rice fallows are mainly spread in the states of Bihar, Chhattisgarh, Jharkhand, Madhya Pradesh, Odisha, and West Bengal. The four states of Odisha, Chhattisgarh, West Bengal and Assam contribute about 66.8% to the total rice-fallow area in India.

Table 1. Estimated area under rice-fallows in India

S. No.	Sate	Rice-fallow area (Mha)
1.	Odisha	2.961
2.	Chhattisgarh	2.856
3.	West Bengal	1.159
4.	Assam	1.042
5.	Jharkhand	0.475
6.	Bihar	0.049
7.	Other sates	3.458
Total		12.00

Constraints in Rice-Fallows

The major constraints in promotion of rainfed rabi cropping include quality seed, short-duration varieties of rice facilitating timeliness in sowing the rabi crops on residual moisture, uncertain rabi season rainfall, and problems of insect pests and diseases. Rice fallow areas face unique challenges that preclude the cultivation of rabi and summer season crop. Access to irrigation water being the prime reason, there are other technical and social constraints that limit multiple cropping within these regions.

Social constraints

Grazing: In eastern India, free grazing of animal is a common practice. Uncontrolled grazing during post kharif season is potential threat to succeeding crops. The fear that grazing animals will eat away the crops is forcing the farmers to keep their land fallow. It is the need of time that animals should be confined to the barns and that the stall feeding should be promoted. Farmers should allocate some land for growing fodder to meet the needs of animal fodder. This is possible only through some policy decisions that bar the farmers from free or uncontrolled grazing on lands that does not belong to them.

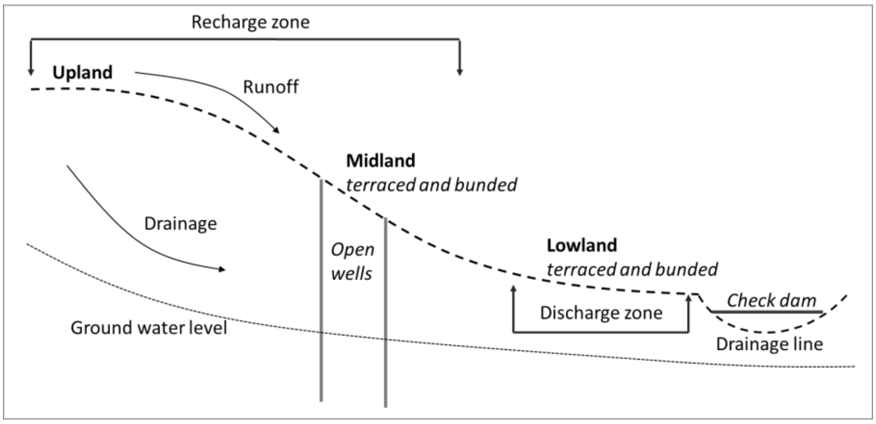
Low purchasing power: Rice fallow states are inhabited by poor people, having small size of landholding and little access to irrigation and other critical farm inputs. Agriculture is their main source of livelihood. But employment opportunities are limited. A large number of farmers migrate for the petty jobs in large townships of India. Agriculture in the eastern region is limited by the income of the farming communities. The risks in cropping begin with sowing. The production is deeply dependent on weather conditions. Water remains the most critical input for bringing more area under cultivation during the dry season. Irrigation can offer some respite—but not to the extent of completely removing production risks. The economic status of the farmers in the eastern region is not supporting development of irrigation infrastructure or in meeting the ends to arrange the inputs required for succeeding crops.

Lack of technical know-how: The farmers in this region are severely lagging in adopting new and improved technologies that can support dry season agriculture. The level of awareness and knowledge about winter or summer cultivation in rice fallows is seriously lacking among the farmers. Although, water conservation can support dry season agriculture, there is lack of knowledge among farmers on water conservation techniques.

Besides the constraints mentioned above, the other constraints like fragmented land holding, shortage of labour, limited access to institutional credit, and poor extension services directly or indirectly discourage farmers from opting for second crop.

Technical constraints

Topography: The region consists of a series of hillocks with drainage lines and low-lying areas near streams, collectively classified as lowlands, where paddy has traditionally been cultivated. In areas represented by the present study, lowlands extend about 60-150 m horizontally with a local relief of 2-3 m above the drainage line. These areas remain waterlogged for prolonged periods after the end of the monsoon season. The soils drain and become workable in the month of January. The area midway between lowlands and relatively planer uplands is categorized as midlands (Fig. 1), which have local topographic relief of about 2-7 m above the drainage line. Much of the original hill slope area (midland) has been terraced and bunded to convert it to paddy fields. The upper non-terraced and non-bunded planer areas generally have shallower, lighter-textured soil. Local water resources are not available to support irrigation in upland areas. Uplands typically lie at an elevation range >30 m above drainage line. Groundwater recharge mainly occurs in the uplands and the midlands (bunded paddy fields) while the low lands are the major discharge areas. The acid, infertile soils are developed mainly on gneiss or granite parent materials and are mainly Alfisols and Inseptisols (Agarwal et al., 2010).



(Redrawn from Cornish et al., 2015)

Fig. 1. Landscape schematic showing upland, midland and lowland areas.

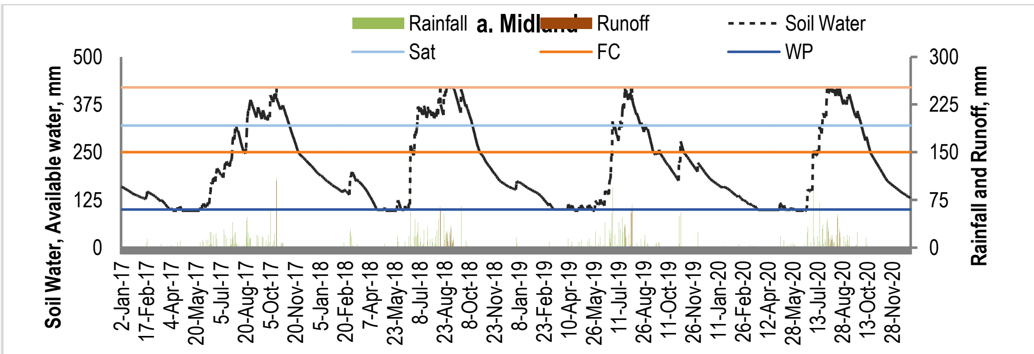
Soils: The characteristic soil properties like soil hardness and development of cracks generally make it difficult to carry out ploughing and other land preparation operations. Hardness of soil in the puddled rice fields deteriorates the hydraulic properties of the soil, which negatively affects the soil moisture distribution and root growth of deep rooted pulses (Ali et al. 2014). Soils in the rice-fallows also affect seed germination, seedling emergence and crop establishment due to disruption of soil structure, soil water deficit, poor aeration and mechanical impedance of the seed zone. Soil hardness combined with limited soil moisture creates potential threat to microbial activity, nutrient availability, root growth and water and nutrients uptake. Because of all these soil related factors major portion of the cultivate lands in the region remains fallows.

Water scarcity: With the withdrawal of monsoon season the soils of the region, owing to their typical hydraulic characteristics, start losing the soil moisture at faster rate. The undulating topography of the region and intense network of small streams and rivulets also favours quick drainage of the monsoon water. Limited surface storage facilities (farm ponds, reservoirs, dams) coupled with quick drainage leads to reduced water availability during dry season. Although, lowlands can support development of dug wells and shallow ponds that are fed by groundwater and can supply water for dry season, the midlands and uplands are grossly deprived of water resources. Small and minor water harvesting structures based upon traditional technology would go a large way in establishing micro-irrigation facilities and reducing soil degradation in such areas.

Poor irrigation infrastructure: As the development of 'traditional' irrigation schemes are also constrained (Srivastava et al., 2009), there is a need for creation of better irrigation infrastructures in the region. The canal irrigation network has very limited coverage in the region and, for instance, it is absent in the state of Jharkhand. Development of water resources would not only create opportunities for cropping in the *rabi* and summer season but will also help to build climate resilience in the farming systems of the region. Looking at typical geographical setup of the Jharkhand state, the minor Irrigation schemes are more feasible as they do not involve forest land and land acquisition. Such schemes can be completed in relatively shorter time and can be put to work in a very short period.

Famers have limited on-farm irrigation infrastructure. A small (1-5 hp) diesel or petrol operated centrifugal pump is the sole irrigation infrastructure with large majority of the farmers. Many poor farmers still irrigate their crops using a traditional pivot supported bucket lifts which have very limited capacity and are labour intensive. The traditional irrigation systems involving food irrigation and corrugations are mainstay of the fields which lead to loss of precious water and reduced irrigation water productivities.

Limited residual soil moisture: Soil moisture is major limiting factor in uplands and midlands. Although, these lands can support kharif crop, the residual soil moisture at the end of the kharif season is not sufficient enough to meet the seasonal water requirement of Rabi season crop. Simulation studies showed that soil water content in the midlands was above field capacity for longer part of the year (July to Nov) (Fig. 2a). During 2014, ponding duration was 102 days, while the prolonged dry spell in 2015 reduced the ponding duration to only 42 days under midland conditions. More than 90 days ponding was deemed necessary for good yields of medium-duration rice (Cornish et al, 2015). Even paddy cultivation bears considerable risk in the midlands and farmers need technological support not only for cultivation of second and third crop but also for the *kharif* paddy. Midlands exhibited substantial soil moisture availability at the end of the paddy season (≃190 mm) requiring only supplementary irrigations for *rabi* season crops and full irrigation for summer crops unless they are in lowlands and benefit from seepage inflow. Arable uplands get an average 132 days of plant available soil water during the *kharif* season, which is more than enough for a short-duration field crop or even vegetables (Fig. 2b). Modelling showed that the monsoon rainfall is sufficient even in dry years for a variety of rainfed crops to be grown in uplands with appropriate management.



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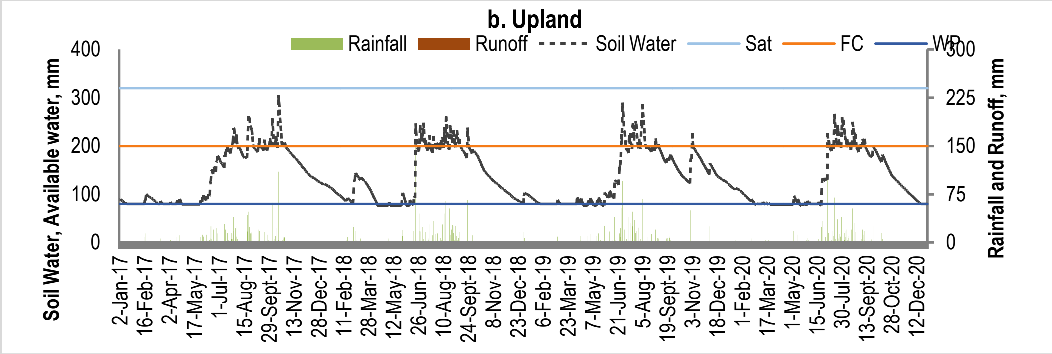

Fig 2. Simulated soil moisture dynamics in the a. midlands and b. uplands of the eastern plateau region

The Concept of Water Productivity

Water productivity has been given different definitions by different authors, often according to the scale of the plant, plot of land or watershed they were investigating or the purpose of their study. Molden (1997) defined water productivity as the physical mass of production or the economic value of production measured against gross inflow, net inflow, depleted water, process depleted water, or available water. Water productivity is usually estimated as the amount of agricultural output produced per unit of water consumed. In broader sense it is defined as the ratio of the net benefits from crop, forestry, fishery, livestock, and mixed agricultural systems to the amount of water required to produce those benefits. The denominator of the water productivity equation is expressed as water either supplied or depleted. Water is depleted when it is consumed by evapotranspiration, is incorporated into a product, flows to a location where it cannot be readily reused (to saline groundwater, for example), or becomes heavily polluted (Seckler, 1996). Mathematically water productivity is expressed as:

Number of social and technological interventions for improving WP in agriculture have been evaluated and demonstrated over past few decades. Major social factors that have direct influence on WP in agriculture include irrigation institutional reforms, privatization of wells, government policy (e.g., free electricity supply) and the response of farmers to water crisis and incentives also influence WP (Blanke et al., 2007; Hira, 2009). Major technological interventions that played a key role in improving agricultural WP were introduction of drip and sprinkler irrigation system and fine tuning of the furrow irrigation to suit the crop geometries and water demands. Effective and efficient irrigation scheduling approaches e.g. sensor based irrigation also offer great potential in improving WP as against the traditional practices of flood irrigation.

Impact of Improved Water Productivity

Apart from direct benefits like water saving and increased yield, WP offers several long term outcomes of livelihood improvement and better ecosystem services. Following chart explains the benefits offered by improved water productivity. Some of these benefits can be quantified through technical and social data. Other benefits are inherent, but their quantification is difficult, rather systematic procedure to quantify these is not available. The potential benefits of improving water productivity are summarised as:

- Non-grain benefits of water use in crop production such as the use of crop residues as fodder and/or mulch.
- Benefits from by-products of livestock and fish production and their role as food supplements for livestock and fish production systems or as inputs to enhance soil fertility.
- Benefits from ecosystem goods and services (biodiversity, ecosystem integrity,

$$Water\ Productivity\ (kg/m^3\ or\ \$/m^3) = \frac{Output\ derived\ from\ water\ use\ (kg}{Water\ input\ (m^3)}$$

habitat maintenance) and socio-cultural benefits, such as aesthetics and cultural importance, derived from hydrologic flows in agricultural water use systems.

Assessment of Water Productivity

Water productivity is expressed as a ratio of two quantities. It has a numerator and a denominator. In case of fodder crops the numerator can be total above ground dry matter, for other crops it can be edible weight of food crops. When we talk about economic water productivity the monetary benefits emanating from the water use becomes the numerator. At ecosystem level we consider the value of other benefits like improved livelihood and services rendered to ecosystem, however, this is very complex to estimate. The denominator of the estimation typically includes the amount of water – supplied or depleted. If the amount of water applied (supplied to field) is used as denominator it is termed as irrigation water productivity. The depleted water consists of evapotranspiration and water incorporated into a product and other flows which cannot be readily reused (to saline groundwater, for example), or becomes heavily polluted. Following schematic (Fig. 3) explains the parameters used in estimation of water productivity.

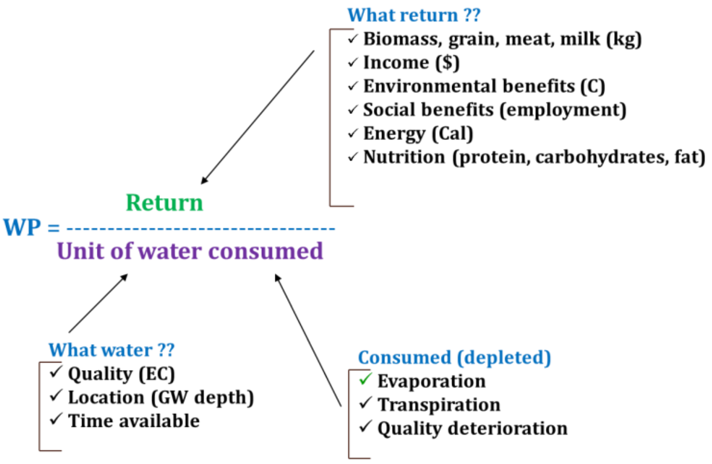

Fig. 3 Water productivity assessment framework

Interventions for improving water productivity in rice-fallows

Water harvesting and supplemental irrigation

Water scarcity in eastern plateau region of India is a well-known and alarming problem and water-related issues have become extremely acute and even critical. Keeping in view that the multiple cropping in rice-fallows is mainly constrained by limited water supplies; creation of water resources should be given top priority. This water resource can provide critical irrigations during dry seasons leading to improved water productivity. Supplemental irrigation is a highly efficient practice with great potential for increasing agricultural production and improving livelihoods in the rice-fallow areas. Among the most promising and efficient techniques for optimizing the use of the limited water available from renewable resources in rain-fed areas are supplemental irrigation and water harvesting (WH) that can improve farmers' income in dry environmental conditions (Oweis and Hachum, 2003).

The Plateau region is characterised as having frequent droughts and low productivity, but also great potential (Sikka et al., 2009) because the high average precipitation (1,100-1,600 mm) should provide for 'rainwater harvesting' which uses small structures to capture runoff or shallow groundwater for irrigation (Srivastava et al., 2009). Construction of farm pond or community water reservoirs to harvest excess rain-water during-rainy season is a feasible strategy to provide the lifesaving irrigation to the successive pulses in rice fallows. Excess run-off flowing out of the watersheds can be harvested in lined ponds to provide irrigation life-saving or supplemental irrigations.

Check dams: As a part of demonstration under ICAR funded project, a check dam was constructed on the stream flowing through Hundru village located in the peri-urban region of Ranchi. The construction was carried out in a participatory way involving the local community. Daily discharge of the stream (m^3 s-1) was monitored during 2015 at the check dam to assess the annual water availability (Fig. 4). The stream discharge represented a typical monsoonal characteristic of a small watershed on the eastern plateau region with peak flows (0.19 m^3/s) during July to August. Since the stream drains an urban watershed, a significant base flow ($\simeq$0.03 m^3/s) was always maintained in the stream (Fig. 4). The annual runoff from the check dam was estimated at 0.59 MCM, if we assume 80 % of these flows are utilizable (considering 20% as environmental flows) the water available for irrigation was 0.49 MCM. It is worth mentioning that major portion of this is available during the monsoon months, and the extent of pumping during this period depends on performance of the monsoon. This case highlights the potential of small water harvesting structures to provide supplemental irrigation during dry season.

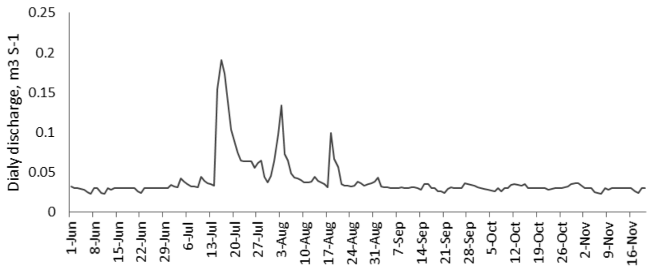

Fig. 4 Discharge of the stream monitored at the weir of check dam

Dug wells: In midland areas of rice-fallows where conveyance of water is not possible, the construction of small diameter (1.5 m) open wells will tap the upstream seepage flows and the stored water can be used for dry season crops. Monitoring of open wells in the midlands showed that groundwater level rises rapidly during June to August and plateaued during August to October. Water levels in the wells were high during the wet season until a steady fall following the end of the monsoon around October (Fig. 5). Water from the open wells can provide water for irrigation of rabi as well as summer crops. Based on pumping tests to assess potential drawdown, it was estimated that water availability varied from 3,600 to 4300 m^3 across the monitored wells. In the events of deficit rainfall (delay in onset or mid-season deficit), the open wells can also support the cultivation of paddy on the midland.

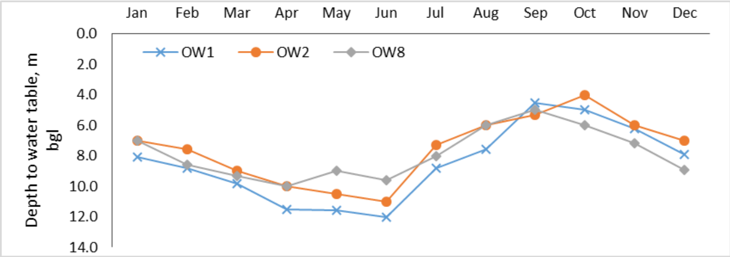

Fig. 5 Monthly water table fluctuation in open wells in the midlands of the study area in 2015

On farm reservoirs: In this method of water harvesting for rain-fed rice cultivation, there is no provision for safe in-situ storage of excess water. The new approach to rainwater management envisages the creation of a small in-situ storage facility, an on-farm reservoir (OFR), in series across or along the slope for collection, diversion and use of excess rainfall, which is otherwise lost as run-off.

Doba for uplands: Small rainwater harvesting structure called *Doba* (Fig.6) can be effectively used for establishment of agroforestry in upland which comprises more than 70% area in Chotanagpur plateau region. Although on an average 140 cm rainfall is received in Chotanagpur plateau, water is the single most important constraint in establishment of agro-forestry. In the process, each Doba structure with 4.5 m3 capacity (3.0 m length, 1.5 m breadth and 1.0 m depth) has been constructed for harvesting of rainwater before the onset of monsoon. The inner sides of the Doba structure were lined with 200 µ black polythene sheet. The excavated soil was used to make a small bund covering the black polythene sheet. Rest of the soils were used to make bunds surrounding the group of 12 budded/grafted trees or MPTs. Clear rainwater is allowed to store in the Doba structure during monsoon months. Finally in the month of October, the Doba structure was covered with thatch made of hogla (Typha elephantina). At fortnightly interval, neem/karanj oil is poured to reduce evaporation. The Doba structure constructed could be used for three years. It was observed that these Doba structures were helpful in providing lifesaving irrigation for establishment of orchards in Chotanagpur plateau region. The dimension of Doba has been designed in such a way that, it can provide lifesaving irrigation to 10 plants for six months. The daily average requirement of newly planted mango plant for life saving irrigation is 1 litre and for six months 1800 litre of water is required by 10 number of mango plants.

Fig. 6 Doba: a small water harvesting tank for uplands

The 5% Model: This is a model developed by PRADAN for in-situ rainwater harvesting is suitable for medium uplands, in which every plot has its own water body, the area of which equals 5% of the total area of the plot. The pit is able to hold rainwater that otherwise flow out of the plot as runoff. The water held in the pits irrigates the plots during water scarcity. Measure the length and width of individual plot and demarcate 5% upper right corner of the plot to dig the pit. This can be achieved by marking one-fifth of the length and one-fourth of the width in the right upper corner of the plot. The pit is dug down to a depth of 2 to 2.5 m depth depending upon the soil type and the permissible side slope 1:1. The excavated loose earth can be used to form a small 4-inch high bund around the pit to keep some standing water in the field. This earth can also be used to strengthen the field bunds.

Supplemental irrigation

Application of supplemental irrigation during dry spells had a significant impact on paddy yields (Table 2). Despite good rains in June and July (523 mm) which triggered transplanting, rainfall during the rest of the growing season was only 234 mm (1^{st} August to 17^{th} October). The yields obtained with 12, 10 and 6 irrigations were not significantly different from each other (average 6.23 t ha^{-1}), but they were significantly greater than with 4 irrigations (289 mm). This demonstrated the value of supplementary irrigation with transplanted rice in a dry year, but also showed the propensity for farmers to over-irrigate and waste water. Six irrigations (≃360 mm) were sufficient for maximum paddy yields. The water use efficiency for the best treatment (10 irrigations) was 7.01 kg ha^{-1} mm^{-1} which slightly exceeded WUE values observed with 12 irrigations. Earlier studies have shown that transplanted rice yields decline as soon as soil water drops below saturation (Bauman and Tuong, 2001), and that the period around anthesis is the most sensitive to rainfall deficits (Garrity and O' Toole, 1995). Maintaining soil water at saturation is a major challenge for areas with variable rainfall, like the Plateau region, especially in midlands that do not benefit from seepage inflows. Whilst the villages in the present research were able to develop water resources capable of providing supplementary irrigation for transplanted rice, this is not the case for the majority of Plateau villages. These finding have implications forming appropriate policies with special focus on water resource development in the plateau region to support agriculture during dry spells.

Table 2 Yield and water use efficiency of rice under different irrigation scenario during 2015

Water source	Number of irrigations	Depth of water applied(mm)	ASW* for the growing period, mm	Average Yield (t ha^{-1})	Water productivity (kg ha^{-1} mm^{-1})
Open well	12	485	959	6.38 ± 1.83^{a}	6.65
Open well	10	413	886	6.21 ± 2.01^{a}	7.01
Check dam	6	360	833	6.10 ± 1.45^{a}	3.72
Check Dam	4	289	762	3.98 ± 1.03^{b}	5.22
Rainfed	no irrigation	0	473	0.64 ± 0.22^{b}	1.35

*Crop water use as estimated from the simulated soil water balance

Timeliness of paddy sowing/transplanting

There are number of instances that showcased the importance of timeliness of paddy sowing/transplanting in achieving better yields and income from succeeding *rabi* crops. In an experiment conducted at farmers' field, the impact of different sowing time of rice (direct sown rice, DSR) was compared with rice transplanted at different dates. The number of irrigations were varied as per the need felt by the farmers in each of the plot. Planting of the timely DSR (DSR_t) and nurseries for timely transplanting (TR_t) took place in the last week of July, with transplanting about 3 weeks later. Harvesting of paddy under timely and delayed DSR treatments was completed in the 1st week of November and 3rd week of November, respectively, while the transplanted rice under timely and delayed transplanting was harvested in 4th week of November and 2nd week of December. From the dates of planting and harvesting, it follows that the duration of transplanted crops was about three weeks longer than with DSR. Early harvest of paddy under DSR_t and DSR_d provided an opportunity for growing of early *rabi* season bottle gourd and mid-season *rabi* garden pea. Late harvests in case of TR_t and TR_d provided for main-season bottle gourd and late season garden pea as *Rabi* crops.

The best treatment paddy yield was with timely planted DSR_t, with a yield of 6.42 t ha^{-1} (Table 4). The response of planting method and date of sowing/transplanting was significant; however, the difference in yield between delayed DSR and timely TR was not significant ($P \geq 0.05$). Fields with delayed transplanting recorded the lowest average paddy yield (2.16 t ha^{-1}). The yield of the rabi crops (bottle gourd and garden pea) was also significantly higher where early cultivation was possible under DSR_t and TR_t treatments (Table 3). Although the yield of early season bottle gourd (November 3rd week) was higher than that of main season bottle gourd (December 3rd week), farmers had the advantage of a higher selling price resulting in better economic return. The model estimated residual soil moisture of 233 and 195 mm at the time planting of second crop supported the establishment and growth of second crop after timely and late DSR, respectively (Table 3). The water productivity for DSR_t + bottle gourd sequence was 42.0 kg ha^{-1} mm^{-1} which was higher than the TR_t + bottle gourd mainly because of higher yields of DSR and bottle gourd crops. Delayed transplanting of rice (TR_d) and cultivating garden pea as second crop recorded lowest PEY (9.06 t ha^{-1}) as well as water productivity (17.5 kg ha^{-1} mm^{-1}).

Table 3 Soil moisture status and irrigation water applied in different cropping sequences during 2014

Paddy			Second crop (bottle gourd/garden pea)	Water use of sequence† (mm)
Planting method and cropping sequence	Number of irrigations		Residual soil water at planting (mm)	
DSRt + bottle gourd	1		233	486
DSRd + garden pea	0		195	437
TRt + bottle gourd	2		178	482
TRd + garden pea	0		163	518

†Water use by rice plus the second crop based on model estimates

Table 4 Comparative performance of different cropping system under midland conditions

Planting	Duration of rice (week/month)	Paddy yield (t ha^{-1})	Vegetable crop grown after rice	Duration of vegetable crop (week/month)	Vegetables Yield (t ha^{-1})	Total paddy equivalent yield (PEY) (t ha^{-1})	Water productivity, PEY$^{\wedge}$/TWU† (kg ha^{-1} mm^{-1})
DSRt	4th/Jul to 1st/Nov	6.42 ±1.96 a	Bottle gourd	3rd/Nov to 2nd/Apr	11.43±2.16	20.29a	42.0
DSRd	2nd/Aug to 3rd/ Nov	4.31 ±1.02 b	Garden pea	3rd/ Nov to 2nd/Feb	6.23±1.31	14.10b	32.3
TRt	1st/Aug to 4th/Nov	4.48 ±1.16 b	Bottle gourd	3rd/Dec to 2nd/May	13.63±2.87	16.16b	33.5
TRd	3rd/Aug to 2nd/Dec	2.16 ±0.47 c	Garden pea	2nd/Dec to 2nd/March	5.83±0.94	9.06c	17.5

$^{\wedge}$Paddy equivalent yield of the cropping sequence, †Total water use for the cropping sequence

Improving on-farm irrigation infrastructure

Surface drip: Better on-farm irrigation infrastructure can play a pivotal role in improving the water productivity at farmers' fields. Drip irrigation systems are the proven technologies to improve the crop yield and water productivity (Mali et al, 2019). Farmers are of the opinion that it is difficult to cultivate *rabi* crops without irrigation and most of them indicate a lack of capital as a major constraint in carrying out on-farm irrigation. Our research to evaluate the effect of on-farm irrigation infrastructure and intensification of cropping systems showed that, from a land of 0.10 ha area, farmers earned an income of ₹ 46890/- from mixed cropping of vegetables in two seasons (Table 5). Another farmer earned ₹ 82090/- from 0.50 ha area. This is a substantial income when it is considered that average family income from all sources in this village is only ₹ 62,103/-. These results clearly indicated the feasibility of increasing the profitability of agriculture in uplands with vegetable cultivation under drip irrigation. One open well supported cultivation of vegetable crops on 0.60 ha.

Table 5 Crop yields and income from drip irrigated cropping sequences

Total Area	Crop Season	Cropping sequence	Growing Period	Crop	Yield (t ha^{-1})	Income (₹)	Gross income, ₹
Farmer 1 Area : 0.10 ha	*Kharif*	sponge gourd + cowpea	May-Sept 2014	Sponge Guard	10.38	18690	46890.0
				Cowpea	4.79	7670	
		indeterminate tomato + capsicum + cowpea	Oct 2014 – Feb 2015	Tomato	7.31	8780	
	Rabi			Capsicum	3.65	6950	
				Cowpea	2.66	4800	

Farmer 2 Area : 0.50 ha	*Kharif*	cowpea + cucumber	July – Oct2014	Cowpea	2.43	4680	82090.0
				Cucumber	5.58	10050	
		bitter gourd	July-Oct 2014	Bitter gourd	11.36	12500	
		cowpea + sponge gourd	Jul – Oct 2014	Cowpea	2.86	6890	
				Sponge gourd	5.92	18650	
	Late *kharif* to mid *rabi*	chilli	Aug – Dec 2014	Chilli	3.86	12560	
	Rabi	cabbage	Oct 2014 – Jan 2015	Cabbage	6.83	4260	
		brinjal	Oct 2014 – Feb 2015	Brinjal	13.4	12500	

Subsurface drip irrigation: One of the most advanced developments in drip irrigation technology is 'subsurface drip'. The SDI has potential for precise water and nutrient management to match the crop needs. Previous research has shown that subsurface drip with 20 cm lateral depth reduced water consumption by 6.7 and 7.3 % and increased the bell pepper yield over DI significantly by 4 % and 13 %, for the two years of experimentation respectively (Kong et al., 2012). Patel and Rajput (2009) reported maximum onion yield and water productivity of 0.55 t ha^{-1} cm^{-1} under 10 cm lateral depths. An experiment conducted on cucumber cultivated at the research farms of ICAR-RCER, FSRCHPR, Ranchi (Mali et al, 2016) to evaluate the response of cucumber to subsurface drip and fertigation. Four depths of drip lateral placement, 0 cm (D00), 5 cm (D05), 10 cm (D10) and 15 cm (D15) and four fertiliser application levels with N, P and K in the ratio of 50:30:30 (F1), 100:60:60 (F2), 120:90:90 (F3) and 150:120:120 (F4) kg/ha were considered in the study. It was observed that placing laterals on surface and at 5 cm depth below soil surface the seed germination percentage was comparatively higher (92.8 and 90.2 %) than placing lateral at deeper depths. Adoption of subsurface drip consistently recorded higher cucumber yield with water productivities in the range of 0.49 to 0.81 t ha^{-1} cm^{-1} for laterals placed at 10 cm and 0.50 to 0.85 t ha^{-1} cm^{-1} in case of laterals placed at 15cm below soil surface. The results showed that subsurface drip maintained uniform moisture in soil profile, minimized the evaporative loss and consequently increased water productivity. Subsurface drip was also found to increase the water productivity of bitter gourd crop (Mali et al, 2017).

Table 2. Water productivity (t/ha/cm) of cucumber under different lateral depth and fertigation levels

Lateral depth	Fertigation level				
	F1	F2	F3	F4	Mean
D0	0.37	0.42	0.52	0.49	0.45
D05	0.41	0.44	0.62	0.52	0.50
D10	0.44	0.49	0.62	0.57	0.53
D15	0.43	0.50	0.66	0.49	0.52
Mean	0.41	0.46	0.60	0.52	0.50

Better crop management practices

Poly tunnel cultivation: Use of poly tunnels for early season cultivation of bottle gourd showed provides an added advantage of higher price for produce and conserving precious soil water. Early sowing of the seeds in November and covering it with transparent polythene sheet and poly tunnel cultivation resulted in maximum yield (3.18 t ha^{-1}) and gross income (₹ 38400.0 per ha) (Table 6). This increase was mainly due to higher percentage of female flowers in early sown crop. In case of February sown crop, healthy nursery raising in pro-trays and use of plastic mulch resulted in 26.57 % increase in yield and 26.96% increase in gross income over traditional practices. Growing of early crop of bottle gourd helped in minimizing irrigation water requirement through efficient use of residual soil moisture as well as minimizing evaporative loss of irrigation water consequently increasing the irrigation water use efficiency of bottle gourd production. Healthy nursery raising using pro-trays and plantation on raised bed with plastic mulching were most convincing to the farmers.

Raised bed with polythene mulch: Raised beds with polythene mulching can be potential technological alternatives for vegetable cultivation during dry season. Transplanted sponge gourd on mulched raised bed resulted in maximum yield (8.15 t ha^{-1}) and gross income (₹ 85000/- per ha) which was 27 and 12 % higher than the yield and income obtained under direct sowing method (Table 7). Increase in yield under transplanted crop may be attributed to optimum and uniform plant population in field and considerable reduction in the incidence of downy mildew. Even when the July planted crop required two irrigations at the initial stage of crop establishment, the increase in yield and gross income was convincing enough for the farmers for adoption of improved practices.

Table 6 Impact of different cultivation practices on irrigation water use efficiency of bottle gourd

Cultivation practice	Number of farmers	Duration of crop in field	Average Yield (t ha^{-1})	Gross Income (₹ ha^{-1})	Irrigation water use efficiency (kg ha mm^{-1})
Early summer season cultivation by covering the seed with transparent polythene and polytunnel cultivation	3	November 2014 -Mar 2015	3.18	38400.0	47.3
Early summer season cultivation in polytunnel and plastic mulch	3	Dec 2014 - Mar 2015	2.62	31400.0	44.1
Pro-tray nursery and raised bed cultivation with plastic mulch	8	Feb-May 2015	1.81	16000.0	36.3
Traditional practice (furrow cultivation)	19	Feb-May 2015	1.43	12600.0	24.8

Table 7 Impact of sowing method on yield and income of sponge gourd

Number of farmers	Method of planting	Duration of crop in field	Total water use, mm	Average yield (t ha^{-1})	Water use efficiency kg ha^{-1} mm^{-1}	Gross income (₹ ha^{-1})
4	Nursery raising in pro-tray and transplanting on mulched raised beds	July-October	345	8.15^{a}	23.62	85000.0
3	Direct sowing on mulched raised bed	July – September	368	6.40^{b}	17.39	76000.0
8	Direct sowing in furrow (traditional practice)	August-October	295	4.18^{c}	14.17	59500.0

Cultivation of bush type cowpea on plastic mulched raised beds resulted in significant ($P<0.05$) increase in the yield over traditional practice during both the seasons (Table 8). However, the increase in yield and water use efficiency was remarkably higher than that of traditional practice (76.24% and 67.84%, respectively) in case of cultivation during the summer season. Rainy season cultivation of bush type cowpea resulted in early harvest of crop (1 month) than that of pole type which created an opportunity for early sowing of winter crop and effective utilization of residual soil moisture.

Table 8 Yield and WUE of cowpea as affected by method of planting

Number of farmers	Method of planting	Crop and Variety	Duration of crop	Average Yield (t ha^{-1})	Water use efficiency (kg ha^{-1} mm^{-1})	Gross Income (₹ ha^{-1})
3	Raised bed cultivation with plastic mulch	Cowpea (Bush type)	Jul-September	7.38^{a}	26.51	81666.0
11	Traditional practice	Cowpea (Pole type)	July-October	5.61^{b}	16.34	62300.0
2	Raised bed with plastic mulch	Cowpea (Bush type)	Feb-May	4.60^{b}	12.32	38000.0
8	Traditional practice	Cowpea (pole type)	Feb-April	2.61^{c}	7.34	18600.0

Utera/paira Cropping: After harvest of kharif rice adequate moisture remains in field and farmers generally do not grow any crop leading to rice-fallow cropping system in about 12.9 Mha area in eastern India. But carry-over residual soil moisture can be utilized to grow low water requiring, short duration pulses and oilseeds like black gram, green gram, horse gram, pea, chickpea and Lathyrus, linseed, mustard. Relay cropping of soaked seeds of pulses (black gram, green gram, horse gram, pea, chickpea and Lathyrus) or oil seeds (linseed, mustard) are broadcasted in well drained field inside the standing rice crop, 10-15 days before harvest for efficient utilization of residual soil moisture during rabi season.. To ensure germination 40-50% extra seed is used. In rainfed lowland of Bhuban block, Dhenkanal, Odisha, under farmer's traditional relay cropping system, only 350, 300, 400 and 220 kg/ ha yield was obtained in lathyrus, black gram, pea and chickpea, respectively. Through our scientific intervention crop productivity of 34-55% and water use efficiency of 35-48% was increased in these four crops.

Fruit based multi-tier systems

Uplands are characterised with rocky terrains and low soil depth with very limited soil water storage capacity. These lands have limited technological options to be brought under cultivation. Fruit based multi-tier systems with vegetables as intercrops can be one of the feasible options. Our research with establishment of such systems in uplands has shown promising results. In this research the uplands were cleared-off of the stones and were minimally levelled with the participation of the community. A system layout involving 40 plants of mango and 120 plants of guava. During November to April, brinjal cv Swarna Pratibha was grown in an area of 0.30 ha as an intercrop between the crop rows. Irrigation was provided from the river water with a 2 hp electric pump set made available to the farmers. During the first year of experimentation the farmer earned ₹ 76400/- from the brinjal crop. During second year French bean was grown as intercrop which accrued an income of ₹ 65000/-. After two years of planting, the survival rate of the fruit trees was 100%, which was mainly possible due to the availability of irrigation. The systems are now well established and farmers are earning income from the harvest of fruit crops.

Conclusions

Despite all constraints, the agriculture in eastern India is witnessing a slow transformation from traditional to modern management practices. The pace at which it is transforming is slow and it needs to be accelerated by devising informed policies and developing irrigation and other infrastructure. Diversification of agriculture in eastern India towards high-value produce is the next step forward to increase the water productivity and the farmer's income. Keeping in view that integration of several components of farming system can lead to many fold increase in water productivity, development of the possibilities for integrated farming systems incorporating dairy, horticulture and fisheries should be explored. An integrated-farming-system approach can generate additional incomes for farmers along with higher crop and water productivity. It would need investment in developing physical and financial infrastructure such as agro-processing, rural warehouses, cold storages, cold chains, and financing institutions. In the context of changing climatic conditions, the farming has become a very risky affair. Government policy should focus not just on higher production but also on helping farmers manage risks through provision irrigation infrastructure, drought escaping varieties and improve crop husbandry practices. Conventional water management guidelines should be revised to ensure maximum water productivity instead of land productivity. Substantial and sustainable improvements in water productivity can only be achieved through integrated farm resources management. Improved on-farm technologies and better irrigation management coupled with timely socioeconomic interventions will help to achieve this objective.

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Strategies for identifying wheat genotypes under climate change scenario

S.K. Dwivedi and Santosh Kumar
ICAR-Research Complex for Eastern Region, Patna, Bihar-800014

Production of food grains in modern decade is not keeping pace with growing population demand, which in turn leads to inflation and a risk to food and nutritional security in India and other developing countries. Furthermore, the spreading of urbanization has forced agriculture into more harsh situations and marginal lands, while the global food requirements has been projected to increase by 70% by the end of 2050 necessitate improvement in agricultural productivity with a lesser amount of resources like land and water (Fischer et al., 2014). Moreover, abiotic stress is the primary cause of crop loss worldwide, reducing average yields for major crop plants by more than 50%. It includes stress condition like drought, salinity, extreme temperatures and heavy metals. All these abiotic stress leads to a series of morphological, physiological, biochemical and molecular changes that adversely affect plant growth and productivity. In current context of climate change the drought and heat are the most serious environmental factor limiting the productivity. Further, estimates indicate that 25% of the world's agricultural lands are now affected by water stress. Moreover, the faster-than-predicted change in global climate (Intergovernmental Panel on Climate Change, 2007), indicated that drought episodes will become more frequent because of the long-term effects of global warming. Global temperature is expected to be increased by 3 to 5 ^{0}C by the end of this century (IPCC, 2014). Drought stress can reduce grain yield, due to drought stress it has been estimated the average loss of 17 to 70% in grain yield (Nouri-Ganbalani et al., 2009). Although drought can strike at any time, depending on which stage of growth a plant experiences drought stress, it reacts quite differently to the stress. The plants are most prone to damage due to limited water during flowering time. Yield loss occurs when crop is exposure to water deficit stress, especially when plants are at flowering or reproductive phases (Saini and Westgate, 2000). Further, temperature accelerates the developmental process in plants leading to the induction of earlier senescence and shortening of the growth cycle (Bita and Gerats, 2013). Terminal heat stress is a key abiotic stress severely affecting wheat growth and yield (Dwivedi et al., 2017). A major part of wheat cultivation in South East Asia including India has been found to be under threat of high temperature stress (Joshi et al., 2007). Heat stress is more prevalent in Eastern Indo-Gangetic Plains (EIGP), central and peninsular India, and Bangladesh and is more moderate in the north western parts of the EIGP. Delayed sowing of wheat due to the late harvesting of rice is one of the main reasons for terminal heat stress in the eastern part of India. Understanding how plants respond to drought and heat can play a major role in stabilizing crop performance under extreme conditions and in the protection of natural vegetation.

Effect of drought and heat stress on wheat growth, physiology and yield

Wheat plant experiences many stress during its life cycle. Among abiotic stresses drought and heat identified as key stress which severely hampering wheat growth, physiology and yield. Study showed that these two key stresses caused negative influence on wheat plant in terms of less tiller number, reduced leaf area, lower plant water status, and severe membrane injury, loss of chlorophyll content and dysfunction of photosynthesis system. Plant experiences water stress either when the water supply to the roots becomes difficult or when the transpiration rate becomes very high. Water stress at stages before anthesis can reduce number of ear heads and number of kernels per ear (Dencic *et al.*, 2000). While, water stress imposed during later stages might additionally cause a reduction in number of kernels/ears and kernel weight (Gupta *et al.* 2001). Zhang and Oweis (1999) reported that wheat crop was found to be more sensitive to water stress from stem elongation to heading and from heading to milking. Moreover, lower yields are obtained in dry and semi-dry environments as a result of continual rise in temperature that coincide with the anthesis and grain filling periods of crops (Dwivedi et al., 2015).

Criteria for Screening Heat and Drought Tolerant Wheat Genotypes

Due to global warming and changes in climate patterns, it is vital to mitigate the effects of heat and drought stress and identify potential ways of improving heat and drought tolerance for the success of wheat production under these stressful environments. To cope up with these stresses several key tolerance mechanisms against drought and heat, including osmolyte accumulation and compartmentalization, ROS scavengers, late embryogenesis abundant proteins and factors involved in signaling process and gene level regulation are major drivers to counteract the ill effect. The tolerance process begins with sensing of drought and heat stress, their signaling and production of many metabolites that enable the plant to counteract the ill effect of water deficit and high temperature stress. The ROS scavengers like CAT, SOD, POX, APX, and ascorbic acid are also the important players in tolerance mechanism of drought and heat stress. Furthermore, at molecular level the induction and expression of HSPs, DREB, LEA, DHN is highly correlated with the tolerance mechanism of the plant. HSPs act as a molecular chaperone and provide protection to the cellular machinery. Many studies pointed out the role of HSPs in various stress responsive mechanisms. Deryng et al. (2014) considered selection of cultivars and managing sowing windows as adaptive measures under extreme heat stress conditions. Some other adaptation measures are surface cooling by irrigation, antioxidants defense (Suzuki et al., 2011), and osmo-protectants (Kaushal et al., 2016). Thus, development of drought and heat-tolerant wheat varieties and improved pre-breeding materials for any future breeding program is vital in meeting food security. Hence, development and identification of drought and heat stress tolerance wheat germplasm may be a noble strategy to resolve the imminent crucial problem caused by global warming. Besides, it is crucial to develop genotypes that are early in maturity so as to escape the terminal heat stress (Joshi et al., 2007).

Various criteria have been reported by many researchers to identify heat and drought tolerant wheat genotypes. Traits like heat susceptibility index (HSI),drought susceptibility index (DSI), membrane stability index (MSI), canopy temperature depression (CTD), chlorophyll content, proline accumulation, stay-green trait and stomatal conductance have been reported as the marker traits to differentiate drought and heat susceptible and tolerant wheat genotypes. CTD is considered to be the most efficient to assess heat tolerance since one single reading integrates scores of leaves, CTD is highly heritable and easy to measure using a hand-held infrared thermometer on sunny days. High temperature at anthesis decreases the grain number per spike and grain size, both of which have significant effects on grain yield. The grain yield affected by decreasing size of individual grains due to high temperature at the grain filling stage. Ferris et al. (1998) reported that in wheat, both number of grains and grain weight seems to be sensitive to heat stress, as at maturity there is a decline in the number of grains per year with rising temperature. Reproductive processes are clearly affected by high temperatures in most plants, which eventually affect fertilization and post-fertilization processes leading to reduced crop yield. Recommended wheat cultivars for sowing under delayed sowings of the Indo-Gangetic Plains are PBW 373, UP2425 and RAJ3765 for the NWPZ and NW1014, HD2643, HUW510, HUW234, HW2045, DBW 14, NW2036 and HP1744 for the NEPZ.

Potential traits/characters for screening wheat for heat and drought tolerance

	Traits/characters
1	Photosynthesis rate
2	Leaf chlorophyll content
3	Canopy temperature depression*
4	Membrane stability
5	Flag leaf stomatal conductance
6	Thousand grain weight
7	Early heading
8	Drought Susceptibility Index / Heat Susceptibility Index
9	Stay-green*
10	Stem carbohydrate re-mobilization
11	Pollen viability
12	Number of fertile spikes
13	Anti-oxidants activity
14	Grain filling durations

*traits for heat stress tolerance only

Table 1: Relatively heat and drought tolerant wheat genotypes developed

Heat tolerant wheat varieties	WH730, GW273, NW1014, RAJ 3765, NW 1014, HUW 234, Halna, HD3120, DBW 14, HD1563 and HD2987
Drought tolerant wheat varieties	C 306, HD2987, HD2888, WH147, K7903, HI1563

Conclusion

In conclusion, it is obvious that drought and heat stress negatively influenced the wheat plant's physiology and yield. Furthermore, despite the vital need to identify drought and heat tolerance genotypes and improve the drought and heat tolerance level in the wheat crop, a very limited number of drought and heat-tolerant wheat varieties have been developed. Moreover, due to the complex nature of co-occurring stresses, the physiological and molecular mechanisms happening inside plant system under heat stress is still not very clear. Few varieties i.e. HD2987, K7903, HI1563 under drought and WH730, NW1014, HD3120 and Raj 3765 under heat stress condition promised good yield in field condition.

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Enhancing water productivity through use of drip irrigation in vegetables

Shivani
ICAR Research Complex for Eastern Region, Patna

Water is the most precious gift of nature and is the most crucial elements for the sustainability of the life. India is the largest freshwater user in the world and the country's total water use is greater than any other continent. The Agricultural sector is the largest user of water, followed by the domestic sector and the industrial sector. The strategic role of irrigation as an essential input for crop production can't be denied. As a traditional productive input, it ensures production by acting as an agent of insurance against inadequate and inconsistent monsoon. Ultimately the outcome provides agricultural production stability. Thus, irrigation is of prime importance in cultivation of vegetable crops as it ensures favourable water balance within the root zone in addition to natural precipitation. It fulfills the crop- water demand and improves the crop production and effectiveness of other agricultural inputs. It is also an important limiting factor of crop yield, because of its association with several factors of plant environment, which directly influence the crop growth and development (Yaghi et al. 2013).The various irrigation methods under different system of irrigation differ with regard to extent of control, timeliness and adequacy of supply of irrigation water for crop cultivation. Consequently, the economic benefits and the costs due to these irrigation methods vary among different irrigation systems. The dominant method of irrigation practiced in large parts of the country is surface irrigation (basin, border and furrow) where the entire soil surface is almost flooded without considering the actual consumptive requirements of the crops. Frequent over or under irrigation create the problems of water stress or water logging leading to reduced irrigation efficiency (<30 %). Thus, in this method crop utilize only less than one half of the water released and remaining half gets lost in conveyance, application, runoff and evaporation. Therefore, to make the best use of water for agriculture and to improve water productivity is a pre requisite. This highlights the need to adopt modern efficient irrigation method. Micro irrigation (MI) methods like drip and sprinklers need to be employed for efficient distribution and application of water for crop production. Drip and sprinkler irrigation is a solution that reduces conveyance and distribution losses and allows higher water use efficiency. Drip irrigation has been found very effective in vegetable production. Efficient use of available water in vegetable production can be achieved by adopting water management practices and adoption of drip irrigation technology is one of them.

Drip irrigation

Drip irrigation system is extremely profitable as it saves 40-70 percent water and enhanced the water use efficiency by 90-95 percent as compared to surface irrigation method i.e. flood, sprinkler, furrow. It also reduces labour cost, protects the plants from diseases by minimizing humidity in atmosphere and ultimately increases the productivity. Beside this, water soluble fertilizers can also be applied through irrigation water. Thus, drip irrigation has become a means of Hi-tech Agriculture/Horticulture and precision farming.

Drip irrigation is an effective irrigation system that permits application of water to plants to closely meet the consumptive use requirements. Drip irrigation is a technique in which water is applied in small and precise amount at frequent intervals, directly near the root zone, through emitting devices via a network of PVC/HDPE mains, sub mains, filtration unit, control valves and LLDPE laterals. It minimizes the wastage of water by delivering the water very near to root zone. In this system water is applied to each plant separately in small, frequent, precise quantities through dripper emitters. It is the most advantage irrigation method with the highest application efficiency. The water is delivered continuously in drops at the same point and moves into the soil and wets the root zone vertically by gravity and laterally by capillary action. The planted area is only partially wetted. In medium- heavy soils of good structure, the lateral movement of the water beneath the surface is greater than in sandy soils. Moreover, when the discharge rate of the dripper exceeds the soil intake rate and hydraulic conductivity the water becomes pond on the surface. This results in the moisture being distributed more laterally rather than vertically. The following table indicates the water lateral spread values.

Table 1: Lateral spread value of irrigation water in different soil texture

Type of soil	Average radius of the water spread
Light texture	0.30m
Medium texture	0.65m
Fine texture	1.20m

The drippers are small-sized emitters made up of high quality plastics. They are mounted on small soft pipes at frequent spaces. Water enter the dripper emitters at approximately1.0 bar and is delivered at zero pressure in the form of continuous droplets at low rates of 1.0 -.24 litres per hour. Drippers are connected to the laterals either on-line i.e inserted in the pipe wall by the aid of a punch; or in-line, where the pipe is cut to insert the dripper manually or with a machine.

Drip irrigation is mainly applied in intensive cultivations planted in rows like vegetables, fruit trees, melons, bananas, papayas, grapes, etc. This technology has the greatest potential where water is either very expensive or scarce or the soils are coarse textured. In drip irrigation the drippers and/or the lateral spacing are directly related to the crop planting spacing. In most vegetable crops, the dripper spacing is identical to the crop planting spacing i.e. one dripper per plant and one dripper lateral per row of cultivation. With drip tapes there are several emission points per plant in order to ensure a continuous wetted strip along the row. Here the arrangement is one drip tape per row of crop. Under drip irrigation most of the vegetable develop the bulk of their roots in the first30 cm depth of the soil profile below the emission point. Thus if both the crop and the emission points along the rows are closely spaced, most of the soil volume can be sufficiently wetted with optimum results. Where the crop is planted closely in beds, one dripper lateral per two rows can be applied with good results. Celery, capsicum and hot peppers planted in double rows are also irrigated by one dripper lateral placed in between the rows. The technology assumes a special significance in Himalayan regions, which are endowed with undulating topography, are difficult to level and having higher runoff rates. Micro-irrigation was practiced in India through indigenous methods such as bamboo pipes, perforated clay pipes and pitcher/porous cup irrigation. Drip-irrigation also enables the use of fertilizers, pesticides and other soluble chemicals along with the irrigation water more economically.

Advantages of Drip Irrigation:

Water Saving: The planted area is partially wetted with precisely controlled water amounts. Due to partial wetting of the soil volume, reduced surface evaporation, decreased runoff and controlled deep percolation losses, the water use efficiency under drip irrigation is markedly higher than traditional flood or furrow irrigation. With drip irrigation water savings to the extent of 52 % in garlic; 50.0 to 70.0% in pea and tomato: 37% in cauliflower and 30% in okra has been reported. In vegetables, drip irrigation is known to save 25-70% of water depending on soil, climate, crop and variety. The irrigation efficiency of drip system is very high (85- 90%).The comparative results on drip and surface irrigation in some vegetable crops are cited in Table 2. Thus, large quantities of irrigation water are saved and the irrigated area can be expanded with the same water supply, resulting in higher income per unit of water

Table 2: Extent of water saving and increase in yield with drip irrigation system

Crop	Water saving (%)	Increase in yield (%)
Tomato	42	60
Watermelon	66	19
Cucumber	56	45
Chili	68	28
Cauliflower	68	70
Okra	37	33

Source: Singh & Singh, 2012

Enhanced plant growth and yield: Slow and frequent watering eliminates wide fluctuations in soil moisture content resulting in better growth and yield. Application of mulch in conjunction with drip system proved more beneficial in saving the irrigation water and improving the yield.

Saving in labour and energy: There is a considerable saving in labour, as the well designed system needs labour only to start and stop the system. Because of high irrigation efficiency much time is not required to supply the desired quantity of water, thus, it also saves energy.

Weed control: Due to partial wetting of soil, weed infestation is very less in comparison to other methods of irrigation. Thus help in less competition of crop with weeds and increase the productivity.

Most Suitable for poor soils: Very light (sandy) soils are difficult to irrigate due to deep percolation of water. Like- wise, very heavy soils are difficult to irrigate, even by sprinkler methods because of low infiltration rates. In these situations drip irrigation method is very effective.

Use on marginal fields: Small irregular marginal plots, remote because of land fragmentation with varying topography and shallow soil full of rocks, can be productive under drip irrigation techniques that deliver the required amount of water and nutrients directly to the plants.

Utilization of saline water resources: With drip irrigation, low soil moisture tensions in the root zone can be maintained continuously with frequent applications. The dissolved salts accumulate at the periphery of the wetted soil mass, and the plants can easily obtain the moisture needed. This enables the use of saline water containing more than 3000 mg/litre TDS, which would be unsuitable for use with other methods.

Salinity hazards: Less moisture content due to frequent irrigations and lesser water requirement over the surface method keep saline concentration below the detrimental levels.

Soil erosion: There is no soil erosion due to drip irrigation. It supplies water near the root zone of the plant at a slow rate and keep the soil intact.

Fertilizer use efficiency: Because of reduced loss of nutrients through leaching, runoff and volatilization and also local placement in the root zone, FUE is considerably improved.

Disease incidence: Easy installation, minimum tillage and incidence of diseases and pests are added advantages of drip irrigation.

Constraints: These are;

- It requires high initial investment.
- Frequent clogging of drippers. The clogging could be due to algae, salt accumulation or foreign particles and insufficient filtration of impurities in the irrigation water.
- Non availability of technical manpower.
- Inadequacy of technical input for efficient management of drip irrigation system.
- It is not suited for frost protection or for cooling during periods of hot weather.
- They are not suited for supplemented irrigation of large areas.
- Availability of components and cost of spares.

Water requirement through drip irrigation

With regard to vegetable crops, generally, yield decreases significantly in the absence of sufficient water to fully replenish ET. In addition, the negative effects of limited irrigation water on the quality of vegetable crops further contribute to a substantial reduction of the marketable yield. Vegetable crops are sensitive to suboptimal irrigation with slight differences among cultivars.

The water requirement in drip irrigation system includes the crop demand to meet out losses due to evapotranspiration (ET) or consumptive use (Cu) and the quantity of water required for special operations such as leaching. Water requirement of crops under drip irrigation varies depending on the factors like (a) type of the crop, (b) age of the crop, (c) effective root zone of the crop which varies according to growth stage, (d) season of the year, (e) evapotranspiration demand and (f) soil type. There is a close relationship between the rate of consumptive use by crops (ET) and the rate of evaporation from a well located standard Evaporation Pan. The water requirement of different crops under drip irrigation system is generally estimated on daily basis by using the following equation as suggested by Shukla *et al*., (2001).

WR= Ep.Kp.Kc.Sp.Sr.Wp

Where,
WR = Volume of water required (litre / day / plant)
Ep = Pan evaporation as measured by Class-A pan evaporimeter (mm /day)
Kc = Crop co-efficient (co-efficient depends on crop growth stage)
Kp = Pan co-efficient
Sp = Plant to plant spacing (m)
Sr = Row to row spacing (m)
Wp = Fractional wetted area, which varies with different growth stage (0.3 to 1.0)

The water requirement thus determined has to be fed to the root zone through the emitters. Depending upon the peak water requirement and time of irrigation, emitters are selected for discharge of 2lph, 3lph, 4lph etc. Lateral movement of water in the soil and the necessary wetted area to create the desired root system are directly related. The wetted area depends on soil characteristics specially infiltration capacity and lateral movement of the moisture in the soil, and on emitter discharge.

Water productivity

"In a crop production system, *water productivity (WP)is used to define the relationship between crop produced and the amount of water involved in crop production*, expressed as crop production per unit volume of water".

Significance of Water productivity

The significance of water productivity is obvious in those major regions of the worlds where, water demand (potential evapotranspiration) exceeds water supply by precipitation. Where water is the major factor limiting crop growth, any increase in water productivity achieved by reducing non- productive water use will lead to an increase in yield. In irrigated cropping, water productivity can be increased by improving the efficiency of the water conveyance and application system as well as by optimizing the timing and distribution of irrigation. In drip irrigation system, application of water at frequent intervals near the plant root zone increases the availability of nutrients and reduces leaching losses. More nutrient availability increases the translocation of photosynthates to storage organ resulting in an increased fruit weight and higher yield. Least water productivity is generally observed in unmulched furrow irrigated treatments which might be due to more water use and lower yield than drip irrigated crop.

Some review of drip irrigation in vegetable crops

Tomato

Sivanappan *et al*., (1998) reported that the yield of tomato under drip (8872 kg/ha) was 43 percent higher as compared to furrow irrigation (6187 kg/ha) and the reduction in crop water requirement was to the tune of 78 per cent. On silt clay loam soils of Bangla desh drip irrigation resulted in higher yields of tomato as compared to furrow method (Biswas *et al*., 2015). Increasing drip irrigation from 0.3 Epan level to 0.7 Epan increased yield from 54 to 71 t/ha. However the WUE was higher at 0.3 Epan irrigation (28 kg/ha-mm). The yield under drip (48 t/ha) was 50 per cent more in comparison to flood-irrigated crop (32 t/ha). Irrigation water saving was to the tune of 31.5 per cent with drip. Use of drip irrigation systems for tomato production in open as well as under mulch cultivation resulted in high fruit yields with good fruit size and cultivation resulted in high fruit yields with good fruit size (Shivani *et al*, 2016).

Cabbage

Drip irrigation resulted in better growth and higher yields of cabbage with bigger head size of higher quality. The experimental findings of Singh *et.al*. (1990) suggested that the trickle irrigation in heavy soils during winter season under shallow water table (1.8 to 2.2m) conditions should be used with care. They obtained lower yields of cabbage crop under drip as compared to furrow irrigated crop, which was country to the general understanding that the crops under tickle irrigation perform better than the ones under surface irrigation.

Chillies

A study to find out the water requirement of chilli crop variety K-land and its response to drip irrigation was conducted at TNAU, Coimbatore in Tamil Nadu. There was saving of 62 per cent of water by drip irrigation. The yield of crop was increased by 25 per cent and reduced weed infestation by 50 per cent. Pandey *et al. (*2013) reported that the drip irrigation enhanced the fruit yield, net income and minimized the time, weeds and diseases of the crop. Fertigation resulted in maximum yield (10.20 kg/m 2), minimal disease and saved water and total irrigation time as compared to top dressing. The drip irrigation had significantly increased yield (10.50 kg/m2) and net income as compared to flood irrigation. Patel *et al*.,(2017) took random sample of 12 chilli growers using drip irrigation system from 10 villages of Barwani district of Madhya Pradesh. Thus, total number of 120 chilli growers using drip irrigation system constituted the sample for the purpose of the study. This study reveals that 68.34 percent respondents had medium level of adoption regarding drip irrigation system, whereas, 100% respondents expressed the benefits of drip irrigation system as it increases the production and productivity of chilli and getting more income by the farmers. 91.66% respondents expressed the benefit of drip irrigation system for improving the socio economic status of the farmers

Capsicum

Paul *et al.* (2013) observed significantly higher fruit weight of capsicum under drip irrigation as compared to control practices. Capsicum yields with trickle irrigation were higher (74 t/ha) than those under sprinkler irrigation (59 t/ha) although similar soil moisture tensions were maintained under both the systems. Capsicum gave higher yield with drip irrigation stystem as compared to furrow irrigation system and overall irrigation efficiencies were 37, 65 and 84 per cent in furrow, sprinkler and drip irrigation, respectively Drip irrigation scheduled at 0.6 Epan gave higher yield (73.6 q/ha) than furrow irrigation scheduled at 0.6 Epan (60.8 q/ha) and 0.8 Epan (61.2 q/ha) level (Bandi, 1994). Reducing irrigation application through drip by scheduling at 0.4 Epan during reproductive stage drastically reduced the yields. A Comparison of drip and mini sprinkler systems with surface method as control was studied both at Navsari and Pantnagar. While at both places the water savings with mini sprinkler was almost same (19-20%) the water saving recorded ofr drip at Navsari was as low as 37 per cent as against 67 per cent at Pantnagar. At both the places the yield increase was negligible. Contrarily in Maharashtra the yield increased ranging from 29 to 44 per cent. But the yield levels (3 to 6 t/ha) in two trials of Maharashtra were well below the yields achieved at Navsari and Pantnagar (11-12 t/ha). Further at Pune, for a yield level of 2.8 t/ha the water requirement through drip was 26 cm, at Rahuri it was 42 cm to achieve a yield level of 6 t/ha and at Navasri where the yield level was 11.8 t/ha the water requirement was 70 cm.

Brinjal

According to Kumar *et al*., (2015) water use efficiency (yield per unit area per unit depth of water used) decreased with increase in irrigation levels for all the treatments of drip irrigation system. The increase in water use efficiency for drip irrigation system, Among the drip irrigation levels, the highest field water use efficiency (6148.31kg ha1 cm-1) was found at 65% irrigation level, indicating comparatively more efficient use of irrigation water with a possibility of water saving of 35% water by adopting brinjal plot (1.58 litre plant^{-1}day^{-1}).Shivani *et al* (2015) reported improvement in yield varied between 16 and 63 per cent and the saving in water was to the tune of around 50 per cent. In Gujarat while the saving in water was around 25 per cent. The yield increase was about 42 per cent. A one-year trial conducted at Pantnagar showed that with mini sprinkler the yield were more than drip but water saving was less. The maximum water saving of 65 per cent was recorded at Coimbatore, but at this level of water saving there was no improvement in the yield. At Pune the maximum improvement in yield (63%) was reported with simultaneous saving in irrigation water to the tune of 56 per cent.

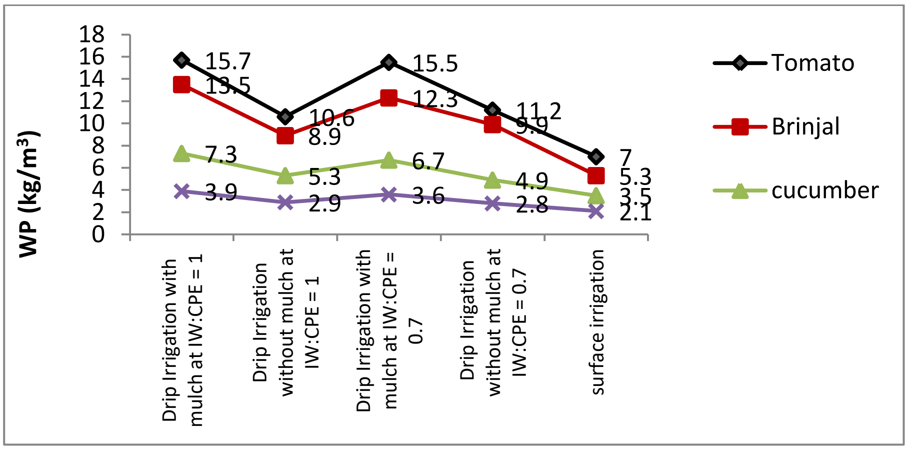
Okra

In okra by adopting drip irrigation a saving of 84 per cent of irrigation water was possible in cv. Pusa Sawani. The maximum water saving has been reported from Coimbatore (84%) followed by Gujarat (47%) and Hyderabad (22%). In one of the three trials at Maharashtra, the water saving was reported to be 41 per cent with about 7 per cent increase in yield. But when the saving in water got reduced to 27 per cent the percent increase in yield rose to about 32. At Pantnagar it was observed that the yield could be increased by about 36 per cent with water saving of about 47 per cent. It could be further increased to 57 per cent with mulch in Andhra pradesh conditions. The yield increase was observed to be 22 per cent with 50 per cent water saving with drip alone and 52 per cent 62 per cent respectively when drip was coupled with mulching also. Similarly in Kerala with water saving of 25 per cent while drip alone could increase the yields by 52 per cent with the use of mulch, the yield was more than doubled (Muhammed *et al.*,2015).

Cucumber and Ridge gourd

Cucumber demands high temperatures and soil moisture for satisfactory yield, and under unfavorable climatic conditions, several problems may occur, such as the reduction of female flowers, delay in fruit growth and mineral disorders. The results of the study conducted in Syria indicated that drip irrigation with transparent mulch excelled all other treatments at yield and water use efficiency (WUE), where its yield was 63.9 t ha−1, and (WUE) was 0.262 t ha−1mm−1, while drip irrigation with black mulch produced 57.9 t ha−1, with a (WUE) of 0.238 t ha−1mm−1. However cucumber yield and WUE declined in the no mulch treatments of DI and SI to reach 44.1 t ha^{-1} with 0.153 t ha^{-1}mm^{-1} and 37.7 t ha^{-1} with 0.056 t ha^{-1}mm^{-1}, respectively. The results showed that (DI + TM) treatment gave the highest soil temperature and moisture during both of the seasons in comparison to (DI + BM). This enhanced its vegetative growth and almost doubled its productivity compared to the SI treatment (Yaghi *et al*, 2013). As shown in Fig.1 drip irrigated vegetable showed higher water productivity and required less water to produce per kg of cucumber and ridge gourd as compare to surface irrigated crop. Irrigation through drip saved 28.2% and 22% irrigation water as compare to surface irrigation in cucumber and ridge gourd, respectively. (Shivani *et al*., 2015).

Fig. 1 Effect of irrigation and mulch on water productivity (kg/m^3)



Source; Shivani *et al*., 2015

Potato, Cauliflower, Frenchbean and Pea

Jha *et al*., 2017 conducted an experiment on evaluation of drip and furrow irrigation methods in participatory mode at the farmer's field of the eastern plateau and hill region. Comparative assessment in terms of yield gain, water productivity (WP) and net returns was carried out for tomato, potato, cauliflower, french bean and pea cultivated in the farmers' fields at Saraitoli village of Ranchi district of Jharkhand. The study revealed that, for the selected vegetables, adoption of drip irrigation improved the yields in the range of 38.2 to 65.8 % over furrow irrigation with highest yield increase in case of pea (65.8%) and tomato (58.7%)as shown in Table 2. Drip irrigation consistently recorded higher water productivity (WP) with more than five folds increase in case of potato and cauliflower.

Table 2: Yield and water productivity of different vegetables

Crops	**Yield (q/ha)**		**Water productivity (kgm^{-3})**	
	Drip	Furrow	Drip	Furrow
Tomato	250	157.5	13.7	2.86
Potto	186.3	134.8	7.94	1.17
Cauliflower	198.9	126.1	8.89	1.28
Frenchbean	71.2	51.2	2.96	0.83
Pea	52.7	31.8	0.97	0.42

Source; Jha *et al*., 2016

Above all the world is facing twin challenges of water stress and food insecurity—challenges that are already pressing and are projected to grow. As crop production is the largest global consumer of freshwater, and water is a key resource in food production, neither of these challenges can be addressed in isolation. Producing more food for each drop of water will be a crucial strategy to address both challenges. Water productivity is an important driver in projecting future water demands. Efficient irrigation technologies like drip irrigation can help to establish greater control over water delivery (water control) to the crop roots, reduce the non-beneficial evaporation from field and non-recoverable percolation and return flows into 'sinks' and often increases the beneficial ET. Water productivity improves with the reduction in depleted fraction and yield enhancement. So, drip irrigation is the best method to improve yield as well as water productivity.

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Herbicides and their improved spraying techniques: efficient weed control under conservation agriculture

SP Poonia, Virender Kumar & RK Malik
International Maize and Wheat Improvement Centre (CIMMYT), Regional Office, Patna

Agriculture experts saying that the success of efficient chemical weed control depends not only upon the quality of herbicides alone but also it depends on its appropriate spraying techniques. Weeds could lead to the loss in the yield of different crops from 20 to even more than 50 per cent. Therefore, timely weed control measures are strongly needed to mitigate the huge loss in crop yield. Suitable herbicides should be applied in consultation with the experts of the agriculture department personnel at appropriate weed stage on suitable soil moisture status by spraying recommended dosage through proper spraying techniques for uniform coverage throughout the field.

Application techniques are most important especially in the management of Phalaris minor (gehun ka mama) as proper spray pump, nozzles, volume of water with optimum herbicide dosage and the time of spray along with uniform coverage certainly help in its better control.

Practically, most of the farmers don’t have proper nozzles to fixe with their spray pumps, results the poor weed control. Weed control experts, recommends to the farmers to use flat-fan or flood-jet type nozzles and for uniform coverage of weedicides on the weeds, spray should be done in a straight strip by the help of 3 or more numbers of nozzle fitted on single boom, the nozzle should not be moved around from the strip and it is always advised that the nozzle should be kept 40 to 50 cm above from crop canopy. Always use the water mixture for herbicides spray should be 80 to 100 litres per acre for effective control of weeds. The whole field must be sprayed uniformly and no spot should be sprayed twice to reduce the injury on main crop. The use of cone type nozzles for spraying weedicides is always forbidden. Weedicides spray at noon during the bright sunny days after evaporation of dew from the plant surface is advisable.

Farmers should also use recommended good quality herbicides and adopt proper spray techniques/schedule recommended by local Agricultural University (SAU) and/or the Government Department of Agriculture (DoA). After spray, the first and second irrigation should be very light, flood like or deep irrigation reduces the effect of herbicides.

Principles of chemical weed control

The selectivity exhibited by certain chemicals to cultivated crops in controlling its associated weeds without affecting the crops provides the platform for the chemical weed control. Such selectivity may be due to differences in the morphology, differential absorption, differential translocation, differential deactivation *etc* from major crop to the weed species.

CLASSIFICATION OF HERBICIDES

1) Based on Method of application

- Soil applied herbicides: Herbicide act through root and other underground parts of weeds. Eg. Fluchloralin & Pretilachlore
- Foliage applied herbicides: Herbicide primarily active on the plant foliage Eg. Glyphosate, Paraquat

2) Based on mode of action

- Selective herbicide: An herbicide is considered as selective when in a mixed growth of plant species, it kills some species without injuring the others. Eg. Atrazine
- Non-selective herbicide: It destroys majority of treated vegetation Eg. Paraquat

3 Based on mobility

- Contact herbicide: a contact herbicide kills those plant parts with which it comes in direct contact Eg. Paraquat
- Translocated herbicide: Herbicide which tends to move from treated part to untreated areas through xylem/phloem depending on the nature of its molecule. Eg. Glyphosate

4) Based on time of application

- Pre-plant application (PPI): Application of herbicide before sowing or along with sowing. Either it is foliar applied or incorporated in soil soon after its application. Pre-plant foliar spraying of glyphosate to control perennial weeds like *Cyperus rotundus* and pre-plant soil incorporation of Fluchloralin to control weeds in ground nut
- Pre-emergence: Herbicide is applied to soil soon after sowing a crop before emergence of weeds Eg. Atrazine, Pendimethalin, Butachlor, Thiobencarb, Pretilachlor
- Post-emergence: When herbicide is applied to kill young weeds standing in the crop plants or application after the emergence of weed and crop. Eg. Glyphosate, Paraquat, 2,4-D Na Salt.
- Early post emergence: Another application of herbicide in the slow growing crops like potato, sugarcane, 2-3 week after sowing is classified as early post emergence.

5) Based on molecular structure

Based on molecular structure, all type of chemical weedicides may defined under two classes' viz. Inorganic & Organic compounds which are not much interested to us in terms of right spraying techniques for efficient weed control under conservation agriculture.

Formulations of Herbicides

Herbicides in their natural state may be solid, liquid, volatile, non-volatile, soluble or insoluble. Hence these have to be made in such a form suitable and safe for their field use. An herbicide formulation is prepared by the manufacturer by blending the active ingredient with substances like solvents, inert carriers, surfactants, stickers, stabilizers *etc.*

Need for preparing herbicide formulation

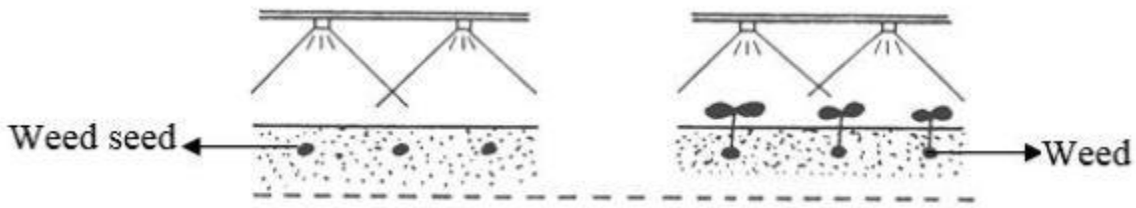
- To have a product with physical properties suitable for use in a variety of types of application, equipment and conditions.
- To prepare a product which is effective and economically feasible to use.
- To prepare a product which is suitable for storage under local conditions.

Types of formulation

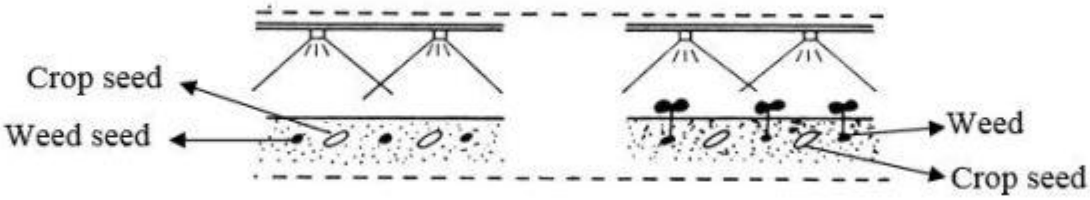
- **Emulsifiable concentrates** (EC): A concentrated herbicide formulation containing organic solvent and adjuvants to facilitate emulsification with water Eg. Butachlor
- **Wettable powders** (WP): An herbicide is absorbed by an inert carrier together with an added surface acting agent. The material is finely ground so that it may form a suspension when agitated with a required volume of water Eg. Atrazine
- **Water soluble Granules** (WSG): The inert material (carrier) is given a granular shape and the herbicide (active ingredient) is mixed with sand, clay, vermiculite, finely grinded plant parts (such as corn cobs) as carrier material. Eg. Alachlor granules.
- **Water soluble concentrates** (WSC): Eg. paraquat, glyphosate
- **Water soluble granules** (SG): Eg. Ammonium salt of Glyphosate

Kinds of herbicides on their application method

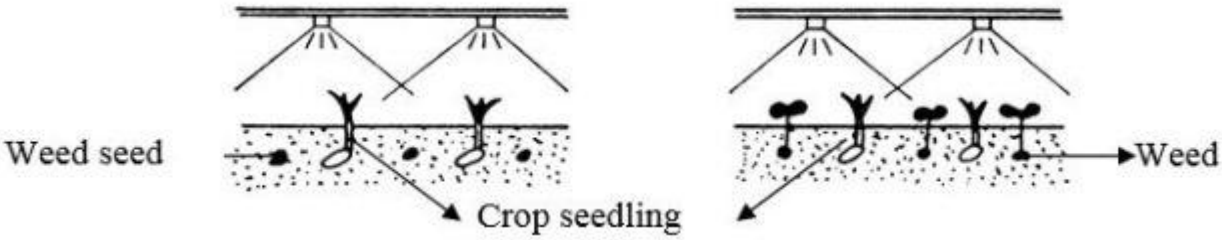
i) **Pre-planting**: application of herbicides before the crop is planted or sown. Soil application as well as foliar application is done here. For example, fluchloralin can be applied to soil and incorporated before sowing rain fed groundnut while glyphosate can be applied on the foliage of perennial weeds like *Cyperus rotundus* before planting of any crop.



ii) **Pre-emergence**: application of herbicides before a crop or weed has emerged. In case of annual crops application is done after the sowing of the crop but before the emergence of weeds and this is referred as pre-emergence to the crop while in the case perennial crops it can be said as pre-emergence to weeds. For example soil application by spraying of atrazine on 3rdDAS to maize can be termed as pre-emergence to maize crop while soil application by spraying the same molecule immediately after a rain to control a new flush of weeds in an inter-cultivated orchard can be specified as pre-emergence to weed.



iii) **Post-emergence**: herbicide application after the emergence of crop or weed is referred as post-emergence application. When the weeds grow before the crop plants have emerged through the soil and are killed with an herbicide then it is called as early post-emergence. For example spraying 2,4-D Sodium salt to control parasitic weed *striga* in sugarcane is called as post-emergence while spraying of paraquat to control emerged weeds after 10-15 days after planting potato can be called as early post-emergence.



METHODS OF HERBICIDE APPLICATION

i) Foliar application (spraying)

ii) Broadcasting

Factors influencing the methods of application

- Weed-crop situation
- Type of herbicides
- Mode of action and selectivity
- Environmental factors
- Cost and convenience of application

Types of foliar application

i) **Directed spray**: application of herbicides on weeds in between rows of crops by directing the spray only on weeds avoiding the crop. This could be possible by use of protective shield or hood. For example, spraying glyphosate in between rows of maize crop using hood to control *Cyperus rotundus*.

ii) **Protected spray**: applying non-selective herbicides on weeds by covering the crops which are wide spaced with polyethylene covers etc. This is expensive and laborious. However, farmers are using this technique for spraying glyphosate to control weeds in orchard crops.

iii) **Spot treatment**: it is usually done on small areas having serious weed infestation to kill it and to prevent its spread over to another near area. Rope wick applicator and Herbicide glove are useful here.

iv) **Blanket spray**: uniform application of herbicides to standing crops without considering the location of the crop. Only highly selective herbicides are used here. Eg. Spraying 2,4-Ethyl Ester, sulfosulfuron, metsulfuron, carfentrazone, Clodinafop etc. We will discuss this part in detail during lecture in classroom.

For designing any weed control programme in a given area, one must know the nature & habitat of the weeds in that area, how they react to environmental changes & how they respond to herbicides. Before selecting a method of weed control, we require much information on the number of viable seeds & their nature of dispersal, dormancy of seeds, longevity of buried seeds & ability to survive under adverse conditions, life span of the targeted weed, soil textures & moisture status and many other factors like: in case of soil applied volatile herbicides Eg. Pendimethaline, the herbicide will be successful only in sandy loam soil but May not in clayey soil. Flooding as a method of weed control Eg. Pretilachlore, will be successful only in heavy soil not in sandy soil.

Chemical weed control

Using chemicals, generally referred as herbicides, for the control of weeds is called chemical weed control. In 1944 – discovery of 2,4-D Na salt as a land mark in herbicide usage.

Merits of chemical weed control:

- Herbicide can be recommended for adverse soil and climatic conditions, as manual weeding is highly impossible during monsoon season.
- Herbicide can control weeds even before they emerge from the soil so that crops can germinate and grow in completely weed-free environment at early stages. It is usually not possible with physical weed comfort.
- Weeds, which resemble like crop in vegetative phase may escape in manual weeding. However, these weeds are controlled by herbicides.
- Herbicide is highly suitable for broadcasted and closely spaced crops.
- Controls the weeds without any injury to the root system of the associated standing crop especially in plantation crops like Tea and Coffee.
- Reduces the need for pre planting tillage
- Controls many perennial weed species
- Herbicides control the weed in the field itself or *in-situ* controlling whereas mechanical method may lead to dispersal of weed species through seed
- It is profitable where labor is scarce and expensive
- Suited for minimum tillage concept
- Highly economical

Some key demerits of chemical weed control

- Pollutes the environment
- Affects the soil micro & macro-flora if the dosage exceeds from recommendation
- It requires certain amount of minimum technical knowledge for calibration
- Leaves residual effects
- Herbicide causes drift effect to the adjoining field
- Some herbicides may costly than other weed control measure

Sprayer Calibration

Sprayer calibration aims to obtaining a spray pattern and droplet size that will ensure optimum coverage of the target area with uniform sized droplets without causing runoff. Calibration should therefore be taken into account

i) ***Target Area*** **–** area to be sprayed (large area would require higher quantities)

ii) ***Droplet size*** **–** fine droplets cover a large area with less volume and reduce run off, but can cause more drift and evaporation losses

iii) ***Nozzle size and spacing*** **–** once the volume of the spray and droplet size is determined, the nozzle size and spacing on the boom should be decided keeping in view the height between the boom and the crop.

iv) ***Nozzle capacity*** **-** Nozzle capacity is a manufacturer's rating that depicts what output a nozzle will have at a given pressure. At constant pressure and speed, nozzle capacity is directly proportional to sprayer output. Output becomes greater as nozzle capacity increases. When multiple nozzle booms are used on knapsack sprayers it may be necessary to keep the nozzle capacity ratings low to avoid exceeding the output capacity of the knapsack pump. Typical nozzle sizes are 700, 800 or 900 ml/minute. Smaller nozzle sizes are manufactured by some companies but may not be universally available. A 1000 ml/minute nozzle will have twice the output as a 500 ml/minute nozzle at the same pressure. The angle rating of a spray tip is not related to output.

v) ***Speed*** **–** keeping boom output constant Speed is inversely proportional to spray application. As you walk faster, less spray is applied to a given area.

vi) ***Pressure*** **-** As pressure increases, sprayer output increases. However, this relationship is not direct. Pressure must increase four times in order to double nozzle output. Variable pressure will cause variable output. Pressure may also affect the spray angle of different nozzles. The nozzle angle rating is for a specific pressure. The spray angle of a nozzle will decrease when pressure drops below the recommended minimum pressure for that nozzle. Low pressure nozzles (nozzles that have spray angles maintained at low pressures) are manufactured, however, they may not be universally available.

Calibration of multiple boom nozzle

Step 1

Make sure that the boom is aligned in a straight line.

- Make sure nozzle interspacing is equal. This is usually 50 cm.
- Measure the length of the boom. This is usually 1.5 m.

Step 2

- To check nozzle output, tie equal sized containers to the nozzles and measure the output of water.
- The water outputs from the three nozzles should be at the same level, if not, adjust the nozzle output.

Step 3

- Measure out a ml of water in a bucket and fill into the knapsack sprayer

Step 4

- Mark out a rectangle that is 33 m long and 3 m wide i.e. approximately 100 square m in area using a tape
- Start spraying from one end of the rectangle in a straight line and make one full pass. Turn around and make the second pass such that the entire area is sprayed
- Measure out the quantity of water (a1 ml) left in the knapsack after spraying the area

Step 5

Calculations:

Initial volume (x) of water taken in sprayer tank = a ml
Water volume (x_1) left after spraying 100 m^2 = a_1 ml
Area sprayed = 100 m^2
Volume per unit area = $(x – x_1)/100 = a_2$
Volume required for spraying 1 acre = $a_2 \times 4000 = a_3$
In terms of number of Knapsack tanks (which we are going to use) per acre
One tank capacity = b L
Number of tanks required for 1 acre = a_3/b L
Number of tanks required per katha = (a_3/b L)/32
(Assuming that 32 kathas = 1 acre)

Numerical example for calibration of water volume per acre:

Initial volume in sprayer = 8.0 L
Volume left in the tank = 5.6 L
Volume consumed = 2.4 L
Area sprayed = 100 square meter
Volume per unit area = 0.024 L
Total water volume per acre = 96 L
Assumed one tank capacity = 15 L
No of tanks per acre = 6.4

Tools and Implement for Conservation Agriculture

Bikash Sarkar
ICAR Research Complex for Eastern Region, Patna – 800014

The concept of conservation agriculture is relative usage of new and modern cultivation practices. Conventional agricultural practices promote extensive soil tillage, burning of crop residues and external inputs. Such practices lead to soil degradation through loss of organic matter, soil erosion and compaction. Conservation agriculture is a system of integrated management of soil, water and biological resources combined with external inputs. It is based on agricultural crop production that achieves acceptable profits together with high and sustained production levels while conserving the environment with resource saving (FAO, 2009). Interventions such as mechanical soil tillage are reduced to an absolute minimum and the use of external inputs such as agrochemicals and nutrients of mineral or organic origin are applied at an optimum level and in a way and quantity that does not interfere with the biological process. The effect of direct seeding/planting has been found to be advantageous (Patel et al., 2018).

It was observed that 25-30 % cost taken in land preparation can be reduced only by using high conservation tillage practice like zero tillage, happy seeder, laser land leveler etc. Continuous use of heavy machines and improper agricultural practices cause soil degradation and also environmental damage that can be rectified only by adopting conservation agriculture practices. Applied at the right time and on the right covering equipment could replace the use of irrigation, pesticide and herbicides for crop establishment. The aim is to leave as many residues as possible in order to increase soil organic matter and to spread them as evenly as possible. Through conservation agriculture, the following objectives can be achieved such as climate resilience, food security, soil nutrition, energy reduction and increased crop yield and thereby farmer's income. Presently farmers are facing the problem of labour shortage and drudgery which can be addressed by conservation tillage practices (Pradhan et al., 2018).

Mechanization, especially power units, seeders, rippers and sprayers is a key input for CA. The principal mechanization requirements for smallholder CA are for no-till seeding and weed control equipments (FAO 2015). No-till planting requires the planter to be able to cut through the surface mulch and previous crop residues that will be on the soil surface or anchored into it. The mulch can be penetrated or cut with vertical discs, chisel tines or jab planter beaks-or even a pointed stick. Chisel point tines are suitable in low-residue cover situations (Baker, 2007). Manually operated jab planters are suitable for very small holdings and are available with both seed and fertilizer metering (Sims, 2014). For weed management all options should be explored including physical, biological and chemical control. Manually powered mechanical control options include shallow scraping with sharp hand-hoes, hand pulling and slashing which are suitable for very small areas. As holdings become larger, then animal traction and tractor power can be used for knife rolling. However a judicious combination of mechanical, biological and chemical weed control methods may be appropriate.

Overview of conservation agriculture

Conservation agriculture aims to improve agricultural production by adopting sustainable methods that conserve, improve and make more efficient use of natural resources based on three principles.

- Permanent soil cover
- Minimal or no mechanical soil disturbance
- Crop rotations and/or associations

Functions of Conservation Agriculture (Kuria, 2012)

- Conserve the soil
- Soil moisture retention
- Improve the soil's productivity
- Reduce machinery costs
- Reduce labour input

Tools and Equipment used in Conservation Agriculture (Kuria,2012)

- Minimum tillage equipment:
- Direct seeding equipment
- Cover crop and weed management equipment

i) Minimum tillage equipment

Application is confined to area where the crop is going to be planted leaving the rest of the area undisturbed. Usually tine based to avoid soil inversion an excessive soil disturbance. Following equipments are used for minimum tillage

- Rippers/Chisels
- Sub-soiler
- Chisel plough

Minimum tillage equipment	
Rippers/Chisels Narrow chisel-point tines can be used to rip a planting slot for subsequent planting. The inter-row area is not tilled and is managed as a CA system. Chisel point tines are suitable in low-residue cover situations. **Disadvantage** ➢ Poor weed control ➢ Clogging ➢ Needs proper soil moisture (crumbling or dryer) ➢ Lifting stones/clods ➢ Needs lots of power	 Ripping practices

Chisel plough Chisel point tines are suitable in low-residue cover situations. Chisel ploughs are used to break through and shatter compacted or otherwise impermeable soil layers. Deep tillage shatters compacted sub soil layers and aids in better infiltration and storage of rainwater in the crop root zone.	**Two row chisel plough**
Laser land leveler Precision land leveling is the foremost step for judicious use of water and laser land leveler is one such equipment which could promote efficient utilization of water. Laser land leveling is one such important technology for using water efficiently as it reduces irrigation time and enhances productivity not only of water but also of other non-water farm inputs. Results in technologically advanced countries have indicated that it saves water to the tune of 25-30% and time by 30% and also improves production and productivity by 10-15%.	

ii) **Direct seeding equipment/methods (**Kuria, 2018)

- Broadcasting
- Planting stick
- Hand jab planter
- Animal drawn
- Motorized or tractor

Direct seeding equipment/methods	
Broadcasting Broadcast seeding is a method of seeding that involves scattering of seed by hand or mechanically, over a relatively large area.	
Planting stick Dibble stick, a pointed stick that opens a small hole. If both seed and fertilizer is used the operator can create two holes for placement of each input. Farmers prefer this technique over more sophisticated implements like the jab-planter because it follows traditional planting methods.	 

Hand jab planter Jab planters insert a preset amount of seeds and fertilizer into the soil. The jab-planter has two compartments, one for fertilizer and one for seed, and both are mounted on a wooden frame with two tips. Once the tips are pushed into the soil and opened by the operator seed and fertilizers drop into the planting hole. They are commonly equipped with a double tip to apply fertilizer at the same time as the seed. Both fertilizer and seed flows are adjustable. To operate, they are jabbed into the ground with the point closed; the handles are then pulled apart, allowing seed and fertilizer to drop into the seeding hole. On closing, the seed and fertilizer points are recharged. The machine can seed very effectively into mulch-covered no-tilled soil but has disadvantages, such as clogging of the tips if the soil is too sticky.	
Animal drawn planter The direct planter has a coulter, which cuts into mulch, a ripper tine that opens a small rip-line, a seed and fertilizer hopper and finally a drive wheel that activates seed and fertilizer release and covers the seed at the same time. Fitarelli planters have seed plates for maize, sorghum and beans but other crops such as sunflower and cowpeas can also be sown.	
Tractor drawn zero seed cum fertilizer drill The zero tillage practices may progress from reducing the number of tillage passes to stopping tillage completely (zero tillage). Zero-tillage planting of wheat after rice has been the most successful resource-conserving technology till date in north-west India. Zero tillage is an extreme form of reduced tillage were wheat is planted in prepared soil after rice harvest in a narrow slit wide enough to cover the seeds without any tillage. It is becoming popular because of the direct economic benefits it provides to farmers. With less tilling, farmers save on machinery use, fuel, labour and their own time. The cover of crop residue helps to prevent soil erosion by water and air, thus conserving valuable topsoil.	

Happy seeder The happy seeder technology offers a solution to the problem of direct drilling into heavy stubbles, enabling the stubble to be retained on the surface as mulch. The equipment is the combination of straw handling unit and sowing unit. It is used for sowing operation in combine-harvested field in a single pass while retaining the crop residue as surface mulch. The unit is compact, light weight and tractor mounted capable of managing rice stubbles and loose straw in a strip just in front of each furrow opener.	
Roto till drill It is a tractor operated equipment and is used for sowing seeds into the soil directly opened with the help of rotavator attached with the machine, in a single operation in the stubble fields. The machine performs the tillage operation and directly place seed and fertilizer in the soil opening in the stubble fields of paddy and maize. Cost reduction by time and energy saving and optimization of environmental health by reducing soil compaction are the main features of this equipment.	
Slit till drill It is a 45-50 hp tractor operated equipment and is used for sowing seeds into the slits opened with the help of rotary slit disc, attached in front of the furrow openers of machine, in a single operation in the stubble fields. The machines prepare a 20 mm slit in the soil and places seed and fertilizer in the prepared slits in the stubble fields of soybean, maize and paddy. It reduces the loss moisture and draft force as compared to strip and roto till drill. Cost reduction by time and energy saving and optimization of environmental health by reducing soil compaction were less as compared to strip till drill machines.	

Multi crop raised bed planter Minimum tillage planting can also be accomplished on permanent beds. While the initial bed forming involves major soil disturbance, once established the regular reshaping of beds involves only minimal soil disturbance. It is used for sowing bold grains like maize, groundnut, peas, cotton, sunflower etc, on the two raised beds formed by ridgers. The planting discs for different crops can be changed without dismantling the seed hoppers main shaft. Missing of grains and grain damage is negligible. Fertilizer can be used simultaneously according to requirement. Roller is provided for shaping the raised bed properly and covering the seeds(Extension Bulletin No.CIAE/FIM/2008/80). Bed planting compared to flat sown cultivation of wheat • Improves yield by 05-10%. • Saves seed and fertilizer by 25-30%. • Saves irrigation by 30-35%.	

iii) Cover crop and weed management equipment

Mechanical weeding is usually more economical to use than manual labor because it involves the use of tillage implements like harrows, weeders and cultivators driven by animals or engine. These implements rely on burying and uprooting weeds grown between crop rows which are wide enough to facilitate movement of the implements without significant injury to crops. Therefore, this method is applicable only in those crops sown in straight rows and having suitable row widths. (Sims,2014; Chetan et.al., 2018).

Weed management equipments (Hand operated)

a)	**Stirrup Wheel hoe** Manually powered mechanical control options include sharp shallow scraping with hand-hoes, hand pulling and slashing which are suitable for very small areas	
b)	Stirrup hand hoe: Weeding tool with 4-7 " long blade attached with a long handle used for top soil work in removing weeds which has shallow roots.	

c)	**Knife rollers:** As holdings become larger, then animal traction and tractor power can be used for knife rolling. It can be an effective management tool both for cover crops and some weeds.	 
d)	**Straight blade hoe** : It is a long handled hand tool operated in standing position by pulling action. Inter and intra row weeding for all type of crops can be done.	
e)	**Hand grubber:** It is a long handled hand tool consists of three tynes, operated in standing position by pulling action. Inter and intra row weeding can be done.	
f)	**Long handle grubber:** Long handle weeder performs weeding operation without bending thus reducing drudgery of the farmers and increasing the field capacity. This weeder is generally hand fork type (3 numbers tine).	
g)	**Twin wheel hoe weeder:** It consists of V or straight blade mounted on a frame attached with long handle. It is best suitable to operate in between crop rows such as wheat, maize, dryland rice etc.	
h)	**Peg type hoe:** It consists of small diamonds shaped pegs welded on rods in a staggered manner. It is best suitable to operate in between crop rows such as wheat, maize, dry land rice etc.	

i)	**Cycle wheel hoe:** It consists of a small V blades mounted on a frame attached with long handle. It is best suitable to operate in between crop rows such as wheat, maize, dry land rice etc.	
j)	**Star weeder:** It has serrated V shaped blades which can be manually driven by a human to do weeding operation in any of the dry land crop.	
k)	**SWI weeder:** It is manually operated weeder widely accepted equipment for weeding and intercultural operation in SWI (System of wheat intensification) field in all types of soil region.	

Benefits of conservation agriculture

In India studies have been conducted to quantify the benefits of conservation agriculture in the Indo-Gangetic plain (Erenstein and Pandey, 2006). Some of the benefits are given as below:

- Yield increased in rice and wheat by 10-17 per cent over conventional tillage.
- Savings of Rs. 5760/- per hectare (5-10%), ranging from Rs. 3055 to Rs. 8500/- per hectare in different soils and eco-regions.
- Water saving by 20-35%, and energy saving, especially of tractor time saved by 60-90%.
- Projected saving of 1 million barrel of oil if zero-tillage practice is adopted in about 3.5 million hectare area of Indo-Gangetic plain.
- High internal rate of returns (57%) assuming 33% adoption of conservation agriculture in Indian part of Indo-Gangetic plain.

Conclusion

Conservation agriculture technologies are the future of sustainable agriculture. CA has direct impacts on farmers' family as it reduces labour requirements for tillage, land preparation and weeding. CA helps lower the overall requirement for farm power and energy for field production by up to 60 % as compared to conventional farming. In India, the concept of conservation agriculture may be integrated with various government programs by sensitizing policy advisors, professionals and financial institutions. The benefits of conservation agriculture need to be effectively communicated to all the stakeholders for its widespread adoption by the farming community.

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Mechanization: An important tool for drudgery reduction in Conservation Agriculture

Prem Kumar Sundaram[1], Bikas Sarkar[1], Sanjay K Patel[2] and S C Sharma[3]

[1]ICAR-Research Complex for Eastern Region, Patna, Bihar, India; [2]College of Ag.Engg., Dr. RP Central Agriculture University, PUSA, Samastipur, Bihar, India;[3]ICAR-Indian Institute of Resin and Gum, Ranchi, Jharkhand, India

Mechanization is the application of machine power to work on the land, usually performed by bullocks or other draught animals or by human labour. It is an economic application of engineering technology to increase labor efficiency and production. However, it not only includes production, distribution and utilization of a variety of tools, machinery and equipment but also planting, harvesting and primary process. Mechanization has a major impact on demand and supply of farm labor, agricultural profitability, and a change in rural dynamics.

Aim of mechanization

- The main aim is to replace animal power on which agriculture was based for very many centuries
- It also aims at reducing the drudgery of certain operations that have to be performed either by human labour or by a combined effort of human beings and animals.
- Reducing the cost of production
- Enhancement of timeliness and profitability in farm operations
- Reduction of labor requirements and enhancement of agricultural production through higher rates of work output
- Improvement of work environment
- Enhancement of safety
- Add value to primary products and so produce employment and income potential along the value chain.
- Increase cropping intensity

Conservation agriculture

Conservation agriculture is the agricultural management practice of permanent soil cover, minimal soil disturbance, and crop rotations (FAO, 2018, Fig. 1).

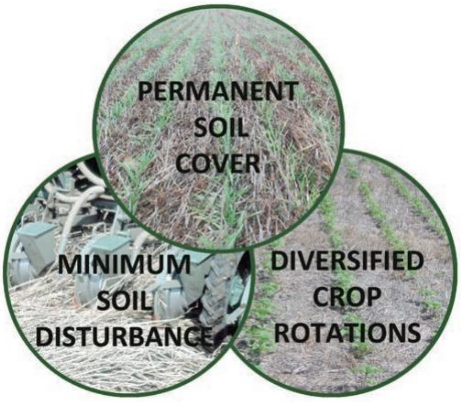


Fig. 1 Three principals of conservation agriculture

This is achieved by:

- Maintenance of a permanent vegetative soil cover or mulch to protect the soil surface
- Direct planting without seedbed preparation through the soil cover to minimize the disturbance of the soil
- Crop residue management and weed control, to stimulate soil structure formation, improve soil fertility, and to control weeds with less dependence on herbicides; and x pest and disease control based on Integrated Pest Management technologies and practices.

Drudgery reduction by boosting farm mechanization

In India, 82.7 % of total workforces are employed in the unorganized sector, where health and stress are worse (Anonymous, 2016). Heavy workloads and drudgery result in stress and poor health in agricultural work. In the view of the manifold workload of the agricultural workers, making available, simple labour saving cost-effective technologies would save millions of workers from drudgery, stress and ill-health. The improved technologies help in reducing energy expenditure, stress, workload, time spent, body disorders, fatigue and drudgery and in turn enhance productivity, efficiency, quality of produce, income and satisfaction of the agricultural workers.

Machines used for drudgery reduction in conservation agriculture in India

To fulfill the criteria of conservation agriculture, the use of machines are indispensable. Without them, it would be difficult to achieve the principles of conservation agriculture. These machines help in reducing the tillage time, soil manipulation, save fuel as well as labour.

Different tillage practices which follow the principle of CA are:

- Reduced tillage: tilling the whole surface but eliminating one or more of the conventional tillage operations.
- Ridge tillage: a system of annual or semi-permanent ridges and furrows, resulting in some residue cover.

- Tined tillage: the land is prepared with implements that do not invert the soil and which cause little compaction, resulting in a good cover of residues on the surface above 30%. Equipment used includes chisel plough, sub-soiler, etc.
- Strip tillage: strips 5–20 cm wide are prepared to receive the seed and the intervening bands are not disturbed.
- Zero tillage (or no-tillage): planting the seed into the stubble of the previous crop without any tillage or soil disturbance. Weed control relies heavily on herbicides. This approach is broadly equivalent to conservation agriculture.

The major equipment/machines used in conservation agriculture are described below:

1. **Laser land leveler:** In irrigated and rainfed environments, precision land leveling improves the uniform application of water, betters the crop stands and enhances the survival of young seedlings and robustness of the crop to withstand stress. Laser-controlled grading technology (Fig. 2) is currently the best method to grade a field. The system includes a laser-transmitting unit that emits an infrared beam of light that can travel up to 700 m in a perfectly straight line. The second part of the laser system is a receiver that senses the infrared beam of light and converts it to an electrical signal. The electrical signal is directed by a control box to activate an electric hydraulic valve. This hydraulic valve raises and lowers the blade of a grader to keep it following the infrared beam. The receiving system detects the beam and automatically guides the machine to maintain proper grade.

Fig.2 Leveling field by laser land leveler

2. **Seed drill/Seed cum fertilizer drill:** The main function of seed drill is to make a small furrow and then place the seeds in the opened furrow and after that, covers them with the soil. This machine works in tilled soil conditions. Drilling requires less quantity of seeds when compared with broadcasting, hence saving of 20-50 percent seeds. Seed cum fertilizer drill has an additional attached fertilizer box that places fertilizer also in the soil. Hence, seed cum fertilizer drill not only saves seed and fertilizer, but also fuel and time.

3. **Zero seed cum fertilizer drill:** This is specialized sowing equipment (Fig. 3) with an inverted "T" type furrow opener. It opens a narrow slit in the soil (Fig. 4) and seed, as well as fertilizer, are placed inside it. Zero tillage reduces tillage to only one pass. It allows timely sowing, which raises yields and lowers costs by saving soil, fuel, tractor costs, water, fertilizer and herbicides.

Fig. 3 Zero Seed sum fertilizer drill working in the field

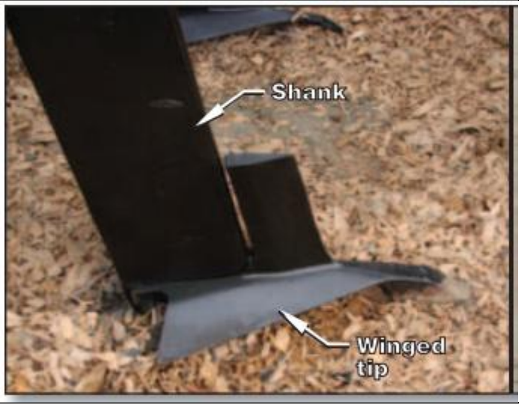
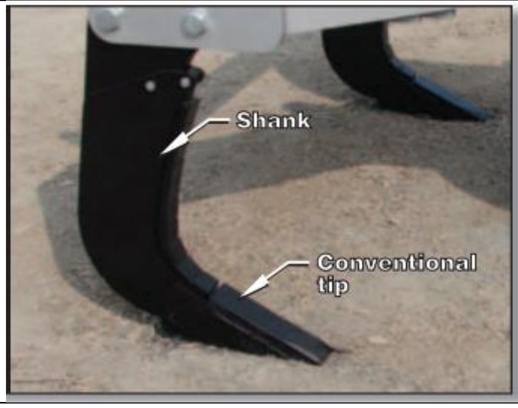
Fig. 4 narrow slit in the soil by furrow opener

4. **Happy seeder:** The Happy Seeder technology offers a solution to the problem of direct drilling into heavy stubbles, enabling the stubble to be retained on the surface as a mulch. It combines stubble mulching and seed drilling function into one machine (Fig. 5). Flail type straight blades are mounted on the straw management rotor which cuts the standing stubbles/loose straw coming in front of the sowing tine for proper placement of seed in the soil. The rotor blades/flails guide/push the residues as surface much between the seeded rows. The soil is not disturbed in this process (Fig. 6). The stubble is then deposited behind the machine as a surface mulch. The mulch assists in retaining organic matter and moisture content of the soil. The surface mulch is broken down and incorporated into the soil by natural biological process over time. This PTO driven machine can be operated with 45 hp tractor or more and can cover 0.3-0.4 ha/h. The happy seeder is not only able to reduce the practice of stubble burning but also improves /retains the quality of soil, saving of time, fuel and energy.

Fig. 5 Wheat sowing by Happy seeder

Fig. 6 Wheat sown field by happy seeder

5. **Subsoiler:** Subsoiling is an important component of vertical tillage and is designed to eliminate the compaction created by horizontal tillage tools such as sweeps and shovel implements. It is a crucial process in conservation tillage which minimizes soil surface disturbance without inversion while shattering subsoil structure (Ehlers and Claupein, 1994).

	
(a) Winged type Subsoiler	(b) conventional Subsoiler

A subsoiler is a tractor-mounted implement used for deep tillage, loosening and breaking up soil at deeper depths. Most tools like moldboard ploughs, disc harrows, or roto-tillers/rotavators will break up and turn over surface soil to a depth of 15–20 cm, whereas a subsoiler will break up and loosen the soil to twice those depths, i.e. up to 30-40 cm. A higher power tractor above 50 hp is required to operate it. It breaks the compacted layer of the soil which helps in increasing the infiltration capacity of the soil. The winged type subsoiler (Fig. 6a) is more useful than the conventional one (Fig. 6b) as it covers/caters more soil volume; however, it requires more power.

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Integrated farming systems: An approach to improve the income of small and marginal farmers

Sanjeev Kumar and Shivani
ICAR Research Complex for Eastern Region, Patna – 800 014 (Bihar)

Farming System research is an approach to agricultural research and development that view the whole farm as a system and focus on 1) the interdependencies between the components under the control of members of the household and 2) how these components interact with each other in respect of physical, biological and socioeconomic factors not under the household's control. Indian economy is predominantly rural and agriculture oriented where the marginal and small farmers constitute 76.2 % of farming community. Due to failure of monsoon, the farmers are forced to judicious mix up of agricultural enterprises like dairy, poultry, pigeon, fishery, sericulture, apiculture etc., suited to their agro-climatic and socio- economic condition.

Unfortunately, FSR means many things to many people. Many different methods appear to be promoted under the broad umbrella of FSR. Besides, various individuals and institutions try to put their own stamp on FSR process by organizing several kinds of activities. Simmonds (1984), made a detailed study on the types of FSR strategy followed by different countries and continents, and grouper them into the following three basic categories:

i) **FSR in strict sense**: it refers to study the farming system as they exist. It is strictly an academic activity oriented towards the description and analysis of farming systems including the in-depth understanding of their functions.

ii) **New farming system development**: Often, this type of research is undertaken at the research stations by using the state-of-the-art technologies, and by integrating the crop, livestock, and tree species in a synthetic farm. Interdependence among the enterprises is acknowledged and taken care of. It seeks to bring about complex and radical changes, rather than step-wise changes, through the development of new farming systems.

iii) **On –Farm Research with a Farming System Perspective**: It is a problem-oriented research, which recognizes that changes to farming systems must be adapted to circumstances of the intended users of the change. It recognizes that on- station research (OSR) research have matched poorly with those obtained by the farmers on their farms using the same package of changes. It also stresses incremental nature of changes to farming system, rather than revolutionary changes. The majority of FSR to date can best be described under this, which has increasingly found favour with the FSR practitioners worldwide.

Integrated Farming systems in Bihar perspective

Agriculture is the bedrock of Bihar's economy, employing 80% of the workforce and generating nearly 40 % 0f GDP. Agriculture in Bihar is faced with major challenges like low productivity, regional disparities and low level of diversification of agriculture into non-food crops and commercial crops. The State requires an action-oriented policy for rejuvenating its agriculture sector. Bihar is a true example of a 'resource rich state' inhabited by 'poor people' and 'high potential low productivity' state. This poses challenge for researchers in agriculture and natural resource management to evolve new, effective strategies for delivering rural services and for implementing local institutional arrangements to improve livelihoods of the rural poor through agriculture-based activities.

Bihar's agricultural performance has been far below its potential, as is evident from the decline in per capita output over the past decade. The growth of agriculture has also been highly volatile, with annual output swings between minus 20% and plus 30%, which has had significant implications for poverty alleviation and income security of the poor. In spite of rich natural resources, as high as 42.60 percent population lives below poverty line (BPL). Bihar's crop productivity is constrained by the general lack of infrastructure, land holding patterns, and other environmental factors. State's gross sown irrigated area of around 50% is relatively low as compared to 95% in Punjab, 67% in Uttar Pradesh, and 60% for India as a whole. The average ground water exploitation is 39%, indicating a large unexploited potential. Annual flooding has exacerbated land degradation and created a host of related economic and social problems. About 9.41 lac/*ha* of land is suffering from water logging / water stagnation / drainage congestion including areas under *tal, chaur* and *mauns* (oxbow lake) and canal induced water logged areas in canal commands. These areas offer great potential and challenge for their productive utilization through multiple use and farming system including cereal crops, fisheries, and horticulture like banana, vegetables, makhana and other aquatic crops.

Crop productivity trends have been below the Indian average for most cereal crops, and far below their potential yield, given Bihar's fertile land and water resources. The causes for the large yield gap (which is difference between current and optimal production) are numerous: low investment rates, lack of water mgt. with annual flooding of the Gangetic plain districts, and weak transport and marketing infrastructure. Severe fragmentation of land holdings also impedes productivity and subsistence farming continues to predominate. Poor agricultural growth clearly been a major factor hindering poverty reduction and has serious implications for the consumption security of poor households.

Land holdings in Bihar consist predominately of small & marginal farm holdings with a high degree of fragmentation. About 85 per cent of the farmers are small and marginal but sharing only 50 per cent of the land. The average size of the holding is 0.83 ha, with that of small and marginal farmers range from 0.32 to 0.5 ha. These tiny holdings are fragmented & scattered and land tenure system does not enable private investments for permanent improvement of land and infrastructure. With the average size of land holdings shrinking as a result of increasing fragmentation, many marginal farms are becoming economically non-viable and oriented towards subsistence. This has slowed the diversification into commercial crops from low value-added cereals that continue to dominate cropping.

Bihar has, in general, grown slower than the rest of India, with less robust links between growth and poverty reduction as compared to other states. About 85% population depends directly or indirectly on agriculture and it contributes 40% to GDP. The State is ranked lowest in terms of per capita income (<Rs. 6000). Given the dependence of Bihar's

economy on agriculture and the large percentage of the state's poor that are dependent on rural economy, improving agricultural performance is particularly important for growth and poverty reduction. This poses challenge for researchers in agriculture and natural resource management to evolve new, effective strategies for delivering rural services and for implementing local institutional arrangements to improve livelihoods of the rural poor through agriculture-based activities.

Bihar is predominantly rainfed with less than 40% of irrigated agriculture in most of the districts. Rainfed agriculture is the primary source of livelihood which is subjected to the vagaries of the monsoon including floods and droughts and the frequent natural calamities. Rice-wheat is the predominant cropping system with low yield levels (< 4 t/ha combined R-W yields). Low agricultural productivity in general and lack of agri-based activities in particular in the region forces the community to work as laborers to earn their livelihood and out migrate for search of job.

Overall, there is a very high incidence of poverty notwithstanding the abundance of natural resources and high potential for the agricultural growth in the region. Nevertheless, the problems are also abounding due to lack of water resource development including water conservation and water harvesting, water management, frequent floods and water logging especially in North Bihar, rampant soil erosion, drought, lack of quality livestock and good husbandry practices, under exploitation of water endowment for fisheries, underutilization of untapped Agri-based alternate income generation activities etc. Besides these bio-physical constraints and limitations, there are number of socio-economic and infrastructural shortcomings such as inadequate knowledge of proper technological know-how, unavailability of quality agricultural inputs, small and fragmented land holdings, lack of participatory approach, lack of extension and poor delivery system, poor socio-economic infrastructural development which are equally responsible for low productivity and poor livelihood conditions.

Crop diversification towards high value/ more remunerative crops considering the agro-ecological conditions, endowment of land and water resources and the market demand both within the state and outside can help to overcome such problem. Our emphasis will be on production of foods, vegetables, agro-forestry, fruits, animal husbandry, dairying, aquaculture, bee keeping etc. Besides, production for the niche market, which has so far not been undertaken, would be encouraged and can be achieved by converting our traditional agriculture into more profitable and more sustainable system i.e. farming system.

Keeping in view, it emphatically entails the need to promote farming system approach as a state programme. Undoubtedly, this approach is a location specific, technically skill based, play multi-dimensional role in fulfilling the domestic requirement, employment avenues, rational use of resources, rejuvenation of resources, sustaining productivity, invest ability and economic ability of the systems (Gill, M.S., 2004). In the present scenario of agriculture sector, this only approach enable the Indian farmers self-sufficient and competitive in the global market by producing quality edible products which is the main base in farming system on account of their inheritance of recycling- the by-products of different enterprises and even a pinch of material always considered of economic value.

Again, it is imperative to say that there is great scope for integrated farming system research in Eastern region and that too in Bihar in all types of ecosystem. Unfortunately, Eastern India is lagging far behind than other regions in respect of Integrated Farming System Research in spite of endowment of good soil of alluvial tract, a markable percentage of land under cultivation, abundant sunshine, ample water resources, a large number of livestock and vast human resources. In other words, we can say that it is high potential, low productivity area. There is ample scope to boost the productivity in terms of resources and endowments. Challenge to us to convert adversity to boon. We have to find the path to convert Indo- Gangetic Basin as a feeding bowl of the country giving main emphasis to lower part of the IGB i.e. Eastern UP., Bihar and West Bengal and integrated farming system may serve the purpose along with other modern technologies. So, a proper attention is needed to strengthen the Integrated Farming System Research Programme in India as well as in the Eastern part of the country.

For such prevailing situations, there is need to integrate agriculture, horticulture, fisheries and other allied enterprises like apiculture, sericulture, mushroom cultivation etc. with livestock which holds promise for this region in a scientific way for improvement in the livelihood of marginal, small and medium household farm families. The resource use efficiency at present level is poor due to lack of adoption of appropriate farming system models. Good quality of fertile land, rich water endowments, biodiversity and manpower can be used in an integrated manner in a farming system mode by recycling of wastes to secure high resource use efficiency and improved livelihood.

Importance of Integrated farming System in Bihar State

It is well accepted fact that future productivity growth would come from better risk management strategies in the drought/ flood prone regions of EIGP and that too from Bihar. During the last decade, there was substantial increase in the productivity of rice, wheat, and other crops. The intensification, however, had its own built-in maladies. These include irrational use of land and water and high-cost inputs like fertilizer, herbicides etc. leading to degradation of the fragile eco-system and depletion of natural resources. It is now appearing that rice-wheat (R-W) systems have fatigued the natural resource base.

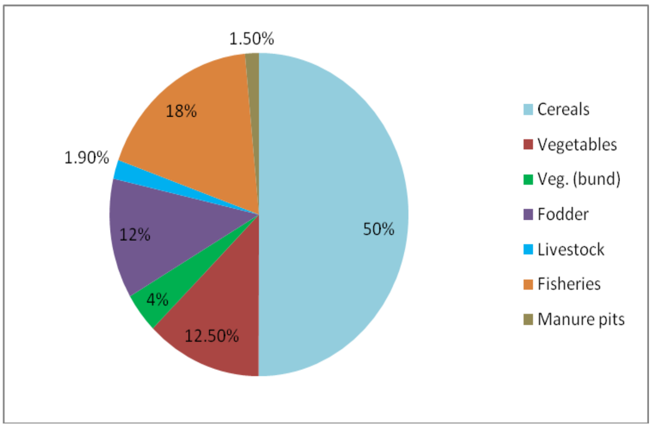
Keeping this fact in view, location specific farming system models were developed which could extend (i) sustainable production system, (ii) ensure food and nutritional security at household and even at individual level, (iii) mitigate climate change impact on crop productivity, (iv) improve resource use efficiency and water productivity, and (v) provide gainful employment through farming practices (Sanjeev *et al*., 2012). The details of the developed IFS model are given below.

One acre IFS model	*Two acre IFS model*
Main enterprises: Crop + Goat + Poultry	Main enterprises: Crop + Livestock (2 no.) + Fishery
Allied enterprises: mushroom, vermicomposting	Allied enterprises: Duckery, composting, vermicomposting

A) IFS models at a Glance (Location: ICAR-RCER, Patna Farm)

Land allocation to different components under two-acre IFS model

1) **Cereal crops** (50 % area)
Kharif: Rice
Rabi: Wheat/MaizeGram/Mustard



2) **Horticultural crops** (Fruits + vegetables): 12.5 % area
Vegetables:
Kharif: Cucurbits/Brinjal/Okra
Summer: Onion/Brinjal/Cowpea/Okra/Bitter gourd/Cucumber etc.
Rabi: Tomato, cabbage, Brocelli, French bean
Fruits:

Papaya (On pond's dike and field bunds)
Banana (On pond's dike)
Lemon (On pond's dike and Horticultural block)
Guava (On pond's dike and Horticultural block)

3) **Boundary plantations** (4 % area)
All around the fields, drumsticks and dhaincha plants were planted to provide fodder to animals and seeds for green manure crop. On field funds, fencing was done and cucurbits, pigeon pea and soybean crops are being raised for maximum utilization of land and to provide protein supplements to farm families.

4) All around the field bunds cucurbits or seasonal vegetables having lesser water requirement may be raised by making wire fences.

5) **Fish + Duck integration (17.8 % area)**

a. Mix carp culture: Rohu (20 % as column feeder), Catla (30 % as surface feeder), Mrigal/common carp (50 % as bottom feeder)

b. Duck: For 1000m^2 water area 40- 45 number of ducks are found sufficient.

Khakhi Campbell breed of duck is right choice for this area (Dual purpose). A thatched hut of 10 X 15' size is optimum for 40 ducks above the water or on the pond's dike.

6) **Livestock** (1.80 % area) + Bio- gas unit
A size of 2 adult cows + 2 calves is optimum for two-acre land in respect of FYM requirement for the fields and fodder requirement for the livestock. A thatched hut of 20' X 30' with sufficient paddock space is sufficient for above no. of animals. The Cow shed was connected with the pond with a drainage channel so that urine and water can move into the pond. A storage hut for storing of animal feed was also made near the animal shed. A bio- gas unit of 2m^3 capacity was also constructed under livestock area for production of bio-gas for energy and slurry to making vermicompost to the crops. It was found that for 2m^3 capacity of bio-gas unit, by product obtained from two adult cows are optimum.

7) **Fodder production** (12.5 % area)

For feeding of 2 cows and 2 calves 1000 m^2 land is sufficient if year-round fodder production is carried out. In addition to green fodder, straw, leaves, stems of different cereals and vegetables can be also used as animal feed.
Kharif: M.P. Chari/Sudan grass/ Napier/Maize
Summer: Boro/Lobia/Maize/Sudan grass
Rabi: Berseem/Oat/Maize etc.

8) **Spices**: In the sheds or where light intensity is less like orchards, spaces between the huts etc. turmeric, ginger or guinea grass are being taken.

9) **FYM/vermicomposting pits**: (1.4 % area)

Optimal sizes pits (9' X 3') for preparation of FYM 93 pits) and Vermicompost (4 pits) has been made. Sizes may depend upon land available near the livestock shed so that required raw materials for making manures should be made available nearby for convenience and to avoid transportation charges.

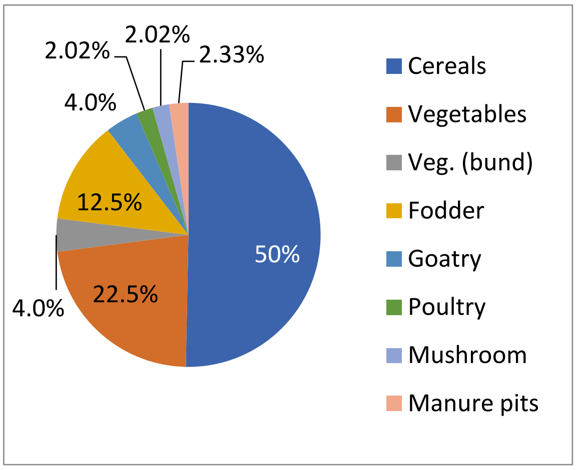
Note: Cattle shed should be always constructed away from birds to avoid attack of any transmissible or contagious diseases to animals or vice-versa.

Land allocation to different components under one-acre IFS model

1. **Cereal crops**: (50 % area)

Kharif: Rice
Rabi: Wheat/Maize/ Lentil/Til

2. **Horticultural crops** (Fruits + vegetables): 22.5 % area



Vegetables:

Kharif: Cucurbits/Brinjal/Okra
Summer: Brinjal/Cowpea/Okra/ Bitter gourd/Cucumber etc.
Rabi: Tomato, Cauliflower, spinach

Fruits:
Banana (On field bund)
Lemon (In Horticultural block)
Guava (In Horticultural block)

3. **Boundary plantations** (4 % area)

All around the fields, Karaunda, drumsticks and dhaincha plants were planted to provide fodder to animals and seeds for green manure crop. On field funds, fencing was done and cucurbits, pigeon pea and soybean crops are being raised for maximum utilization of land and to provide protein supplements to farm families.

4 **Livestock (Goat)**: 2.5 % area

A size of 20 female got + 1 buck is optimum for one acre land in respect of manure requirement for the fields and fodder requirement for the livestock. A thatched hut of 20' X 30' with sufficient fenced paddock space (to move the goats freely as goats have to kept on stall feeding) is sufficient for above no. of animals. The goat shed was made airy and sunny. A storage hut for storing of animal feed should was also made near the animal shed. Black Bengal breed of goats are found suitable for this region.

5 **Poultry** (200 birds)

200 birds (broiler) are being reared in an area of 225 sq. ft. by making a thatched hut. All around the thatched hut's walls, wire meshing has been done at the inner walls to protect the birds from predators and hunting animals. The hut was made airy and proper arrangement of bulbs was made before rearing the chicks.

6 Mushroom

Year-round mushroom production is being done in an area of 25 X 20' by making a thatched hut for optimum return. In this shed about 200 mushroom bags are being kept at a time by making bamboo shelves. Selection of the mushroom strains is done on the basis of climate, temperature and humidity in the atmosphere as:
March – September: straw/paddy/milky mushroom
October- February: Oyster/ Button mushroom

7 Fodder production (12.5 % area)

For feeding of 20 + 1units of goat an area of $600m^2$ is sufficient if year-round fodder production is carried out. In addition to green fodder, dry husks, leaves, stems of different cereals and vegetables are also being used as feed.

Kharif: M.P. Chari/Sudan grass
Summer: Boro/Lobia/Maize/Guinea grass
Rabi: Berseem/Oat/Maize etc.

8 Spices: In the sheds or where light intensity is less like orchards, spaces between the huts etc. turmeric, ginger or guinea grass can be taken.

9 Compost pits/ vermicomposting pits (1.4 % area)

Optimal sizes pits for preparation of goat manure and Vermicompost should be made depending upon land available near goat shed so that required raw materials for making manures should be made available nearby field and livestock.

Note: Goat shed should be always constructed away from poultry shed to avoid attack of any transmissible or contagious diseases to animals.

Income and expenditure from IFS model

Table 1.: Establishment cost, Expenditures and Net income for one-acre IFS model

Components	Estb. Cost (Rs.)	Recurring expd./ann. (Rs.)	Net returns /year
Crop (0.2 ha)	-	14,062	14,112
Horticulture (0.09 ha)	5000	10,946	12,843
Fodder	--	10,175	4,165
Goat (20 + 1) (0.018 ha)	65,220	34,632	18,225
Mushroom (0.003 ha)	9,000	6,200	3,461
Poultry (700 chicks) (0.0015 ha)	15,000	64,920	24,282
Crop waste/V.c/FYM pits	8000	3,287	2,163
Total	1,02, 220	1,44,222	79,251 B: C :: 1.71

The farming system models were started in the year 2010, and on the basis of five years data, now it can be analysed that by integrating Crop + Livestock + Fish/ duck in two-acre area of land, a net income of Rs. 1,37,209/- can be achieved with a B:C ratio of 1.8 while by integrated crop + goat+ poultry in one acre of land a net income of Rs.. 79,251/year can be obtained which is about 4 times higher over rice-wheat cropping system (Table 1) with an additional income equivalent to 118 Kg urea, 247 kg SSP and 71.2 kg SSP as due to nutrient recycling within the system 56.5 kg N, 39.6 kg P and 42.7 kg K were added to the soil which will be utilized by the next crop. To start up with all these components an initial investment of Rs. 2,05,000/- may be required.

Contributions to income from different enterprises play an important role while selection of components for a particular IFS model development. While selecting the components one should be enough careful about his needs, technical knowledge about the component, water, land and labour availability, transportation and marketing facilities etc. to get maximum profit. In the developed two-acre IFS model, Fish integration has resulted in maximum contribution to income and was followed by Horticulture and dairy components while maximum contribution to income was gained towards poultry and was followed by goatry and horticulture under one-acre IFS model, respectively (fig.1).

Nutrient recycling

Nutrient recycling within the system is prerequisite for development or integration of any component in the IFS model. Priorities should be given to those components whose by-product can be recycled within the system or can be reused as input for another component to increase nutrient use efficiency on one hand and also for decreasing the cost of cultivation and addition of organic forms to the system for its sustainability. Under two-acre IFS model, 13.8 t of cow dung from two cows, 11.3

t of vegetable wastes and 1.21 t of duck dropping were produced and were recycled within the system which added an amount of Rs. 4,826/year to the income (Sanjeev et al., 2012).

Likewise, 2.5 t of goat manure, 6.62t of vegetable wastes, 1.78 t of poultry droppings and 4.64t of rice/maize/lentil straws were recycled within the system which contributed Rs. 3,175 to the income and added 44.0 kg N, 29.5 kg P and 31.2 kg K in the soil which was equivalent to 93.0kg urea, 184.0 kg SSP and 52.0 Kg MOP. In addition to these nutrients an ample quantity of micronutrients was also added to the soil upon nutrient recycling.

Employment Generation

It was often said there is hidden unemployment in Agriculture which can be best descried with an example with seven members in a family (four adults and three children), they possess a land of one acre and rice- wheat cropping system is being followed. It was observed that all the members are engaged in the farming itself while it is not required. Most of the time they are sitting idle. IFS model here is ready to overcome this type of problem by integrating more number of remunerative components in the system. By integrating one or two small components say 500 no. of poultry and 500 bags of mushroom cultivation, about 110 man-days requirement is enhanced and these family members are able to perform these works easily. Women's and children can be also involved in many of agriculture-based activities like nursery raising, mushroom cultivation, poultry farming, vermicomposting etc. Man- power requirement by different combinations and component wise were also studied in the farmers' field and presented in table 4. It was observed that livestock base IFS model engaged the maximum no. of man- days and generated an additional 281man- days over cereal based cropping system only.

Table 4. Employment generation (man-days) by different IFS models

Farming Components	Crop	Hort.	Poult	Duck	Fish	Goat	Dairy	FYM/V. comp.	System emp.	Add. M-days
Crop alone (cereals)	237		-	-	-	-	-	-	237	-
Crop + Hort.	172	242						21	435	120
Crop/Hort. + fish + poultry	135	145	110	-	36	-	-	20	446	181
Crop/Hort. + fish + duckery	155	145	-	40	36	-	-	25	401	136
Crop/Hort. + fish + goat	135	145	-	-	36	110	-	30	456	191
Crop/Hort. (0.4ha) + fish + cattle	133	145	-	-	36	-	210	32	568	281
Crop/Hort. + fish + P + D	135	145	110	40	36	-	-	20	486	221
Crop(c/v)+ mush. + goat	155	145	-	-	-	110	Mush . 40	20	470	205
Crop / Hort.+ P+ Mush. + Goat (1 acre)	72	84	63	-	-	110	Mush 40	32	351	86
Crop / Hort. + Fish + D + Cattle (2 acre)	133	145	-	40	36	-	210	32	619	382

Impact of the developed Integrated Farming Systems

- IFS models developed were able to improve the organic carbon in the soil by 3.4 to 10.2 % in five years. Hence, sustainable agriculture development is possible only by adopting farming system approach of land use.
- Employment generation was improved by 40 to 225 % in IFS compared to traditional rice-wheat cropping systems.
- The sustainability index of developed models was found in the range of 0.18 – 0.76; whereas the traditional rice - wheat system had shown sustainability index ranging from 0.02-0.2, which is not capable of sustaining the poor farm families.
- The line departments of eastern India are extending support to promote integrated farming system mode of food production. Department of agriculture, Govt. of Bihar has already adopted the one and two-acre farming system models developed by ICAR RC for ER, Patna and the department is promoting the adoption of these models in 1068 farmers' fields through National Food Security Mission and providing a subsidy of Rs. 10,000/- per farmer to integrate at least one additional enterprise with crop. Govt. of Odisha, West Bengal, Jharkhand and Chhattisgarh is also supporting IFS through various schemes.
- Ministry of Agriculture and Farmers Welfare, Govt. of India has suggested to establish IFS model in each KVK besides SAUs and ICAR institutions. This approach will help in technology refinement and fine tuning of existing farming systems for better returns.
- The fruit based multitier system has already been included in the Wadi programme. NABARD and National Horticulture mission (NHM) are extending financial support for their expansion in hill and plateau region of India. Similarly, ultra-high density orcharding in guava is also being promoted in the region under NHM and different programmes of NABARD.
- Under rainfed conditions of EHPR, adoption of multitier system resulted in six times increase in productivity. Apart from this, the system has an estimated carbon sequestration potential of 9.8 Mg C per ha per year. A total of 1000 man-days per ha could be generated during the initial 7 years of orchard establishment.

Farming System Research in my opinion:

The increase in ever growing human population is increasing pressure on available agricultural land, which is decreasing due to its diversification for non-agricultural uses. Moreover, with the opening of the Indian markets to the world, there will be enormous pressure on Indian farmers to produce quality food at low cost from shrinking land and natural resource for ever growing human population. Under such a paradoxical situation, the answer lies in efficient utilization of crucial natural resources but it is not as easy as it sounds. Now- a- days we are giving more emphasis on implementation of integrated farming systems. This approach is not only a reliable way of obtaining fairly high productivity with considerable scope for resource recycling but also a concept of ecological soundness leading to sustainable agriculture. Farming system is an ever-changing process as farming system evolve and change with the time, in respect to their own logic, as well as to the changes, which occurs in the society within which they are immersed. Often agricultural innovation is rejected because of socio-cultural constraints to their adoption but become rapidly adopted if the economic circumstances change (eg. capital, labour, market, general economic development etc.). Diversification in predominant cropping pattern from traditional crops to high value /medicinal plants, bee keeping, duck keeping, piggery, fish farming, mushroom cultivation may be taken as potential alternative has its pros and cons. One system may be effective at one location but not at other. Integration of farm enterprises (crops, livestock, agroforestry, agro-horticulture and aqua culture will certainly offer opportunity to raise farm income, employment, nutrition and food security of household and finally improve livelihood. The entire philosophy of integrated farming system revolves around better utilization of time, money, resources and family labour. The farm family gets scope from gainful employment round the year thereby ensuring good income and higher standard of living even from small land holdings. The increase can be further increased if the farming system is such managed to harvest the crop during festival. Early harvest can also help to get high price.

Farmers are certainly integrating different farming components as far as possible to the best of their knowledge, skill, awareness, resource endowment, labour availability, taste and preferences etc. Now it is responsibility of Agricultural scientists to develop relevant agricultural technologies by focusing attention on the conditions and problems of the farmers, particularly the small, resource poor farmers operating in less favorable natural environment. We have to evolve suitable policies and programmes and make their effective implementation. The success of any programme depends on the concern, commitment and effectiveness of person managing the programme. They should have a clear-cut sight into the objectives and goals of the programme and have an attitude that ensures its effective implementation.

In my view, the most important fact for any farming system to sustain in the region, it is necessary that situations/ condition is generally favorable/compatible and encouraging for existence and growth of the particular system. The condition may include many things which may be comprehensively described by the term "Resource Endowment milieu" of the region/ farmer. REM of a farmer refers to his all resources including all kinds of SWOTs (S= strength, W= weakness, O= opportunity and T= threats) a farmer is faced with. The REM varies from region to region and to be very precise from farmer to farmer. It is the REM of a region/person which plays an important role in deciding the farming system to be integrated or not by a particular region/farmer.

Agroforestry in climate resilient farming with special reference to Eastern Indo-Gangetic Plains

Nongmaithem Raju Singh

Division of Crop Research
ICAR-Research Complex for Eastern Region, Patna, Bihar-800014

Agricultural and allied activities remained the major functioning sector in Indo-Gangetic Plain (IGP) due to its rich and diverse natural resources, which enable to produce 50% of the food grains to feed 40% of the country (Pal *et al*., 2019). This region consists of a large alluvial plain abound with rivers Indus, Ganges, and Brahmaputra. The lower and middle Gangetic plains are collectively referred as Eastern Indo-Gangetic Plains (E-IGP) with an area covering of about 23.97 M ha. The states of West Bengal, Jharkhand, Eastern Uttar Pradesh and Northern part Bihar has come all under the realm of E-IGP (Pathak *et al*., 2014). The ever increasing human population coupled with intensive agricultural practices by use of excessive chemical fertilizers, pesticides, herbicides, etc., has severely affected the land productivity of this region. In this context, agroforestry a promising land use system, which involves the integration of trees or woody perennials along with agricultural crops on same unit of land, has been considered as a viable option with the aim to conserve the natural resources on one side and sustainable production on the other side. The works of agroforestry and its related activities has been paid attention by different stakeholders in this region with the advent of All India Coordinated Research Project on Agroforestry (AICRP-AF) in 1983. Since, then, the practices of agroforestry are being employed in different scales across the region with an expectation of increasing agroforestry area in the coming years. Improved agrisilviculture, agrihorticulture based agroforestry systems have been recommended for this region for higher production and economic sustainability while homegardens, boundary plantation are commonly practiced traditional agroforestry systems for this region.

Agroforestry as climate resilient option

Agriculture becomes the sole source for livelihood in most underdeveloped and developing countries. Unfortunately, the agricultural production system has been severely affected by land pressure as well as climate change related events in these countries. Diversification of existing farming systems by developing suitable agroforestry models seems to be the need of the day to cope-up with ever increasing demand for diversified products such as food, fibre, fodder, fruit, timber, etc. Agroforestry is ecologically based land used system which involves the integration of trees on farm in the same agricultural land management unit whereby diversifies and sustains production for increased social, economic and environmental benefits for land users at all levels. Integration of trees on farm enhances overall farm productivity, improve microclimate and enable more species of plants and animals to develop and survive in the system. It also has the potential to enhance ecosystem services through carbon sequestration process, prevention of deforestation, watershed conservation, biodiversity conservation, and soil and water conservation. Agroforestry is the only alternative to meet the country's target of increasing forest cover from present less than 25 to 33%.

According to FAO (2010) resilience refer to the ability of a system to maintain key functions and processes in the face of stresses or pressures by either resisting, adapting or mitigating change, key functions includes: production (soil and nutrient management), ecological services (carbon sequestration). In simple word, for a system to be resilient, it must be able to continue to thrive and reproduce, and compete for space and resources in face of perturbation. The land use systems to secure food availability by creating better living environment needs to be devised and improved keeping in view the needs and changing climatic conditions without compromising the productivity and sustainability of land use system put in place and resources used. One such land use system being advocated fit to address above said questions world over is agroforestry (Jose, 2009; Padmavathy and Poyyamoli, 2013). Agroforestry is a dynamic, ecologically based, natural resources management system that, through the integration of trees on farms and in the agricultural landscape, diversifies and sustains production for increased social, economic and environmental benefits for land users at all levels (ICRAF 2006). During the past few decades of years, it is spreading over the world as a significant land management system. The definition developed by (Lundgren and Raintree 1982) is one of the simplest and most comprehensive, "Agroforestry is a collective name for land use system and techniques where trees are deliberately used on the same land management unit as agricultural crops and or/animals, either in the same form of spatial arrangement or temporal sequence. In agroforestry systems, there are both ecological and economical interactions between the different components. The conclusion based on previous work and its results depicted that agroforestry majorly contributed in (i) biodiversity conservation; (ii) goods and services to society; (iii) augmentation of the carbon storage in agroecosystems; (iv) enhancing the fertility of the soils; and (v) providing social and economic well-being to people.

Agroforestry Systems Practiced in E-IGP

Agroforestry has been an age old practice in the region (Pathak and Dagar, 2001). Different forms of agroforestry systems have been adopted by farmers of this zone according to their needs and demands as well as the suitability of the site and crop combinations. Some of the traditional agroforestry systems practices in this region are presented in table1. However, with the changing time, new improved agroforestry technologies have been suggested by National Research Centre for Agroforestry (renamed as Central Agroforestry Research Institute) (2007) which are being successfully adopted by farmers (table 2).

Table1: Traditional agroforestry systems practiced in E-IGP region of India

Traditional Agroforestry System	Characteristics
Homegardens	Diversified; multi-tier system; trees generally form the uppermost canopy layer, fruit trees like guava, lime, litchi, banana, jackfruit, etc. form the middle layer of the canopy while vegetables, herbs, shrubs covered the ground canopy; generally practiced for sustenance requirement of the farmers; size may be varied on the availability of land around the home or backyards.

Scattered trees on farms	Scattered trees with agricultural crops combinations; 10-50 trees/ha; generally practiced in the areas of rainfed condition, common tree species grown are *Dalbergia sissoo, Azadirachta indica, Litchi chinensis, Acacia nilotica, Syzygium cumini*.
Trees on farm boundaries	Generally tree species which have early economic returns like *Eucalyptus* and *Poplars* are commonly grown along with agricultural crops. Sometimes farmers also grown tree species like *Dalbergia sissoo, Dalbergia latifolia, Wendlandia exserta* on their farm boundaries.
Silvopastoral systems	Fodder production trees species and grasses are grown on the agricultural lands or grazing areas, quality and sustainable fodder production is the main objective of this system.

Table 2: Improved Agroforestry Systems Eastern-Indo Gangetic Plains (NRCAF, 2007)

Agro-climatic Zone	Agroforestry System	Tree component	Crop/Grasses
Lower Gangetic Plains	Agrisilviculture (Irrigated condition)	*Eucalyptus, Albizia lebbeck*	Paddy
	Agrihorticulture (Irrigated condition)	*Mango/Banana/Litchi*	Wheat, Paddy, Maize
	Silvipasture	*Morus alba, Albizia lebbeck*	*Dichanthium, Pennisetum*
Middle Gangetic Plains	Agrisilviculture (Irrigated condition.)	*Populus deltoides*	Sugarcane-Wheat
	Agrisilviculture (Irrigated condition)	*Eucalyptus spp.*	Rice-Wheat
	Agrisilviculture	*Dalbergia sissoo*	Sesamum
	Agrihorticulture (Irrigated condition)	*Mango/Citrus spp.*	Rice-Wheat
	Silvipasture	*Albizia lebbeck*	*Chrysopogon, Dichanthium*

Case studies

Rana *et al.* (2007) in eastern Uttar Pradesh found that maximum farmers which of small and marginal land area has given the preference of adopting agroforestry practices. *Artocarpus heterophyllus, Azadirachta indica, Dendrocalamus strictus, Psidium guajava, Musa paradisiaca,* and *Citrus spp* are commonly trees grown in agroforestry systems in this region. Moreover, a well develop and efficient agroforestry systems would able to diversify the overall farm and its related activities. It is also believed agroforestry practices are more climate resilient, helps in improving the carbon storage, ultimately helps in adapting and mitigating the climate change.

Chaturvedi and Jha (1998) observed that litchi based agroforestry system in Bihar has proved to increase the benefit cost ratio (B: C ratio) to 2.73 and also able to generate employment opportunities of 130–140 man days ha^{-1} under nine year old litchi based agroforestry system. Similarly, silvo-pastoral system a prominent agroforestry system of Bihar and other states of E-IGP has potential to generate employment generation to local people. On an average 10 year cycle of silvo-pastoral system in Bihar would able to provide employment of 120 man days ha^{-1} per year (Chaturvedi and Khan, 2009).

Das and Chaturvedi (2005) at Pusa, Samastipur, Bihar found that 9 year old *Populus deltoides* based agroforestry had improved the soil nutrient status through addition of litter fall nutrients (146.2 N, 17.9 P and 66.3 K) in soil. Yadava and Kuli (2007) at Birsa Agricultural University, Ranchi also reported that *Senna siamea* based agroforestry system helps in increasing the soil fertility by improving 40.4 % soil organic carbon, 24.8 % phosphorus and 29.3 % potassium content in the soil in three years after establishment of *Senna siamea* agroforestry. In high erosion areas, silvipastoral agroforestry system (growing of native grasses along with suitable tree species) not only helps in improving the livelihood security but also conserving the natural resources by preventing erosion and conservation of soil (Quli and Siddiqui, 1996). It is also worthwhile to mention that stated agroforestry could provide a big opportunity to rehabilitate the wasteland and degraded land areas by introduction tree based farming system after selecting the suitable and adaptive tree species of the specific site.

Conclusion

Agroforestry is playing a tremendous role in E-IGP by increasing the agricultural productivity while improving fertility of the soil and diversification of crop at the same time. Agroforestry has great potential of ecological rehabilitation of upland, deforested, and already eroded watersheds, provide employment to rural and urban population through production, industrial application and value addition ventures. However, due to lack of government support like incentives, capacity building programme, lack of supply of quality planting materials, improper implementation of agroforestry policy, etc. had creating a big challenge to convince people for adoption and promotion of agroforestry.

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Suitable intervention for improving Makhana-based farming for higher productivity and profitability

I S Singh, Manoj Kumar, S.M. Raut, Ashok Kumar and Dhiraj Prakash

ICAR RCER, Research Centre for Makhana, Darbhanga-846005

Makhana (*Euryale ferox)*, an aquatic crop of the Family *Nymphaeaceae* is unique, highly nutritious dry fruit mainly grown in flood prone zone of north Bihar, lower Assam, and part of Bengal. It is commonly known as g***orgon nut or fox nut.*** It is also found to be growing instagnant perennial water bodies like ponds, land depressions, oxbow lakes, swamps and ditches. Makhana seeds are also called as **black diamond.** The seeds of Makhana are popped and eaten as roasted as well as used in preparation of various kind of sweets and recipes. It has nutritional [carbohydrate (70-80%), fat (0.1-0.2%), protein (9-12%), also rich in trypsine, cystine, phenylalanine, calcium, magnesium, sodium, iron and zinc] and medicinal properties and there is a great export potential of this crop.

Climate and Morphology:

Makhana is a plant of tropical and subtropical climate. For its proper growth and development the conducive range of air temperature is 20^0C--35^0C, relative humidity 50-90% and annual rainfall 100 cm-250 cm, organically reach water bodies with less than 50% water transparency. An important aquatic herb, prickly water plant with gigantic floating nature leaves of a size of 1-2 mandthese leaves are born on 3-5 feet long petioles predominantly nerved and reticulated-veined beneath, green in upper and purple in lower side, thorny in both sides of leave even in entire plant. It has thick rhizomatous stem, rooted in cluster form in sediment up to 20 cm depth.

Makhana Flower Riped makhana seed Makhana fruit

Crop cultivation

Fox nut is cultivated either in water bodies/ponds having water depth of 1.20-1.80 m or in 30-60 cm deep shallow agricultural fields.

Ponds system of cultivation

Traditionally it is grown in naturally formed ponds where seed sowing is not required, since leftover seeds of previous crop serve as planting materials of subsequent crops. However, Makhana cultivation in new water bodies(ponds) requires an addition of FYM @ 20 t/ha followed by two to three wet ploughings of the field after that the fields must be filled with 45 cm depth of water. The seeds are broadcasted @ 80 kg/ha in the month of December. The transplanting of saplings is done in the month of March in agricultural fields.But pond cultivation is linked with low productivity as collection of seeds from bottom of the pond is a very tedious process and possesses drudgery to health to makhana farmers.Under pond condition, it takes duration of complete one year. Thus, no other crop is grown.

Makhana pond at farmer's field

Makhana pond at RCM, Darbhanga

Field system of makhana cultivation

The possibility of makhana cultivation in agriculture fields consisting 30-60 cm depth of water has been standardized by the Research Centre for Makhana, Darbhanga. This system is very easy to operate and provides opportunities to cultivate cereals and fodder crops in the same piece of land in same year. It raises the crop intensity by 200-300%. The prerequisite for this system is to raise a nursery.

Transplanting of makhana in field

Effect of makhana cultivation on fertility status of soil

On the whole on dry weight basis (w/w), makhana plants contain 0.31% nitrogen (N), 0.48% phosphorus (P), 0.40% potassium (K), 2200 mg/kg iron (Fe), 1000 mg/kg manganese (Mn), 8.0 mg/Kg copper and 105 mg/Kg zinc (Zn). While the seeds of Makhana contain 1.67% nitrogen (N), 0.40% phosphorus (P), 0.12% potassium (K), 960 mg/kg iron (Fe), 40 mg/kg manganese (Mn), 12.0 mg/Kg copper and 125 mg/Kg zinc (Zn). Makhana cropping adds 7.0 t/ha/yr (Dry weight basis w/w) biomass to the soil which significantly helps in sustainable management of soil. Makhana significantly contributes 34.35 kg/ha N, 56.04 kg/ha P, 53.07 kg/ha K, 27.26 kg/ha Fe and 12.31 kg/ha Mn to the soil system per year.

The following aspects are taken under consideration for producing healthy plant.

1. Improved plant type
2. Soil and water properties
3. Improved cultural practices
4. Cultivation in cropping system mode
5. Climate (Rainfall)

1. Improved plant type

The first ever variety of makhana crop namely *"Swarna Vaidehi"*was released on 15.11.2013 by ICAR Research Complex for Eastern Region, Research Centre for Makhana, Darbhanga. The variety has potential yield of 2.8 t/ ha whilelocal variety yielded 1.6 t/ha. The variety has been developed by pure lineselection. *Swarna Vaidehi* is also highly resistant to leaf blight disease.

2. Soil and water properties

The most suitable soil for its cultivation is clayey soil type as such soil retains water for longer time. The soil should also rich in nutrients like nitrogen, phosphorus, potassium, iron, manganese, zinc and organic matter. The makhana plant is primarily highly responsive to organic matter as well as the nitrogen content. It has also been noticed that the plants growing in nutrient rich soil are very less affected by any kind of diseases. The irrigation water should not be salty; the pH of irrigation water should vary around neutrality.

3. Improved cultural practices

Nursery raising:

It is well known that nursery raised plants have higher yield potential than the direct sown crop. Thus, the nursery raising technology in makhana crop was also introduced by Research Centre for Makhana, Darbhanga. Under this technology the field is well prepared by two to three deep ploughing, however, before ploughing, for the proper nourishment of seedlings, fertilizers @ 100:60:40 / ha, respectively, of N, P and K in combination of 20 t/ha compost is applied. Prior to puddling the soil should also be treated with cakes of neem/mahua /karanj @ 0.8-1.0 t/ha. These cakes helps in keeping the soil-born diseases at way form the rhizospheric region of plants. It would be more fruitful if the mixtures of these cakes (in equal proportion) are applied in the soil. The field is filled with water up to the 45 cm height of bund and the seeds are sown in the month of December. An amount of 20 Kg healthy seed is broadcasted uniformly in the entire nursery plot. For transplanting in one-hectare area, an area of $500m^2$ is enough for raising the nursery. A water level of 45 cm height is maintained throughout the growing period of seedlings, i.e., from December to March. The seedlings are transferred from the nursery plot to the already prepared main field in the first week of April and transplanted at a distance of 1.20 x 1.25 m. Same doses of nutrients are also applied in the main field where transplanting has to be done.

4. *Cultivation in cropping system mode*

The disease incidence in makhana crop may be decreased up to a certain level through its cultivation in cropping system mode. The Research Centre for Makhana has developed some popular makhana based cropping systems such as makhana-rice, makhana-wheat, makhana-berseem, makhana-water chestnut, makhana-water chestnut-berseem. The makhana-water chestnut-berseem has been found most economical and sustainable cropping system in terms of maintaining the soil fertility.

Following suitable interventions should be made to improve the productivity and profitability:

a) Use of high yielding varieties

b) Removal of weeds during early growth period i.e. up to first two months after the emergence of leaves over the water surface.

c) Judicious use of fertilizers: N:P:K @ 100:60:40 kg ha and FYM @ 20 t/ha

d) Cultivation in cropping system mode.

Traditional makhana pond having a depth of 1-2 m can be utilized for fish and water chestnut crops in cropping sequence. Due to this high water depth in Makhana water bodies, the agronomic management of this crop is very tedious and as a result, the productivity of this crop is very low (1.0-1.5 t/ha). Further cultivation of other crops such as rice, wheat, lentil and berseem except some some other aquatic crops such as water chestnut and Indian Lotus is not possible.

In order to address this problem an experiment was conducted to find-out the possibilities of successful cultivation of Makhana crop in field conditions. In the field system, in addition to Makhana, various other crops including cereals and forages can be grown successfully. While 4-5 months are sufficient for Makhana cultivation, other crops could be cultivated during rest of the months. In general, Makhana is transplanted in the second week of April and harvested by the second week of August. Thereafter, short duration varieties of rice are cultivated in the same field. After harvesting of rice (November), wheat is sown by mid of December and harvested by the second week of April and the field is prepared for the subsequent crop of Makhana. Hence, cultivation of two to three crops per year is possible in field method of cultivation. Makhana based cropping systems, i.e., Makhana-Water chestnut, Makhana-Berseem, and Makhana-Rice-Wheat have been developed which are being adopted by the farmers. Economics of different Makhana based cropping systems have been worked-out and net monetary returns have been recorded highest through Makhana-rice-wheat cropping system (Rs 1,22,570.00 per ha), followed by Makhana-barseem (Rs 98,465.00 per ha) and Makhana-water chestnut (Rs 88,790.00 per ha). Other Makhana based cropping systems are also developed:

(i) Makhana (March – July) – Rice (July – Nov.)

(ii) Makhana (April-Aug.) – Wheat (Nov. – April)

(iii) Makhana (March – July) – Water chestnut (July – November)

(iv) Makhana (April – Aug.) – Berseem (Nov. – April)

Economics of field based systems of Makhana cultivation analysed at farmer's field

IFS model by integration of fish and singhara with makhana was developed in 50 ha of land in Darbhanga district. The net benefit from the system was recorded at Rs. 52,435/- as compared to traditional system (makhana production alone) of Rs. 20,614/-. The makhana contributed the major share of around 40% followed by fish at 22.5%. Field-based system of makhana cultivation was standardized with other crop like fish, rice, and water chestnut in cropping system mode. The gross return from makhana-fish, makhana-rice and makhana-water chestnut was obtained as Rs. 2,82,810/-, 2,73,480/- and 3,54,340/- per ha, respectively while a gross return of Rs. 1,32,552/- was obtained from makhana cultivation alone. The net return from the above system was recorded at Rs. 1, 21,520/-, 1, 16,322/- and Rs 1, 56,436/- per ha, respectively as compared to Rs. 88,368/- per ha in makhana cultivation alone.

A view of makhana crop at farmer's field under NAIP

A view of fish harvesting from makhana field

e) Sequential double cropping systems of Makhana (Euryale ferox Salisb.) cultivation in agricultural fields of north Bihar, India

Makhana (*Euryale ferox* Salisb.) is an aquatic crop mostly grown in stagnant fresh water bodies of north Bihar, Assam, West Bengal and Manipur etc. To explore the possibility of two crops of makhana per year in the same field, the present study was conducted during 2011 and 2012 at the Research Farm of ICAR–RCER, Research Centre for Makhana, Darbhanga, Bihar. During both the years, the transplantation of first crop was made in the first week of February and its harvesting was made in the last week of June. In the same field the second crop was transplanted in the first week of July and harvested in the last week of October. All standard packages of practices were followed to raise the good experimental crops of makhana. The mean values of seed yield of spring crop of makhana was observed to be 3.04 t/ha while the yield potential of kharif crop was recorded to be 2.23 t/ha. However, the yield potential of kharif crop was not at par with the spring crop, yet it was very high as compared to the productivity of traditional crop of makhana in pond system (1.0-1.2 t/ha). The net return of these two makhana crops was recorded as Rs. 1,00,305/- and Rs. 80,205/- for spring and kharif crops, respectively. Findings of this study suggest that per year, two crops of makhana could be grown successfully in the field system of makhana cultivation.

f) Dynamics of nutrients under makhana-based cropping systems grown in inceptisols of northern Bihar

This study showed that makhana-water chestnut-berseem cropping system was identified as the most suitable, sustainable and remunerative cropping system under field based cultivation of makhana crop.

g) **Measures to control highly damaging insect i.e. aphids:** It should be controlled by spraying wood ashes during its infestation period i.e February to March.

5. Climate (Rainfall)

Makhana is suitably grown in regions having annual rainfall in the range of 100-250 cm. The region which receives precipitation less than 100 cm, the cultivation of the crop is not economical since from the date of sowing/transplanting to harvesting a constant water level i.e. 45 cm is essentially required for getting good yield.

Challenges and Researchable Issues

Though suitable production technologies have been developed including makhana based farming system mode of food production system, nevertheless, many core issues of importance are yet to be addressed. The same has been depicted below:-

- Varietal development in makhana to be enhanced in networking mode.
- Weed management in makhana ponds.
- Technology refinement of Integration of air-breathing fish, carp fish in both system of makhana cultivation.
- Technology refinement in integrated farming system mode of makhana cultivation.

Insect Pest and Disease Management in Conservation Agriculture

Md. Monobrullah
Principal Scientist, ICAR-RCER, Patna

Insects are the dominant animals in the nature, so it is not surprising that they interact with humans in more ways than any other group of organisms. It provides important ecological services as decomposers, consumers, predators and parasites (Miller 1993). Decomposition of plant and animal matter by fly maggots (blow flies, muscid flies, small dung flies, etc.) and grub and adult beetles (dermestid beetles, scarab beetles, carrion beetles, etc.) is essential for recycling organic matter in ecosystems (Frost 1959). Other predators (green lacewing, lady beetles, predaceous diving beetles, ground beetles, etc.) and parasites (*Encarsia* ssp, *Ichneomids,* etc.) play an important role in regulating many phytophagous pest populations (Olembo and Hawksworth 1991).

No doubt, conservation agriculture is advantageous for controlling insect pests by increasing biodiversity. The term biodiversity describes the variety of plants, animals, and microorganisms on Earth. Biodiversity provides resistant genes, anti-insect compounds, natural enemies (NEs: predators, parasitoids, entomopathogens) of pests, and community ecology-level effects to check pest attacks in the field (Gurr and Wratten 2012). Biodiversity does not function well under the common practices of conventional agriculture including burning of crop residues, continuous ploughing and harrowing, deforestation, overgrazing, monocropping, misuse of pesticides, excessive use of fertilizers, and misuse of water. The consequences of these practices are loss of soil fertility, food insecurity, health risks, soil and surface water contamination, greenhouse gas release, pest invasion, and loss of biodiversity (Bot and Benites 2001). Traditional systems of agriculture are broadly linked to the decline in biodiversity due to agricultural practices of tillage and intensive use of pesticides. The world's population will be approximately 9.7 billion in 2050. It is predicted that another 1 billion ha of natural ecosystems will be converted to agriculture by 2050, with a two- to threefold increase in nitrogen (N) and phosphorous (P), a twofold increase in water consumption, and a threefold increase in pesticide use primarily in the developing world (Tilman *et al*., 2001). This will reduce biodiversity in the natural environment which ultimately affects the biological management of insect pests in crop production systems. Agricultural systems such as CA which can conserve biodiversity needs to be more extensively adopted. The biodiversity of both plants and insects play an important role in pest management through top-down and bottom-up approaches (Gratton and Denno 2003).

Plant biodiversity as a bio-resource allows development and exploitation of naturally occurring compounds as well as diverse plants for IPM. Conventional agriculture is the main cause of plant diversity loss in agroecosystems. Current research tends to focus on diversified cropping systems based on intercropping, agroforestry, and cover cropping systems because these systems are considered more stable and conserve resources. Plant diversity has had a positive impact on herbivore insects by favouring associated NEs (Thies and Tscharntke 1999). Increased parasitism was observed in flowering plants which provide pollen and nectar for normal fecundity and longevity of parasitoids (Vandermeer 1995). These plants also attract non-herbivore insects which serve as food for other predators. Wild vegetation around crops enhanced biological control and served as overwintering sites for predators including pollen and nectar from flowering plants (Leius 1967). A number of studies have showed the positive impact on the flora and fauna on field and farm levels in organic farming systems when compared with conventional farming systems (Fuller and Norton 2005; Hole and Perkins 2005).

Conservation Agriculture promotes biological diversity below- and above ground by making ground cover favourable to the natural biota (Jaipal et al. 2002), which helps to control insect pests. More beneficial insects (predators, parasitoids) have been observed in fields with ground cover and mulch (Kendall et al. 1995; Jaipal et al. 2002) which keep insect pests in check. There is no evidence of complete control of insect pests in CA farming systems, which remains a challenge for researchers, farmers and agriculture policy makers. Recently Mishra et al (2019) reported rice mealybug, *Brevennia rehi* as a potential threat to rice in a long-term rice-based conservation agriculture system in no-till direct seeded rice (NTDSR) in the middle Indo-Gangetic plains. They attributed grassy weeds, in fields and bunds, as alternate shelter to the mealybugs to survive and multiply in the off seasons. The best option in this regard is IPM by integrating different techniques to keep insect pest populations at acceptable levels in CA cropping systems.

There may be differences between the pest species occurring in conservation agriculture and in tillage-based systems, but not in the size of their populations. Tillage and/or the presence of crop residues directly affect species that spend one or more stages of their life cycle in the soil. However, these conservation agriculture practices also favour their natural enemies, and it is therefore rare to experience pest or disease outbreaks related to CA. Pests that were never a problem in tillage-based systems may appear in the no-till system. In general, conservation agriculture systems are at greater risk from the following insect pests:

i. Cutworm larvae find a suitable habitat in crop residues for overwintering. It damages seedling plants by cutting them below their growing point, resulting in stand loss.
ii. Grasshoppers (most species) overwinter as eggs buried in the soil of an uncultivated field. Its incidence varies widely from year to year and seems to be regulated primarily by the weather and natural enemies.
iii. Slugs (*Deroceras* spp.) benefit from crop residues, which provide a source of food and habitat. However, slug populations thrive in the simultaneous occurrence of warm temperatures and high humidity.
iv. Wireworms, *Agrypnus variabilis* in cotton and false wireworms in rapeseed, wheat, sorghum and sunflower are stand-reducing insects affected by tillage. Adults are attracted to fields with crop residue to deposit their eggs. However, the same habitat favours their natural predators like carabid beetles.

On the other hand, pests that were a problem in tillage-based systems may disappear with no-till and examples are as below:

i. Greenbug aphids, *Schizaphis graminum* pests of wheat, do not respond well to the light reflection from straw in no-till and prefer to move to tilled fields with no residue cover.

ii. Army cutworms, *Euxoa auxiliaris* pests of wheat, prefer to lay eggs in bare fields and therefore are harmful in tilled fields.
iii. Thrips in cotton are deterred by the mere presence of accumulated biomass e.g. from a cover crop such as vetch or rye.
iv. Hessian fly, *Mayetiola destructor* populations carry over in wheat, barley and cereal rye stubble and tend to be more of a problem in areas where continuous wheat is grown. Therefore, it is important to use diversified and sufficiently wide crop rotations.

In general, it is useful to grow flowering plants in field margins to increase populations of natural enemies and to reduce pest populations in adjacent field crops. For example, phacelia and buckwheat attract syrphid flies, which feed on aphids.

Similarly crop residues reduce the incidence of several splash-dispersed pathogens, for example:

i. *Pyrenophora triticirepenetis* and *Puccinia* sp. in cereals.
ii. *Roselina* sp. in soybean.
iii. *Sclerotina sclerotiorum* in soybean and rapeseed.
iv. *Fusarium* sp. and *Helminthosporium* sp. in maize.

However, if contaminated residues from previous crops are not removed and if crop rotations are not sufficiently long, diseases may transfer (via raindrops) from the partially decomposed residues to the new germinating crop. This should nevertheless not justify burying crop residues with the plough. Ploughing in the crop residues distributes the infestation more uniformly and exposes more roots of the successive crop to the pathogen. It is recommended to remove only the infested crop residues from the field and to practise crop rotation as a prevention measure.

Pest and disease management

Prevention is key in insect pest and disease management, as in weed control. Farmers should diversify the crop rotation, opting for longer crop rotations and ensuring the inclusion of crops that favour natural enemies of the pest connected to each crop currently grown. Certain cover crops are good hosts for populations of beneficial insects. Generalist predators feed on many species and act as important biological control agents. When pests are scarce/absent, these predators subsist on nectar, pollen and alternative preys hosted by cover crops. Some cover crops host beneficial insects *viz*., various vetches, clovers and certain cruciferous crops can support high densities of predators of thrips and aphids, such as insidious flower bugs (*Orius insidiosus*), bigeyed bugs (*Geocoris* spp.) and various ladybirds (Coleoptera coccinellidae). Certain crops suppress particular disease or pest organisms e.g., in potato-based crop rotations, oat, white lupin and field pea help reduce *Rhizoctonia solani* stem lesions, and sorghum helps reduce Verticillium wilt. Brassica varieties release bio-toxic metabolic by-products active against bacteria, fungi, insects, nematodes and weeds.

Conclusion

Various farming systems have been adopted for sustainable pest management but none have been entirely successful in managing insect pests. Chemical insecticides are still the predominant pest control measure but causes health hazard and environmental pollution. The long-term sustainability of agricultural and natural ecosystems depends upon the conservation of natural resources. Conservation agriculture (CA) is a novel approach with a series of practices that strives for acceptable profits together with high and sustained production levels while concurrently conserving the environment. It also increases biodiversity of both flora and fauna which helps to control insect pests, contradictory reports incite concerns regarding reduced yields, increased labour requirements due to avoiding herbicides, and insect pest problems. It is therefore necessary to integrate alternative cultural, biological, mechanical, and appropriate chemical and biotechnological control methods for pest management. The principle of integrated pest management (IPM) creates a balanced environment between sustainable practices and profitable farming. IPM is not only compatible with CA but also works on same principles to help increase biodiversity and conservation of natural resources. For example, IPM enhances biological processes and expands its practices from both crop and pest management to the whole process of crop production. The augmentation of soil microbiota would not be possible without adopting IPM practices. Similarly, CA depends on enhanced biological activity in the field to control insect pests and other disease-causing soil biota. IPM promotes the judicious use of crop rotations and other beneficial plant associations as well as agrochemicals to control insect pests and disease problems (FAO 2006). With the passage of time, enhanced biological activity brought on by CA technologies and IPM, results in less agrochemical use for crop protection. CA does not specify recommendations for pest control, so would benefit if combined with IPM which uses information on the life cycles of pests and their interaction with the environment. Thus, CA and IPM are economical and pose the least possible risk to human health, property, and the environment.

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Farmers Perception in Adoption of Conservation Agriculture

Ujjwal Kumar
ICAR-Research Complex for Eastern Region, Patna (Bihar)

Conservation agriculture (CA) technologies are the future of sustainable agriculture. Acceleration of CA based technologies can reduce the labour requirement as well as reduce the drudgery of women farmers. In Bihar, efforts to adopt and pro- mote conservation agriculture have been underway for nearly a decade but it is only in the last 8-10 years that the technologies are finding rapid acceptance by farmers (Singh *et al*. 2014). Efforts to develop and spread conservation agriculture have been made through the combined efforts of several State Agricultural Universities, ICAR institutes and the Rice-Wheat Consortium for the Indo-Gangetic Plains (Joshi, 2011). The spread of technologies is taking place in India in the irrigated regions in the Indo-Gangetic plains where rice-wheat cropping systems dominate. Conservation agriculture systems have not been tried or promoted in other major agro-ecoregions like rainfed semi-arid tropics and the arid regions of the mountain agro- ecosystems (Bhan and Behera, 2014). The focus of developing and promoting conservation technolo- gies has been on zerotill seed-cum fertilizer drill for sowing of wheat in rice-wheat system (Hobbs, 2008). Other interventions include raised-bed planting systems, laser equipment aided land levelling, residue management practices, alternatives to the rice-wheat system etc. It has been reported that the area planted with wheat adopting the zero-till drill has been increasing rapidly (Sangar *et al*. 2005), and presently 25% - 30% of wheat is zero tilled in rice-wheat growing areas of the Indo-Gangetic plains of India. There are several factors that influence the adoption of CA technologies, one of which is farmers' perceptions. The perceptions and views of the farming community are at the centre of the adoption of conservation agriculture technologies.

A study was conducted in Madhubani district of Bihar to analyse farmers' perception key benefits, advantages, disadvantages, issues and the key decision processes and criteria for adoption of conservation agriculture technologies. Data were collected through focus group discussions involving male and female farmers. All the farmers expressed saving of labour and reduction in drudgery in Zero Tillage Direct Seeded Rice (ZTDSR). Higher yield through adoption of ZTDSR was revealed by 75 % farm- ers. Equal percentage (100 %) of male and female farmers expressed labour saving as one of the most important criteria for adoption of the ZT technologies. Majority of farmers (86%) expressed that limited knowledge of herbicide use restricts adoption of ZTDSR. All the female groups were in the view that there is reduction of drudgery through adoption of mechanical paddy transplanter. Preparation of mat type nursery was top most disadvantages for 90 and 70 %male and female groups respectively. Eighty percent farmers groups expressed their opinion thatnon availability of trained tractor drivers for machine operation limits adoption of ZT machine. Preparation of mat nursery and trained operators for paddy transplanter was major criteria for adoption of mechanical paddy transplanter. There was contradiction in the perception among male and female farmers with respect to yield advantage and associated risk for poor yield due to the adoption of CA technologies.

Farmers' Perception about Advantages and Disadvantages of CA based Technologies

The advantages associated with adoption of zero tillage direct seeded rice (ZTDSR) as identified by the farmers of Madhubani distrct of Bihar include: labour saving (97.77%), time saving/timely seeding (77.77%), increased yield/better production (75.55%), lesser tillage cost (95.55 %), reduction in drudgery (84.44 %), less irrigation/ water saving (84.44%) (Table 1).

Table 1. Advantages of ZTDSR

S. No.	Factors	Group Response (N= 45)			
		Male (N=20)	Female (N=20)	Mix(N=5)	Total
1	Labour saving	19 (95)	20 (100)	05 (100)	44 (97.77)
2	Time saving and timely seeding	16(80)	15(75)	04(80)	35 (77.77)
3	Reduction in drudgery	14 (70)	20(100)	04(80)	38 (84.44)
4	Lesser tillage cost	19(95)	19(95)	05(100)	43 (95.55)
5	Water saving	12(60)	13(65)	03(60)	38 (84.44)
6	Higher Yield	15(75)	15(75)	04(80)	34 (75.55)

*Figures in parentheses indicates percentage

On the other hand, the problems associated with the use of ZTDSR technologies include: more weed/weed control/weed problem (77.77%), poor germination/ reduced germination (48.88 %), low yield (68.88%), uneven sowing/not uniform seeding (46.66%). Among those groups that identified the disadvantages, limited knowledge of herbicide use (100%) and excess weed (80%) topped in female FGD groups followed by low (70 %), poor germination (55%) and not uniform seeding and spacing (50 %). For male groups, an equal distribution of FGD sessions cited the same disadvantages such as excess weed (80%), lower yield (70 %), limited knowledge of herbicide use (70 %), poor seed germination (50%) and not uniform seeding and spacing (40%) (Table 2).

Table 2. Problems associated with adoption of ZTDSR

Sl No.	Factors	Group Response (N=45)			
		Male	Female	Mix	Total
1	Excess weeds	15(75)	16 (80)	04 (80)	35 (77.77)
2	Poor germination	10(50)	11 (55)	01(20)	22 (48.88)
3	Limited knowledge of herbicide use	14 (70)	20 (100)	05(100)	39 (86.66)
4	Not uniform seeding and spacing (Seedling uniformity)	08 (40)	10 (50)	03(60)	21 (46.66)
5	Low Yield	15 (75)	14 (70)	02(40)	31 (68.88)

*Figures in parentheses indicates percentage

Participants in focus group were asked about advantage and disadvantage of mechanical paddy transplanter. Major advantages includes: line sowing (100%), re- duction in input cost (82.22 %), drudgery reduction (88.88%), more yield (80 %) and labour saving (77.77 %). Male and female groups expressed almost similar advantages of mechanical paddy transplanter (Table 3). The machine has some disadvantage also, that include: preparation of mat nursery (80 %), uneven sowing (no uniform trans- planting) if land is not levelled (68.88 %) and gapfilling in case of missed placing of rice seedlings (48.88 %). Among male groups, preparation of mat nursery (90%) was top most disadvantages, followed by seedling uniformity (75%) and gap filling (50%). Among female groups also, preparation of mat nursery (70%) was top most disadvantage, followed by seedling uniformity (60%) and gap filling (45%). Mix groups expressed preparation of mat nursery and seedling uniformity (80%) as top most disadvantage (Table 4) for further scaling of area under mechanical transplanted rice in Madhubani district.

Table 3. Advantages of paddy transplanter

Sl. No.	Factors	Group response			
		Male	Female	Mix	Total
1	Labour saving	15(75)	16(80)	04(80)	35 (77.77)
2	More yield	16(80)	16 (80)	04(80)	36 (80)
3	Reduction in input cost	17(85)	15(75)	05(100)	37 (82.22)
4	Line sowing makes intercultural operation easier	20(100)	20(100)	05(10)	45 (100)
5	Reduction in drudgery	15(75)	20(100)	05 (100)	40 (88.88)

*Figures in parentheses indicates percentage

Table 4. Disadvantages of paddy transplanter

Sl. No.	Factors	Group response			
		Male	Female	Mix	Total
1	Preparation of Mat type nursery	18(90)	14(70)	04(80)	36 (80)
2	Gap filling	10(50)	09(45)	03(60)	22 (48.88)
3	Seedling uniformity	15(75)	12(60)	04(80)	31(68.88)

*Figures in parentheses indicates percentage

The advantages of ZT wheat are presented in Table 5. All groups (100 %) revealed saving of input and tillage cost, timely sowing (93.33 %), saving of labour (91.11%), saving of water (82.22%) and higher yield (73.33%) in ZT sown wheat. On the other hand, the problems associated with the use of ZT wheat technologies include: non availability of trained tractor drivers for machine operation (80%), appropriate moisture at the time of sowing (77.77%), poor germination in case of inappropriate depth of sowing (62.22 %), more weeds at the time of sowing (55.55%) and choking of seed and fertilizer pipe in case of excess moisture (53.33%) (Table 6).

Table 5. Advantages associated with adoption of ZT Wheat

Sl. No.	Factors	Group response			
		Male	Female	Mix	Total
1	Timely sowing	18 (90)	19 (95)	05 (100)	42 (93.33)
2	Saving of labour	18 (90)	18 (90)	05(100)	41(91.11)
3	Saving of input and tillage cost	20 (100)	20 (100)	05(100)	45(100)
4	Higher yield	15 (75)	14 (70)	04(80)	33 (73.33)
5	Saving of Water	16 (80)	17 (85)	04(80)	37 (82.22)

*Figures in parentheses indicates percentage

Table 6. Problems associated with adoption of ZT wheat

Sl. No.	Factors	Group Response			
		Male	Female	Mix	Total
1	Choking of seed and fertilizer pipe in case of excess moisture	12 (60)	10 (50)	02 (40)	24 (53.33)
2	Poor germination in case of inappropriate depth of sowing	13 (65)	12(60)	03 (60)	28 (62.22)
3	Appropriate moisture required at the time of sowing	15 (75)	16(80)	04 (80)	35 (77.77)
4	More weed at the time of sowing	10 (50)	12(60)	03 (60)	25 (55.55)
5	Trained tractor driver	15 (75)	16 (80)	05 (100)	36 (80.00)

*Figures in parentheses indicates percentage

In Purnea, the CASI technologies were considered cost effective by the majority (81%-91%) of the farmers. Labour saving was identified by the majority (50%-85%) of the participants during both seasons. About 85%, and 78% of male participants agreed to labour saving advantage of zero-tillage, direct-seeded rice, and other conservation agriculture respectively. Water saving advantage was also reported by using zero-tillage and other conservation agriculture technologies. Soil health improvement was also one of the primary advantages of zero-tillage (41%) and other conservation agriculture technologies (53%). Weed control and uneven sowing was major disadvantages of direct-seeded rice technologies in Purnea (Table 7).

Table 7. Advantages and disadvantages of CA technologies

Advantages	Disadvantages
• Low cost of tillage • Water saving • Timely seeding and crop establishment • Lesser stalk lodging problem • Time saving	• Weed problems in ZTDSR • Poor germination in case of low moisture and inappropriate depth of seeding • Undulated land causes difficulty in operat-

• Labour saving • No need for nursery, seedling uprooting and transplanting in case of ZTDSR • Improved soil health condition	ing ZT machine

A study conducted in Haryana revealed that the farmers who had adopted ZT method in wheat production were interested to continue with this method of sowing in future. According to farmers, ZT method was good in terms of seed germination and yield of wheat than the CT method. Sowing of wheat crop could be accomplished 10 to 15 days earlier than in CT method. Zero tillage considerably reduced the use of tractor and saved time and diesel in field preparation. They, however, reported that weed management was a problem in ZT method of wheat production. Many farmers were deprived of wheat sowing by ZT technique because of high demand and less availability of zero-till seed drill machines in the study area. it is possible to save labour and irrigation water under zero tillage than under conventional method. Due to resource saving, net return has been significantly higher in zero tillage technology. Hence, this technology is an important alternative to save scarce resources and enhance the net farm income (Tripathi *et al.* 2013)

Farmers' perception may varies among the farmers who are using CA technology and who are not using it. A conceptual frame work on farmers' perception on CA has been depicted in the Fig. 1 above. Farmers' perception may be recorded on five point continuum (Strongly agree, Agree, Neither agree nor disagree, Disagree, Strongly disagree) based on the set of statements (Table 8). An outline for recording farmers' perception and success cases on conservation agriculture has been given in the Table 10.

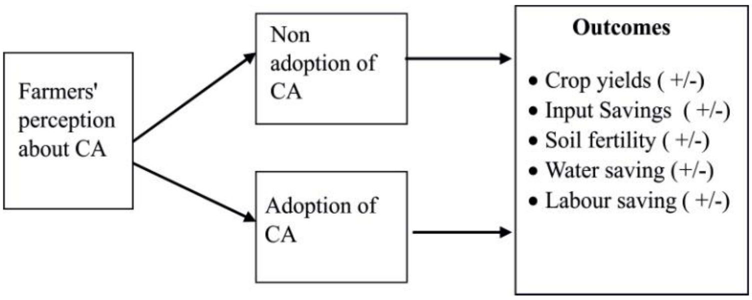

Fig. 1. A Conceptual frame work on farmers perception on CA

Table 8. Farmers perception about CA technologies

Statement about CA technologies	Perceptions * **SA/ A/NAN- DA/DA/SDA**
I am fully aware of the CA technology	
I have the knowledge required to use CA technology.	
I am confident with my skill to use CA technology.	
CA technology increases yield over traditional methods.	
CA technology decreases costs over traditional methods.	

CA technology requires less labour/drudgery over traditional methods.	
CA technology requires less water over traditional methods.	
CA technology promotes timely seeding.	
CA technology allows early planting.	
CA technology allows me to increase my cropping intensity (i.e, plant more crops per year).	
CA technology promotes healthy soil.	
CA technology is easy/simple to use.	
CA technology is affordable over traditional methods.	
CA technology increases my returns/income from crop production.	
CA technology is women-friendly.	
Weeds are easily controlled with CA technology.	
Suitable inputs are available for CA technology.	
Some of my neighbours are already using CA technology.	
I have observed positive results with CA technology on other people's farm.	
Some people in my village believe that CA technology is a good technology.	
CA technology results to more weed problem.	
CA technology results to poor germination.	
CA technology results to uneven sowing.	
CA technology results to more insect and pest diseases.	
Competent drivers and mechanics for CA technology are limited.	
Hiring cost of ZT/ST/RT/MT machines is too high.	
There is a lack of suitable herbicide to complement CA technology.	
I believe my crop yield will be lower if I use CA technology.	
I believe CA technology may harm my crops.	
I believe CA technology may have negative health impact to me and my family.	
Some people in my village believe that CASI technology may harm their crops.	

SA: Strongly agree, A: Agree, DA: Disagree, SDA: Strongly disagree, NANDA: Neither agree nor disagree.

Table 10. Proforma for farmer's perception / Success Case on CA

<table>
<tr><td>Name of farmer:
Name of spouse:</td><td>Age of farmer:
Age of spouse :</td><td>Gender of farmer: M/F
Gender of spouse: Male</td><td>Photogrph</td></tr>
<tr><td colspan="4">What is(are) the CA technology(ies)/ intervention(s) you are using/ testing? (please provide full description):</td></tr>
<tr><td colspan="4">How did you come to know about the CA technology (ies):</td></tr>
<tr><td colspan="4">What do you think are the benefits of using the CA technology(ies)? (e.g., yield, price received, economic, social, reduction in labour, cost savings, reduction in pests/ diseases, etc. Give a before and after scenario. Please be specific (e.g., yield increased from 3 tons to 4 tons instead of just saying yield increased). Ask both farmer and spouse.</td></tr>
<tr><td colspan="4">What have been the key challenges/ issues you encountered in relation to the use of the CA technology (ies) ?</td></tr>
<tr><td colspan="4">What do you think are the solutions to these challenges/ issues?</td></tr>
<tr><td colspan="4">Will you continue to use/ adopt the technology(ies)? Why or why not?</td></tr>
<tr><td colspan="4">Any good anecdote(s) by the farmer (male or female) and his/ her family members :</td></tr>
</table>

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SRI: A technique for improving water use efficiency in rice production system

S.K. Singh

ICAR-Research Complex for Eastern Region, Patna (Bihar)

Rice is known to be less water efficient than many other crops. The crop is traditionally established by transplanting of rice seedlings in puddle soil. This establishment system requires 3,000-5,000 litres of water to produce 1.0 kg of rice (IRRI, 2001). The per capita availability of water resources is expected to decline by 15 to 54 % by the year 2025 compared to 1990 (Guerra et al., 1998). Therefore, rice could face a threat due to water shortages and hence there is need to develop and adopt water saving methods in rice cultivation so that production and productivity levels are elevated despite the looming water crisis. The system of rice intensification (SRI) developed in Madagascar increases yields substantially, 50% to 100 % or more, while requiring only about half as much water as conventional rice (Uphoff and Randramiharisoa, 2002).

SRI Technique:

The SRI is a metholology aimed at yield enhancement with resource saving technology for rice production. SRI technology includes (i) transplanting of young seedlings that are 8-12 days old, in shallow (1-2 cm) submergence, (ii) wide planting in a square geometry (25 X 25 cm or slightly more or less), (iii) providing intermittent irrigation and drainage during the vegetative stages to create soil aeration (iv) supplying nutrients from organic or organic + inorganic sources (v) controlling weeds mechanically (cono-weeding) either thrice at 15, 25 and 35 days after transplanting (DAT) or twice at 15 and 30 DAT and transplanting completed quickly, preferably within ½ an hour of uprooting.

History and spread of SRI:

SRI was developed three decades before by the French Jesuit Father Henri de Laulanie in Madagascar in 1983, after having worked with farmers and experimenting with rice for about 20 years. This method of rice-growing led to tremendous yield enhancement in Madagascar. From there it took-off to different countries of the world in 2000. In fact, credit of SRI spread goes to Dr. Norman Uphoff of Cornell (Cornell International Institute for Food and Agriculture, Ithaca, USA) for bringing SRI to the notice of others and promoting it in different parts of the world. In Asia, along with India, China, Sri Lanka, the Phillippines, Malaysia and Vietnam have made notable progress. Till 2013 more than 10 million farmers were benefitting from adoption of SRI in 54 countries. In India SRI was introduced in 2000 as a promising alternative to high-water demanding conventionally transplanted rice. However, initially, SRI did not find adequate favour and support in India. Now SRI has reached to almost all states of India.

Irrigation effects:

Yield

It has been well established that rice is not an aquatic plant and does not necessarily require flooding for producing best yields. Growing rice with SRI methods envisaging intermittent irrigation, offers efficient use of limited water and higher yield. Many workers have reported that rice grown with SRI methods give higher yields and water productivity. In SRI, cycles of repeated wetting and drying were found beneficial to rice plant growth through increased nutrient availability leading ultimately to higher grain yield (Ceesay and Uphoff, 2003). There are visible gains in terms of yield enhancement and water saving with alternate wetting and drying and non-flooding conditions (Ceesay et al., 2006, Kabir and Uphoff, 2007 and Sinha and Talati, 2007). But, implementation of such types of irrigation by the farmers is difficult primarily due to lack of reliable water source, little water control and accepting less water-use (McHugh *et al.,* 2002). At Hangzhou, China, Zhao *et al.* (2009) observed 21.5% increase in rice yield with SRI compared to traditional flooding though above- ground biomass was similar between SRI and conventionally flooded rice. Harvest index was also significantly higher with SRI. Tao and Ma (2003) and Zhong *et al.* (2003) observed 26-51 and 19% increase in yield from SRI, respectively, over traditional flooding. Under continuous flooded condition, rice yields tend to be very low on soils with unfavourable physico-chemical environment, particularly due to limited growth during the vegetative phase (Vizier, 1990). Yang *et al.* (2007) showed 7-11% increase in yield and up to 38% reduction in irrigation water by maintaining critical soil water potential at -15 KPa. Therefore, irrigation water input can be reduced by decreasing ponded water depths to soil saturation; water saving under saturated soil condition was on an average 23% with yield reduction of only 6% (Bouman and Tuong, 2001). These results clearly demonstrate the benefits of general alternate wetting and drying or intermittent irrigation. But the fact still remains to be analysed is what should be the duration of drying interval between two successive irrigations. Recently, there have been some studies which included evaluation of response of variable irrigation on rice grown employing SRI methods; the most prominent ones are reported here as follows (Table1).

Table1. Effect of irrigation management on yield and water productivity (WP) of rice under system of rice intensification

Treatment	Southern Iraq, Silty clay-loam to clay loam soil		Tarai belt, Uttarakhand, India (Sandy loam soil)		Eastern India, Mendhasal Farm, Khurda, Odisha (Sandy clay loam)	
	Yield (t/ha)	WP (kg/m^3)	Yield (t/ha)	WP (kg/m^3)	Yield (t/ha)	WP (kg/m^3)
CWS	5.31	0.0665	-	-	5.46	0.524
1 DADPW	-	-	6.32	0.30	6.24	0.617
3 DADPW	6.56	0.165	6.16	0.32	6.35	0.647
5 DADPW	-	-	5.82	0.31	5.79	0.608
7 DADPW	5.07	0.229	-		4.28	0.457

CWS, Continuous water submergence; DADPW, days after disappearance of ponded water (Source: Hameed *et al.,* 2013; Thakur *et al.,* 2014; Dass *et al.,* 2015)

In mollisols of *tarai* belt of northern India, rice yield did not decrease significantly when irrigations were delayed from 1-3 DADPW, however further delay in irrigation to 5 DADPW, caused significant reduction in rice yields. Water productivity was greatest when irrigations were scheduled at 3 DADPW. Another interesting result of this study was that rice yields from SRI crop irrigated at 5 DADPW was 11.5% higher than from conventional transplanted rice irrigated at 1 DADPW (Dass and Chandra, 2013 a). Similarly in silty clay loam soil of eastern India (Patna), the highest grain and straw yields of 7.75 and 10.59 t/ha respectively were recorded under 25 X 25 cm spacing when 6 cm irrigation was applied 3 DADPW as compared to farmers' method of rice cultivation (4.82 and 5.79 t/ha of grain and straw yields respectively), where 4-5 cm depth ponding throughout the growth period was maintained. Water saving up to 25 and 35 per cent was observed in 3 DADPW and 5 DADPW respectively as compared to farmers' method (Singh and Batta, 2008). This indicates that under water scarce conditions, irrigating SRI crop even at 5 DADPW offers substantial yield gain compared to CT. In eastern India (Bhubaneswar), Thakur *et al.* (2014) also reported that SRI grain yield and water productivity were the greatest at 3 DADPW (Table 1). In Southern Iraq also applying irrigation at 3 DADPW was the most rewarding irrigation schedule for SRI-rice in terms of yield and water productivity. In contrast, Dhar *et al.* (2008) reported that at Jammu, the maximum grain yield (5.29 t/ ha) of rice under SRI methods was recorded when the crop was irrigated at 7 DADPW, which was significantly higher than the yield obtained from other treatments like alternate wetting and drying, applying irrigation at 3, 5 and 9 DADPW, but similar to the yield obtained from continuous submergence (4.93 t/ha).

Water saving in SRI compared to conventional transplanting

Water productivity of conventional transplanted rice is merely 20-30% (Walker and Rushton, 1984; Tuong and Bhuiyan, 1999). Zhao *et al.* (2009) found 40-47% reduction in water-use with SRI, 68-94% increase in water-use efficiency (WUE) and 100-130% increase in irrigation WUE compared to traditional flooding. Thiyagarajan *et al*. (2002) reported that applying limited irrigation (2 cm depth after development of surface cracks) to rice crop raised with conventional and young seedlings saved 56 and 50% water, respectively, without significant yield reductions. The corresponding water-use was 11,853 and 5,205 m^3/ha, and 13,347 and 6,699 m^3/ha for conventional and young seedlings, respectively. Irrigation 1 DADPW water saved 25% water without reduction in yield compared to continuous submergence (Ramamoorthy *et al.,* 1993). During a dry season, irrigation at saturation to 5 cm depth consumed only 47% of the water required by the continuous submergence (1850 mm), and in wet season too, there was a saving of 18% irrigation water (Mohandass *et al.*, 1987). They also reported that irrigation at saturation to 25% depletion of available soil moisture consumed the lowest irrigation water in summer (620 mm) and wet season (685 mm) with concomitant yield reduction of only 11%, but had higher WUE.

Chapagain and Yamaji (2010) observed that alternate wetting and drying can save a significant amount of irrigation water (28%) without yield reductions. Dhar *et al.,* (2008) reported that irrigation at 5 DADPW saved 22.7% water with a slight reduction in grain yield compared to continuous submergence. During a low rainfall year in *Tarai* belt of India, the SRI crop irrigated at 5 DADPW (nine irrigations of 6 cm each) saved 25% irrigation water while producing 10.2% higher grain yield compared with conventional transplanting that required 12 irrigations (Dass and Chandra, 2013 b). In eastern India, SRI practice with intermittent irrigation produced 49% higher grain yield with 14% less water than under continuous water submergence (Thakur *et al.,* 2014). Similarly, Singh et al. (2018) from eastern India (Patna) observed that saturation all throughout using surface irrigation (4.93 t/ha) as well as through micro irrigation (4.93 t/ha) maintained not only superiority in grain yield over farmers' practice (2.57 t/ha) but also saved 43 and 38 % water respectively over 1" standing water throughout. However, saturation till PI followed by 1" standing water irrigation and maintaining 1" standing water all throughout also recorded significantly superior grain yield of 4.72 and 4.41 t/ha, respectively, over farmers' practice. They also reported that saturation all throughout under SRI resulted in higher water productivity(1.1 kg/m^3) during *Boro* as compared to Kharif season (0.95 kg/$m^{3)}$. But, implementation of such types of irrigation by the farmers is difficult primarily due to lack of reliable water source, little water control. Micro-irrigation if complied for less water use under SRI, may be recommended to the farmers. However, more initial investment and skilled manpower in the case of micro-irrigation limits its advantage over saturation throughout through surface irrigation.

In southern Iraq, 3-day interval irrigation in SRI led to about 50% saving of water, while also raised yields; with 7-day irrigation interval, although rice grain yield reduced by 6% (Table1) but water consumption was lowered by three-quarters.

Kumar et al. (2015) from eastern India (Patna) reported that SRI under micro irrigation system (LEWA and micro-sprinkler) resulted in significantly higher (128 and 123 %) grain yield of rice as compared to farmers' practice of rice transplanting under check basin irrigation (3.80 tonnes/ha). However, the grain yield variation between LEWA and micro-sprinkler irrigation under different establishment methods was insignificant. Whereas, a combination of SRI and micro-irrigation (LEWA and micro-sprinkler) significantly increased water productivity by 153 and 156 % respectively in comparison to check basin under framers' practices of rice establishment (0.34 kg/m^3). There was a mean saving of 27 and 39% water observed in LEWA and micro sprinkler irrigation, respectively as compared to check basin irrigation (340 mm) in rice crop.

Overall, water saving of 20-50% has been achieved with SRI method. Although under SRI the best yields of rice were obtained when irrigations were applied at 3 DADPW, but water savings were larger with bearable yield reductions when irrigations were applied at 5 or 7 DADPW. The water so saved can be diverted to additional area for higher total rice production. As the water is becoming increasingly scarce world-over, irrigation options of 5 and 7 DADPW should be considered, even if these schedules do not maximize yields. These two schedules could support a larger area of production and greater total output of rice.

Future thrusts in SRI

The irrigation treatments applied in most of the studies have been scheduling of irrigation based on status of water ponding on soil surface or drying of soil surface. Soil and plant water status based irrigation need to be further evaluated. Thus, protocols for quickly and precisely determining soil and plant water status for precise irrigation scheduling in SRI need to be developed.

Certain sensors like moisture-meter, theta probe, time-domain reflectometry (TDR), tensiometer are now available in the market, which need to be evaluated for irrigation scheduling in SRI.

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Water budgeting for climate resilient cropping with special reference to Eastern Indo-Gangetic Plains

Pawan Jeet
Scientist, ICAR-Research Complex for Eastern Region, Patna

Unpredictable and erratic climatic pattern resulting in erratic spatial and temporal variability in weather parameters like precipitation, temperature, humidity etc. in long term, are the most severely affecting production and productivity of crops, forestry, livestock, fisheries and aquaculture. At the same time, availability of water resources is also under pressure due to changes in climatic condition and overexploitation of water resources. This negative effect of climate will impact the availability of natural resources like land water and vegetation etc., farmers' livelihood and food security. The management of agricultural systems and natural resources like land, water and vegetation etc., needs to be urgently developed or improved a cropping system like climate resilient cropping system that ensure farming communities and practices are sufficiently resilient and sustainable to cope with the impacts of climate change.

What is climate resilient agriculture?

Climate Resilient Agriculture (CRA) is defined as 'agriculture that reduces poverty and hunger in respect of climate change, improving the resources availability it depends on for future generations' (Christian Aid, Time for Climate Justice 2015).

It is also defined as "an approach that guides actions needed to transform and reorient cropping systems to effectively support development and ensure food security in a changing climate".

It wants to transform the current agriculture systems, and has a wider perspective than increased agriculture production only. In addition, CRA aims to strengthen livelihoods and food security, especially of small and marginal farmers', by improving the management and use of natural resources like land, water and vegetation, and adopting appropriate methods and technologies for the production, processing and marketing of agricultural produces.

Components of climate resilient agriculture

It is not a set of practices that can be universally applied, but rather an approach that involves different components embedded in local contexts. There are various components which can be integrated in climate resilient agricultural approaches that includes:

- Ecosystem and landscape management to conserve ecosystem services that are key to increase at the same time resource efficiency and resilience.
- Management of farms, crops, livestock and aquaculture to manage resources better, produce more with less while increasing resilience.
- Changes in the wider food supply ecosystem, including demand-side measures and value chain interventions that enhance the benefits of CRA.

- Services for farmers and land managers to enable them to implement the necessary changes.

Basic objectives of climate resilient agriculture

In general, its main aim to tackle three basic objectives under the climate resilient cropping approach is

- Sustainably increasing agricultural productivity and farmers' incomes.
- Adopting and building resilience to climate change, and
- Reducing and/or removing greenhouse gas emissions.

Why climate resilient agriculture is necessary?

The Climate resilient cropping concepts mainly focus on developing agricultural decision support tools (DSTs) and resources to help farmers that better manage the risks of climate change. It serves as an interactive platform that integrates climate information in order to support decision-making of farmers' at a farm or agricultural-system level within a specific region. This farming model helps farmers' in improving their farm productivity and resiliency in the face of the changing climate. The CRA tools can be used in response to a variety of climate-related impacts including drought, flood or extreme precipitation and seasonal shifts etc. CRA provides the means to help stakeholders from regional to national and international levels identify agricultural strategies suitable to their local conditions.

The CRA model enables farmers' to determine when the best time for planting, irrigating, harvesting and many other necessary actions. These CRA tools are designed to help farmers implement best management practices through sustainable, resilient agriculture. Best management practices have the capacity to benefit farmers and the environment simultaneously.

Transforming natural resource management in Eastern Indo-Gangetic Plain (E-IGP)

The Eastern Indi-Gangetic plain is endowed with best natural resources availability like abundant water, sunshine and labour etc. This plain is highly dependent on agriculture for their food security and livelihoods. But, the agriculture system in this plain is still subsistence and laggard and facing concurrent twin problems of drought and flood, creating high risk in agriculture and vulnerable to climate change. Today, the E-IGP having the highest concentration of rural poverty in respect of the world due to the following constraints to sustainable and resilient intensification are:

i. Lack of agricultural development, high yield gaps and poor adoption of resources management infrastructures.

ii. Low investment in agriculture and capital deficit farming systems.

iii. Overall emphasis on cereal based farming system (mainly rice and wheat).

iv. Small and scattered size of landholding and low farmers' economics.

v. Vulnerable to high risks due to climate changes, market and prices.

vi. Poor governance and property rights.

The EGP area is crucial to future food security in South Asia, where production of rice, wheat and maize must increase by about 1.1, 1.7 and 2.9 percent each year respectively, to meet food demand in 2050 (CGIR, 2015). So, In the E-IGP huge opportunity to ensure food security for increasing population by adoption of promising technology like agricultural diversification, climate resilient agriculture, rice-fallow system, introduction of solar based water pumping system, and at last but not last through water budgeting system.

Necessity of water budgeting for climate resilient agriculture in EGP

Water is essential renewable natural resources for living being. Now-a-days, the demand of water is rising but the supply of water is limited or going down. The Indo-Gangetic basin encompasses more than 250 million hectares, which is supporting more than 750 million people and constituting over 100 million hectares of agricultural land that accounts for a quarter of global groundwater extraction. Almost 60% of the groundwater in the Indo-Gangetic basin contaminated with high concentration of arsenic or salt and they are unusable (Ray, 2016). Widespread contamination, rather than depletion of the water resources, has emerged as a serious cause of concern for millions of population who are living in the EIGP. This situation is arising due to increase in population, increasing demand of food supply, extreme weather condition, uneven surface as well as groundwater water supply, poor water management of water resources and so on. The importance of water assessment has been increased in recent time due to the significant usage of water resources in the all water use sectors like irrigation, domestic water supply, industry and power etc. All water systems loss some amount of water through a variety of reasons. There are no specific statistics for how much water is lost. The amount of water lost is measured as the component of climate smart farming practices. Climate smart farming approach is highly built upon a knowledge base that largely already exists, and a range of sustainable agricultural approaches such as sustainable intensification, conservation agriculture, water smart agriculture and sustainable land management.

Climate smart irrigation is the good irrigation practice for a given agro-climatic and societal conditions that takes explicit account of challenges and opportunities that may result directly or indirectly from different facets of climate change (GACSA, 2018). Estimates of incremental water requirements to meet future demand for agriculture, domestic and industry etc. are met through water budgeting of available water for various sectors.

What is water budgeting?

As per EPA “Water budgeting is a water management tool that is used to estimate the amount of water a landscape will require”.

As per the Foundation for Ecological Security (FES) “Water Budgeting is a tool which assist communities for the proper management of water resources”.

It is a farmer-friendly and farmer-centric tool that assists in creating the support system needed for village communities to balance demand with supplies, so that water consumption does not exceed the limits of groundwater recharge. It is used to evaluate the occurrence, distribution and movement of water through the natural environment. Water budgets commonly go well beyond how much water is available for agriculture, domestic and industry etc. and where it is. They also include a detailed understanding of the flow dynamics. These flow dynamics include the origin and movement of groundwater and surface water as well as the interaction between the two systems. It plays an important role in four major parts such as usage, recharge, surplus and deficit.

Components of water budgeting

In simple term, a water budgeting system compares the input and output of water in a specific region. It is generally expressed as shown in fig.1.

Fig. 1: Water budgeting system

Generally, water budget model is expressed in equation as

$$Input = Output + Changesinstorage$$

It describes the various components of hydrologic cycle or water cycle. The major components of water cycle are

Input Parameters

- Precipitation (P)
- Surface Runoff (R)
- Groundwater inflow (I)
- Surface water inflow such as canal inflow (I)
- Water diversion

Output parameters

- Evaporation
- Transpiration
- Evapotranspiration (ET)
- Surface water outflow (D)
- Groundwater outflow (D)
- Water diversion
- Water used in different sectors like irrigation, industry etc.

Mathematically, water budget is expressed as an equation relating these components:

$$P = R + AET + I + D + A \pm \Delta I \pm \Delta S \pm \Delta g$$

Where,

P = Precipitation; R = Surface runoff; AET = Actual evapotranspiration; I = Interflow; D = Groundwater discharge; A = Anthropogenic inputs and/or supplies/abstractions; ΔI = Change in land surface storage; ΔS = Change in soil moisture storage; and Δg = Change in groundwater storage.

A positive change in storage is often termed a surplus, while a decrease in storage is termed a deficit. It considered data of reference evapotranspiration (ET), plant type, irrigation parameters like irrigated area, irrigation efficiency, water quality, and weather parameters like rainfall etc. It can be controlled by following factors like air temperature, humidity, amount of rainfall and soil type etc.

Importance of water budgeting

1) Efficient utilization of available water resources for bringing more area under irrigation.
2) To reduce excess or over irrigation and losses like runoff.
3) To increase farm productivity and cropping intensity of region.
4) To provide irrigation during *rabi* season or dry spell of the year to the crop.

Participatory water budgeting

The participatory water budgeting model helps in the understanding of how water flows in a unit of hydrologic cycle or watershed, its judicious use and its long term availability. This model is based on the principles of equity and water requirements for all uses like irrigation, industry and drinking purposes etc.

Community based water budgeting system is very important for quantifying the various water and crop information for balancing or budgeting the resources for appropriate use and is represented as shown in figure 2.

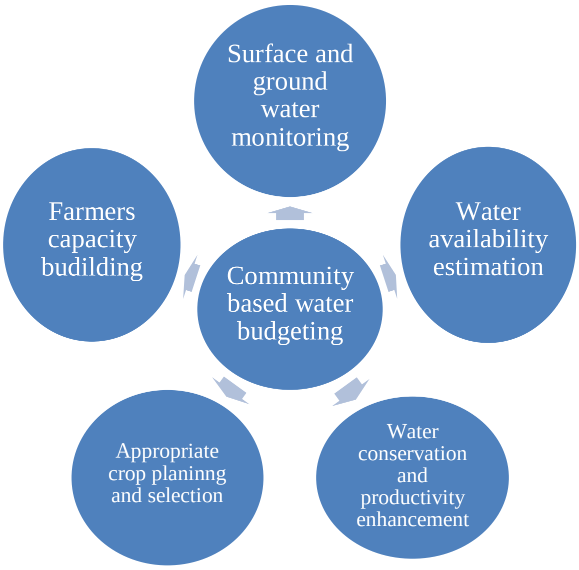

Fig. 2: Components of community based water budgeting system

National Bank for Agriculture and Rural Development (NABARD) applied community based water budgeting approach and found that average cultivated area has increased by 48% and crop production by 82% (mainly cereals and pulses), and also helps in combating water scarcity and reduces chances of failure of *rabi* season crop.

Conclusions

Water budgeting plays an important role as water management tool that increase the awareness among farmers on water resources, use of advance water saving and efficient technologies such as drip irrigation, sprinklers irrigation etc. possible shift from high water intensive crops to low water intensive crops, peoples' or community participation in the promotion of water conservation and recharge structures, sharing of information among community and fund mobilization for operation and maintenance of existing or new water resources structures. It is widely used as the basis for making projections about Eastern Indo-Gangetic Plain water future and its related policy making for climate resilient agriculture.

Impact of Conservation Agriculture on Soil Physical Properties

Surajit Mondal

ICAR-Research Complex for Eastern Region, Patna (Bihar)

By 2050, world population is expected to reach 9.8 billion with continuing dominance of China and India together comprising of 37% of the total (United Nations 2017). A large increase in food demand is therefore projected to feed the growing world population (54%, FAO estimates; 59-98%). However, parts of the most productive lands in the world are being degraded through imprudent farming practices that cause soil and water degradation in various forms and means, and therefore, more than 80% of production gains must come from existing agricultural land through sustainable intensification.

Rice-wheat rotation is a unique system due to its completely contrasting edaphic environment. Two of major issues with soil physical environment under rice-wheat system are the degradation of soil structural condition and depletion of soil carbon status, and the development of a sub-surface compact layer due to repeated puddling in rice over the years. Conservation agriculture (CA) is a suite of practices encompassing no- or reduced tillage, maintaining crop residue on the soil surface and introduction of legumes to the system (Pittelkow *et al.* 2015). Adoption of CA in rice-wheat system can be a logical and environment-friendly option to sustain or improve the productivity and economic viability of rice-wheat cropping system.

Soil Bulk Density

Bulk density (BD), the most fundamental soil physical property plays the most important role on soil moisture-soil air relationship and root development and therefore, influence crop growth and yield (Unger and Cassel, 1991). It can thus be considered the critical parameter for soil quality assessment, largely due to its relationships with other soil properties, e.g., porosity, air permeability, penetration resistance, soil moisture, hydraulic conductivity etc.

Tillage practices have variable effect on soil BD. Conventional tillage which includes repeated soil manipulation have different effect on soil BD than no-tillage which involves minimum soil disturbance. Bulk density of agricultural fields under- goes significant transformations through agricultural activities and rainfall and/or irrigation events during the crop growth period. After the tillage, surface soil usually will have lowest BD which tends to increase with time due to rearrangement of particles and aggregates after irrigation or rainfall events, and intercultural operations like spraying, fertilization, weeding etc. Different natural soil processes like freezing-thawing cycle, swelling and shrinking process, clay deposition and soil erosion can significantly impact soil BD. There are two schools of thought on the effect of tillage on soil BD. One group of authors has reported higher BD in NT system than in CT, while another group has concluded lowering of BD through NT practice. Time of measurement can influence the outcomes significantly. Measurement just after tillage operation can generate a significantly lower BD value in CT practices than NT. A few weeks after tillage, the benefits of soil loosening are lost due to rainfall and action of gravity (Alletto and Coquet 2009).

Penetration Resistance

Penetration resistance which is typically expressed by 'cone index' as measured by a cone penetrometer, imitates the elongation of plant roots and the resistance offered by the soil against growth of the root system. Mechanical impedance caused by soil compaction (surface and/or subsurface) limits root growth and proliferation in deeper soil layers, and thus restricts the water and nutrient availability. Variations in penetration resistance in soil generally happens due to differential management practices (Whitmore *et al.* 2011). A penetrometer resistance value of 2 MPa has been suggested as the threshold value for inhibiting root growth and indicates where mechanical resistance becomes a major limitation for root development, unless cracks, bio-pores, decayed root channels or fissures are prevalent in soil for roots to exploit. Mechanical impedance is a major problem of soil that affects the crop productivity across countries. Globally, 4% of the land area is affected by soil compaction. The soil compaction is a hidden problem, as it occurs below the soil surface and impairs water and air exchange with growing roots. Effects of compaction are long lasting or even be permanent unless corrective measures are taken. Continuous use of intensive tillage practice for many years leads to soil compaction particularly at the subsurface. Initial soil condition like soil type, moisture content, bulk density and aggregate stability also play major role in the extent of soil compaction. The process is exacerbated
by the presence of low amount of soil organic matter content.

Soil Aggregation

Soil aggregation is considered as the most widely accepted indicator for evaluation of soil structure. Aggregates are formed through the process of flocculation and cementation of mineral particles in the presence of organic as well as inorganic sub- stances (Bronick and Lal, 2005). The formation and destruction of soil aggregates has a great bearing on soil physical health and C dynamics. A well-aggregated soil has a better potential to improve the agronomic productivity and offer greater resistance against erosion by water or wind (Yu *et al.* 2016).

Agricultural management (like tillage, fertilization, seeding etc.) has direct effect on soil quality. Soil physical change due to compaction and erosion, which is mostly attributed to repeated tillage, could be regarded as an important negative consequence of modern-day agricultural practices. In conventional tillage, repeated tillage breaks down the stable aggregates and thereby accelerates the macro-aggregate turnover. In this context, wet tillage in puddle transplanted rice could be the best example to cite, which also form subsurface hard layer.

Conservation tillage which encourages minimum soil disturbance increases the amount of stable macro-aggregates (Mondal *et al.* 2018). Retained surface residue or cover crops in conservation tillage can reduce the impact of rain and wind and thus protects the aggregates from erosion. Residue retention increased microbial and enzyme activity and promotes larger microbial community, favoring the formation and stability of aggregates.

Number of authors have reported beneficial role of earthworms for macro-aggregates formation during their feeding and casting activities. Earthworm casts have higher amount of organic carbon and water stability in comparison to surrounding soil (Arai *et al.* 2017), and therefore add to the quality of soil. The CT practices reportedly have detrimental effect on earthworms causing either physical injury or decrease in earthworm biomass.

Soil Hydraulic Parameter: Hydraulic Conductivity and Infiltration

Hydraulic conductivity, saturated and unsaturated, are highly variable soil properties both in space and time. The unsaturated conductivity is a function of soil water content, and can change considerably with little change in soil water content. Tillage can alter the surface roughness, aggregation, porosity and crop residue distribution. All these bring high change in soil hydraulic characteristics. Although bulk density and porosity are the two widely measured soil physical properties that affect the hydraulic processes of soil, a clear understanding of pore geometry and continuity can provide a fundamental for identifying the tillage effects on these properties. The infiltration rate may increase or decrease with the amount of total porosity, but it may not be always true if continuity of larger pores is disturbed. The effect of compaction on the relative abundance of textural (matrix) and structural (micropores) pores determine the change in unsaturated hydraulic conductivity.

Effects of tillage are not consistent and highly varied with type, duration and depth of tillage. Generally, tillage makes the soil more open to water and air. Soil hydraulic conductivity improves immediately after tillage, and decreases gradually through the season and that reduction could be attributed to increased bulk density in conjunction with concomitant decrease in conductive mesopores. Need for studies of irrigation or rainfall effects on recently tilled soil hydraulic properties have been stressed. Time of measurement affects the infiltration rate significantly.

No tillage with crop residue retention on soil surface can improve water infiltration, reduce erosion and enhance water use efficiency compared to the conventional tillage. However, with passage of time, the slaked soil particles blocked the pores causing surface sealing in CT. Residues absorb kinetic energy of raindrops or irrigation water and reduce the risk of slaking and surface sealing. Residues further decompose and increases the SOC content which helps in formation and stabilization of soil aggregates.

Soil Porosity

Knowledge of soil pore geometry and distribution is fundamental for understanding of water and air movement in soil. Hydraulic characteristics of a soil entirely depend on pore size distribution. Soil pores of different size, shape and continuity affect the infiltration, maintain the balance of air-water ratio, and determine the ease of a soil for root growth. To note, water flowing through connected pores involves the notion of structural hierarchy.

Tillage again has a strong impact on soil porosity. It is understood that aggregates are broken down by tillage leading to obliteration of pore continuity, and gradually soil pores are formed by rearrangement of soil particles after rain or irrigation. On the other hand, biological activity is the dominant factor of pore formation in no-tilled soil. No tillage favours the formation of decayed root channel, biopores, burrows by earthworm and other macro-fauna, and network of macro-pore, cracks and other structural voids through which most of the water flows deeper down the soil profile. Pore geometry has a prominent role in compressibility of soils. The macro-pores that are created through tillage are unstable in nature and mostly efficient immediately after the tillage. In contrast, pore network in NT is less susceptible to destruction and supports water drainage and aeration despite compaction. The CT system generally brings lower bulk density and greater porosity especially in the plough layer, while NT increases the surface soil density and decrease total porosity. Changes in total porosity are related to the change in pore geometry depending on soil type. The soil moisture state and pore stability as modified by tillage systems are the factors that determine the rate of water absorption and transmission at the time of measurement.

Soil Water Retention

Excessive tillage affected soil properties and resulted in lower availability of water and nutrients, causing lower and variable crop yield. Crop residue removal from soil surface before tillage or residue incorporation during tillage operation leaves no residue mulch on the soil surface and aggravates the soil water evaporation.

Conservation tillage maintains at least 30% surface coverage with crop residue or cover crops, has increasing been accepted as the best management practice for water and soil conservation (Corsi *et al.* 2012). Due to its in-situ moisture conservation, NT can sustain the agricultural productivity in water deficit arid and semi-arid regions. Minimum root impedance and adequate soil moisture are essential for effective crop production. Higher soil moisture in NT can effectively reduce the penetration resistance of soil in comparison to CT. Residue mulch in NT protects the surface soil from rain and wind, and maintains a better soil physical affecting the surface layer hydrology like reduction in runoff and increase in infiltration.

Crop residue on soil surface intercept the radiation and decrease soil evaporation and moderate the temperature. Warming of soil under conservation agriculture with surface residue is also slower than the CT. No-tillage and minimum tillage have reported to escalate the amount of storage pores and hence, retained higher plant available water than the conventional practice. Due to an improvement in soil hydrothermal environment, conservation tillage is advocated as better alternative of tradi- tional system. Conservation agriculture has a higher potential of rainwater harvesting and may serve as an effective mitigation strategy for late or variable rainfall and climate change.

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Role conservation agricultural in horticultural crops

Tanmay Kumar Koley, Nongmaithem Raju Singh, Ujjwal Kumar

ICAR-Research Complex for Eastern Region, Patna

In the present scenario of depletion of natural resource, the adverse effect of climate change, rising input price and volatile market price of agro produces, achieving food, nutritional, and livelihood security to the growing population is a significant challenge to the researchers. In addition to this, soil erosion, depletion of soil organic matter are the major hurdle in achieving sustainability in agriculture system. Continuous practices of intensive tillage, non-incorporation of organic material and monocropping are the main reason behind this. Therefore there is a need to shift from conventional agricultural practices to sustainable agro practices. Conservation agriculture is a concept evolved as a response to concerns of sustainability of agriculture globally.

"Conservation Agriculture is a concept for resource-saving agricultural crop production that strives to achieve acceptable profits together with high and sustained production levels while concurrently conserving the environment" (FAO 2007). It enhances biodiversity and natural biological processes above and below the ground surface, which contribute to increased water and nutrient use efficiency and improved and sustained crop production. It is based on three principles, i.e., maintenance of a permanent soil cover, minimum soil disturbance (i.e., no-tillage), and diversification of plant species.

A. **Soil organic cover:** One of the fundamental principles of CA is keeping the soil under organic cover. Generally, crop residues are left on the ground surface. However, cover crops are needed if the gap is too long between harvesting one crop and establishing the next. It is particularly crucial for perennial orchard crops like fruit and plantation crops. Generally, a bare soil surface (clean cultivation) is mostly advocated for orchard crops. However, clean cultivation is undesirable for the orchard located in hilly or other erosion-prone areas. In addition to this, clean cultivation is often costly for large orchard and not conducive to maintaining the favorable soil condition. Therefore the judicious selection of cover crops and their use in orchard crops is beneficial.

Advantage of cover crops:

- Protecting the soil from erosion.
- Providing an additional source of organic matter to improve soil structure.
- Recycling nutrients (especially P and K) and mobilizing them in the soil profile in order to make them more readily available to the following crops.
- Provide "biological tillage" of the soil; the roots of some crops, especially cruciferous crops, like oil radish are pivotal and able to penetrate compacted or very dense layers, increasing water percolation capacity of the soil.
- Utilizing easily leached nutrients (especially N).

Use of cover crops in horticultural crops

Fruit crops: In Taiwan, where seasonal typhoon storms cause bananas to be replanted on an annual cycle, erect legumes such as *Sesbania cannabina* are sown in the inter-rows when the new seed pieces are transplanted. The legumes help suppress weeds and are subsequently tilled in as green manure or used as mulch. In India, green manure crops like sunhemp, cowpea, daincha, lupins are more commonly used. Legume cover cropping in grape, mango, guava, and other fruit crops is becoming a common practice in the management of orchards. Cowpea and french beans grow well under guava and sapota tree. Some of the research demonstrated the suitability of specific cover crops in fruit crops. For example, Isik et al., (2014) reported that cover crops including *V. villosa* and *Festuca arundinacea* Schreb were effective in suppressing the weeds and increasing yield of hazelnut orchards. In apricot, the highest weed suppression was obtained with the cover crops including lacy phacelia, buckwheat, hairy vetch and Triticale + Hungarian vetch (Tursun et al., 2018). In another study Sofi et al., (2018) reported that in Kashmir valley of India, in the mid-altitude soils, berseem (*Trifolium alexandrinum*) and the higher altitudes alfalfa (*Medicago sativa*) are grown as a nitrogen-fixing cover crop.

Plantation crops: In rubber plantations of Kerala and Kanyakumari district, permanent cover cropping is a common feature. To prevent soil erosion, certain permanent cover crops like *Calapogonium muconoides*, *Centrosema pubescens* and *Peuraria phaseoloides* are raised in the alley spaces. These leguminous crops, establish in a short period, dry up during summer to conserve moisture. With summer showers they come up again because of their profuse seeding habit and spread themselves as a vegetative mat by the time the heavy monsoon starts pouring in. In coconut plantation, *Tephrosia purpurea, Calapagonium muconoides, Mimosa invisa, Stylosanthes gracilis* are grown as the cover crop. Cover cropping is also common in some other plantation crops. For example, Hutasoit et al., (2017) reported that *Clitoria ternatea* was the best species of legume tested as a cover crop in oil palm plantations.

Vegetables crops: Mulching is often used for vegetable production. It is common in perennial vegetables such pointed gourd, ivy gourd. There is little research which demonstrated that cover crops beneficial for some cucurbitaceous vegetables. Buchanan et al., (2016) have reported that cover crops of crimson clover (*Trifolium incarnatum* L.) and barley (*Hordeum vulgare* L.) reduced the weed infestation in vegetables such as crookneck squash (*Cucurbita pepo*L.) and broccoli (*Brassica oleracea* L.) by 50% compared to the un-weeded control.

B. Minimal mechanical soil disturbance or conservation-tillage

One of the fundamental principles of conservation agriculture is minimal mechanical soil disturbance (conservation-tillage). Mechanical tillage is not compatible with biological tillage. Biological tillage is the process of soil biological activity which produces very stable soil aggregates as well as various sizes of pores, allowing air and water infiltration. With mechanical soil disturbance, the biological soil structuring processes will disappear. Minimum soil disturbance provides/maintains optimum proportions of respiration gases in the rooting-zone, moderate organic matter oxidation, porosity for water movement, retention and release and limits the re-exposure of weed seeds and their germination. Conservation tillage includes a range of different tillage practices, most of which are non-inversion techniques that aim to conserve soil moisture and reduce soil erosion by leaving more than one-third of the soil surface covered by crop residues. These methods include no-tillage, subsoil tillage, reduced or shallow tillage with tines or discs, subsoil tillage with straw mulch and straw-returning tillage.

Conservation-tillage has been readily adopted in agronomic crop production with a high degree of success. However, for the production of annual horticultural crops, for example, vegetables, conservation-tillage remains in its infancy. Conservation-tillage is only commercially used for processing tomato production. For perennial orchard crops such as fruits and plantation crops conservation tillage is desirable and easy to perform. Orchard located in hilly or plateau region is susceptible to soil erosion if mechanical tillage is followed. Thus adaption of conservation tillage in this region has always an advantage.

Use of conservation tillage in horticultural crops:

Vegetables: Among the vegetable, the tomato is well studied for conservation tillage. Mitchell et al., (2009) reported that in California's San Joaquin Valley vegetable producing farms used winter cover crops and spring strip-till to mix cover crops and incorporate herbicide in the transplant line. In one tomato farm, subsurface drip irrigation was carefully managed to avoid wetting the soil surface and to control weeds. At the other, over-the-top herbicide was used.

Conservation tillage is also experimentally explored for cantaloupe production using the strip-till method. In California, cantaloupe was produced in the strip-till method using rye grain-vetch and subclover as cover crops and compared with conventional tillage. It has been observed that standard tillage methods produced slight higher yield compared to strip-till methods because of the delay in growth and development of the plant in the strip-tilled plot.

Fruit crops: Unlike tomato, in fruit crops conservation tillage is not adopted at large scale. Most of the work is limited to the experimental field. Liu et al. (2013) reported that subsoil tillage with straw mulching treatment was found optimum practice for improving the soil water-holding capacity in this non-irrigated apple orchard in the Loess Plateau of China. In another study, Gomez et al. (1999) reported that no-tillage significantly affects the surface soil organic matter content, bulk density, cone index, macroscopic capillary length and hydraulic conductivity of an olive orchard. Neves et al. (2010) indicated that the soil has a higher resistance to penetration between rows with conventional tillage than does a zero tillage system in a citrus orchard.

C. Species diversification: Another principle of CA is species diversification which is achieved through crop rotation. The rotation of crops is not only necessary to offer a diverse "diet" to the soil microorganisms, but also for exploring different soil layers for nutrients that have been leached to deeper layers that can be "recycled" by the crops in rotation. Furthermore, a diversity of crops in rotation leads to a diverse soil flora and fauna, as the roots excrete different organic substances that attract different types of bacteria and fungi, which in turn, play an important role in the transformation of these substances into plant available nutrients. Crop rotation also has an important phytosanitary function as it prevents the carryover of crop-specific pests and diseases from one crop to the next via crop residues.

Although crop rotation is an effective means of species diversification, this practice can only be applicable for the annual plant such as cereals, pulse, oilseeds, vegetables, annual ornamental crops, medicinal and aromatic plants. For personal orchard crops such as plantation or fruit crops crop rotation is not possible. However, the practice of intercropping, multitier cropping may serve the same purpose.

Species diversification in horticultural enterprises

Crop rotation: Crop rotation is the practice of growing a series of unique or different types of crops in the same area in sequenced seasons. In horticultural enterprises, crop rotation followed in vegetables, annual ornamental crops, and annual medicinal and aromatic crops. The basic principle is the rotation of crop by plant family or by plant nutrient demand. Cultivation of crop plant of the same family in the same soil year after year may lead to building up of pathogen and pest. Crop rotation with vegetable with the different family (Table 1) leads to the breaking of their breeding cycle. Thus the occurrence of disease and pest is reduced. The notable example of crop rotation for disease prevention is cole crop.
Similarly, cultivation of plant having higher nutrient demand may lead to exhaust soil. Based on nutrient demand, crops are categorized into three group viz. heavy feeder, light feeder, and heavy giver. Thus rotating crops with different nutrient demands (Table 2) on the soil, we can maintain soil fertility and maximize productivity. Another principle is not to grow an underground bearing crop in consecutive seasons in the same soil.

Table 1: Vegetables classification based on family

Family	Vegetables crop
Solanaceae	Tomato, Brinjal, Chilli, Capsicum, Potato
Brassicasae	Cabbage, Chinese cabbage, Kale, Radishes, Cauliflower, Broccoli
Cucurbitaceae	Pumpkin, Cucumber, Bottle gourd, Bitter gourd, Watermelon, Muskmelon, Summer squash
Leguminosae	Green peas, cowpea, French bean, vegetable soyabean,

Table 2 Vegetable classification based on nutrition demand

Nutrition demand	Vegetables crops
Heavy feeder	Asparagus, Beet, Broccoli, Cabbage, Cauliflower, Corn (Sweet), Eggplant, Kale, Kohlrabi, Okra, Pepper, Potato, Pumpkin, Radish, Rhubarb, Spinach, Squash (Summer), Tomato, Watermelon
Light Feeders	Carrot, Garlic, Leek, Mustard Greens, Onion, Sweet Potato
Heavy Givers	Beans, Peas, Cowpea, Soybeans

Intercropping Intercropping is multiple cropping practices involving growing two or more crops in proximity. Numerous type of intercropping followed in horticultural enterprises. Some of them are mixed cropping, row-cropping, temporal cropping, and relay cropping.

In the case of vegetables, mixed cropping is rarely followed. Generally, row cropping is followed. In India, cole crops grow as main crops where bulb crops or root crops grow as intercrop. Often marigold is intercropped as trap crops for brinjal and tomato.

For orchard crops, both mixed cropping and row cropping is followed. At the initial stage, where the plant is small, various kind of annual crops, such as cereals, pulse, vegetables, the medicinal plant can be intercropped. However, after a specific time period, when crop canopy spread, then limited crops can be grown. Mostly shade-loving crops are well situated in such a situation. In addition to field crops, some short duration, less exhaustive and dwarf type inter- fillers like papaya, guava, phalsa, etc. can be grown till these do not interfere with the main crop.

Multi-tier cropping system: The multi-tier cropping system is a self-sustainable system where solar energy, soil moisture and nutrient resources from various depths and also airspace are efficiently utilised. The system consists of three main components such as, main crop; filler crop and intercrops which occupy three different tiers in the space of the production system. This cropping systems mainly followed in the coconut plantation and some fruit crops.

The main crops/upper story: The main crops are the fruit/plantation crop species having a larger canopy size and prolonged juvenile as well as the productive phase. They utilize the uppermost layer of the multi-tier system from which the economic productivity is obtained. Mango, litchi, and aonla were found suitable main fruit crops. In addition to this, sapota, jackfruit, bael, can be used as main crops. Some of the plantation crops such as coconut and cashew nut also used as main crops.

The filler crops/ central story: The filler crops are the fruit species which are precocious, prolific bearers having short stature. They utilize the middle layer of the multi-tier system from which economic productivity is obtained. The filler plants can be removed after the main crops attain an effective canopy size for yielding economically. Guava, lemon, custard apple and drumstick were found as suitable filler crops. The cocoa plant is used as a storied middle plant in coconut plantation.

Intercrops/lower story: The intercrops occupy the lowermost layer of the multi-tier system and are grown in the remaining unused land of the multi-tier system. Generally, the intercrops are the location-specific annual crops, selected as per the climatic and socioeconomic suitability. The intercrops also include the dependant crops like creepers which are grown with the support of main or filler crops. During the initial years of the multi-tier system, any crops can be taken whereas during the later years shade tolerant crops can be grown as intercrops. Turmeric, ginger, elephant foot yam was found suitable as intercrops. In addition to this groundnut and rice can be grown as intercrops depending upon the climatic condition. In coconut plantation pineapple used as intercrop in the lower story.

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Socio- economic Impact of Conservation Agriculture

Abhay Kumar

ICAR Research Complex for Eastern Region, Patna

Conservation agriculture (CA) defined as minimal soil disturbance (no-till, NT) and permanent soil cover (mulch) combined with rotations, is a recent agricultural management system that is gaining popularity in many parts of the world. Cultivation is defined as 'the tilling of land', 'the raising of a crop by tillage' or 'to loosen or break up soil'. Other terms used include 'improvement or increase in (soil) fertility'. All these definitions indicate that cultivation is synonymous with tillage or ploughing.

The other important definition that has been debated and defined in many papers is the word 'sustainable'. This is an important concept in today's agriculture, since the human race will not want to compromise the ability of its future offspring to produce their food needs by damaging the natural resources used to feed the population today.

The discussion will introduce and promote CA as a modern agricultural practice that can enable farmers to achieve the goal of sustainable agricultural production. But first, the paper discusses some issues related to tillage.

Conservation tillage and conservation agriculture

Since the 1930s, during the following 75 years, members of the farming community have been advocating a move to reduced tillage systems that use less fossil fuel, reduce run-off and erosion of soils and reverse the loss of soil organic matter. The first 50 years was the start of the conservation tillage (CT) movement and, today, a large percentage of agricultural land is cropped using these principles. However, it is still not popular in Bihar. However, Indo- Gangetic Plain ranked fifth in the world in adoption of Zero Till technology (Hobb,Savre and Gupta, 2005)

While Conservation Agriculture maintains a permanent or semi-permanent organic soil cover. This can be a growing crop or dead mulch. Its function is to protect the soil physically from sun, rain and wind and to feed soil biota. The soil micro-organisms and soil fauna take over the tillage function and soil nutrient balancing. Mechanical tillage disturbs this process. Therefore, zero or minimum tillage and direct seeding are important elements of CA. A varied crop rotation is also important to avoid disease and pest problems. A comparison of traditional tillage, conservation tillagev and conservation agriculture is mentioned as under:

Table 1. A comparison of Traditional tillage, conservation tillage (CT) and conservation agriculture (CA) for various issues.

Issues	**Traditional tillage (TT)**	**Conservation tillage (CT)**	**Conservation agriculture (CA)**
practice	disturbs the soil and leaves a bare surface	reduces the soil disturbance in TT and keeps the soil covered	minimal soil disturbance and soil surface permanently covered
erosion	wind and soil erosion: maximum	wind and soil erosion: reduced significantly	wind and soil erosion: the least of the three
soil physical health	the lowest of the three	significantly improved	the best practice of the three
compaction	used to reduce compaction and can also induce it by destroying biological pores	reduced tillage is used to reduce compaction	compaction can be a problem but use of mulch and promotion of biological tillage helps reduce this problem
soil biological health	the lowest of the three owing to frequent disturbance	moderately better soil biological health	more diverse and healthy biological properties and populations
water infiltration	lowest after soil pores clogged	good water infiltration	best water infiltration
soil organic matter	oxidizes soil organic matter and causes its loss	soil organic build-up possible in the surface layers	soil organic build-up in the surface layers even better than CT

Issues	Traditional tillage (TT)	Conservation tillage (CT)	Conservation agriculture (CA)
weeds	controls weeds and also causes more weed seeds to germinate	reduced tillage controls weeds and also exposes other weed seeds for germination	weeds are a problem especially in the early stages of adoption, but problems are reduced with time and residues can help suppress weed growth
soil temperature	surface soil temperature: more variable	surface soil temperature: intermediate in variability	surface soil temperature: moderated the most
diesel use and costs	diesel use: high	diesel use: intermediate	diesel use: much reduced
production costs	highest costs	intermediate costs	lowest costs
timeliness	operations can be delayed	intermediate timeliness of operations	timeliness of operations more optimal
yield	can be lower where planting delayed	yields same as TT	yields same as TT but can be higher if planting done more timely

Models for Socio-economic Evaluation

Cost-benefit Analysis

Cost-benefit analysis (CBA) is a highly structured method to organize information and quantify social advantages (benefits) and disadvantages (costs) in terms of a common monetary unit. Unquantified effects (intangible) are described and put against quantified values. CBA analysis is required for the following reasons: (i) Market deficiencies, lack of information, externalities, risk, etc. may create a difference in the private versus the social perspectives. Thus, reliance on the market forces is insufficient.
(ii) Government distortions, trade barriers, pricing policies, etc., affect land management and hence need to be analyzed. Thus, reliance on the market forces is insufficient. (iii) Resources are limited; somehow the allocation of resources between sectors (industry and agriculture) and within sectors (conservation here or there) has to be decided.

Basic Economic and Evaluation Principles

The evaluation of any technologies may be done either with or without adoption of technologies, or before and after the adoption of the technologies.

With and Without Adoption

Evaluation of conservation technologies may be made with and without its adoption. Costs and returns are measured at their exchange value, at the time to accrual. This approach becomes analytical device for determining the effects of various measures of formulation and evaluation phases. The anticipated need for land, water and other related goods, future land use as related to productivity should be projected both by time and productivity. Thus, with the technique of project evaluation one needs to make estimation for the likelihood output from the project area and also the surrounding agro-climatic region.

Before and After Adoption

Another method for evaluation of a project on soil water conservation and watershed management is before and after project. In this, input and output data are collected from the project area at two points of time, i.e. before start of the project and after completion of the project. This method is more accurate but it needs more time for evaluation. Secondly, this method cannot be applied in the appraisal of the project i.e. ex-ante evaluation. Secondly, this method cannot be applied in the appraisal of the project i.e. ex-ante evaluation. Thirdly, it fails account for changes in production that would accrue without the project and thus, it may overestimate the benefits of the project.

Technical Data Collection

It is very important to collect and analyze the current information on input use, output produced and their prices. This represents the key components in the evaluation of conservation measures. The information is collected on cost paid for items such as, (a) equipment and power, (b) seeds and fertilizers, (c) labour, (d) irrigation, etc. The cost resources are estimated by systematic listing of physical resources used in the production and it provides value of each resource on hectare basis. Identification of input and output of a project (i) Identification of inputs: Programmes/projects involve a set of new or altered activities directed to obtain maximum possible production per unit of area on sustained basis. The inputs are costs and may occur either on-site and / or off site. The inputs involved in these programmes are, use of the factors of production (land labour and capital) over and above the level of their use without the project. (ii) Identification of output (benefits): The benefits accrued from soil and water conservation programme are numerous / multiple. The first step in this is to identify those benefits, enlist them and group them in to following five broad categories. (Kumar, R, 2014)

Particulars	Bihar		Haryana		Punjab		UP	
	Adopter	Non adopter	Adopter	Non adopter	Adopter	Non adopter	Adopter	Non adopter
Human and mechanical labour	3125	3886	2859	3608	2940	3705	2992	3854
Seeds	1409	1459	1734	1771	1780	1830	1599	1641
FYM	2560	2411	3952	3592	2381	2238	2124	1897
Plant nutrients	2688	2992	3228	3582	2896	3126	2699	2907
Irrigation	1399	1547	2607	2799	3220	3575	1167	1369
Plant protection	2168	2404	1804	2150	1524	1787	1594	1800
Total INPUT COSY	13367	14706	16177	17506	14741	16259	12169	13477
Productivity – q/ha	4.0	3.9	5.0	4.8	5.4	5.0	4.3	4.1

Economic benefits: Those benefits which can be measured in physical terms and valued at market price; these include:

1. Additional crop production from the reclamation of land, development of new topsoil, introduction of new crop technology, etc. 2. Additional crop production from increased irrigation potential through soil and water conservation. 3. Additional production from trees, horticultural plants, grasses, etc.4. Sustained yield. 5. Increase animal production 6. Additional income from fish, etc, through developed water resources. 7. Increase in net income and reduction in income-inequality.

An analysis conducted for comparing performance of adopter and non-adopter in IGP is summarized in following table 1.

Protective or ecological benefits: This group includes those benefits, which are mostly intangible and cannot be included, when the project is evaluated from private point of view. These are generally in one category called as externalities from the project.

(i) Area directly protected against erosion, such as, gullying, stream bank erosion, etc.

(ii) Protection of existing production from land liable to be lost as a result of erosion.

(iii) Proportionate investment on dam and its commands protected/ proportionate loss due to flood hazards likely to be reduced.

(iv) Proportionate damage to crops, trees, grasses, etc., due to erosion, floods/drought prevented.

(v) Enrichment or maintenance of genetic diversity.

Environmental benefits

(i) Preservation of ecological diversity and control of floods.

(ii) Protection of soil, water and air-quality.

(iii) Control of industrial pollution.

(iv) Bio-diversity maintenance.

(v) Better microclimate.

Secondary Benefits to the Community

Project can lead to benefits created outside the project itself. These are termed as secondary benefits or technological externalities. For the economic analysis of the project, these secondary benefits must be accounted for so that you can be properly attributed to the project investment. Due to non-availability of data and the techniques to convert them into money value it becomes difficult to consider all these benefits / costs aspects of soil and water conservation programmes for its evaluation Following are pre-requites for adoption of Conservation Agriculture.

1. Availability of machinery / equipment for promotion of resource conservation technologies is a prerequisite for achieving targets of agricultural production. Availability of implement at economical cost is major constraint in promotion of bed planting of crops. Likewise, machinery is not available for crop residue management that is impeding acceleration of this practice.

2. Organizing farmers' days, holding of field demonstrations, cross-farm visits of extension experts and effective use of mass media i.e. print and electronic media for transfer of technology may play a major role in promotion of resource conservation technologies amongst farming community.

3. Capacity building of farmers to acquire, test and adopt technologies through participatory approach will enable them to seek resource conservation technologies for their farms and thus they can reduce their production cost and combat production constraints.

4. Improvement in coordination among various stakeholders (research, extension service, farmers, service providers, agricultural machinery manufacturers, etc.) for transfer of technologies will play a pivotal role in accelerating adoption of new interventions.

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Strategies for Wide Scale diffusion of Conservation Agriculture Technologies

Dhiraj Kumar Singh & Anirban Mukherjee
ICAR Research Complex for Eastern Region, Patna

Traditional agriculture which includes activities like excessive tillage operations, residue burning, high doses of inorganic fertilizers & pesticides, mono-cropping etc resulted in soil erosion, decrease in water quality, soil compaction and poor adaptation to stresses. It also adds to global warming through emission of Green House Gases (GHGs). The concept of Conservation agriculture (CA) involve minimum soil disturbance, permanent soil cover through crop residues or cover crops, and crop rotations for achieving higher productivity. In India, efforts are under way to develop, refine and disseminate conservation-based agricultural technologies for last two decades and made significant progress even though there are many constraints in diffusion of CA technologies. The rice-wheat cropping sequence of North Western plains though provided food security in the country, but the over exploitation of resources have led to problems like falling water table and yield plateau in cereals. The CA technologies like zero tillage, direct seeded rice, laser land levelling, crop residue incorporation in soil etc provide opportunities to reduce the cost of production, save water and nutrients, increase yields, increase crop diversification, improve efficient use of resources, and benefit the environment.

Information requirement of farmers about CA Technologies

Adoption of Conservation Agricultural Technology is a prerequisite for increasing productivity and improving socio-economic status of farming community. The information about any technology must reach to farmers before he/she takes a decision about its trial, adoption, continued adoption or rejection. In the context of conservation agriculture, a farmer will require following information in a comprehensive manner:

- **How to do land preparation**: Minimum soil disturbance, slashing/rolling of weeds or previous crops r use of herbicides.
- **What is direct seeding:** Information about Zero tillage/No tillage/direct drilling of seeds etc.
- **How to do planting in CA**: Use of equipment for creating a slot for seed and placing of large size seeds in that slot viz. maize, beans etc.
- **How to apply fertilizers**: Broadcasting or during seeding or planting.
- **Cover crops**: during fallow season, provision of cover crops to protect soil, mobilize nutrients; improve soil structure and controlling weeds, insects and pests infestation.

- **Practice crop rotation:** To provide diverse diet to soil microbes, increase nutrient availability in different layer of soil, increasing diversity of flora and fauna as well as phytosanitary effect of crop rotation i.e reduction in insect/pest infestation .
- Designing and implementing different crop rotation schemes as per various objective i.e food and fodder production, residue production, green manuring, mulching, nutrient uptake, pest and weed control etc.

Strategies for diffusion of Conservation Agriculture Technologies

There are a number of CA technologies and practices that are known and available for use under different agro climatic conditions. No one extension approach is best suited for diffusion of CA technologies and therefore specific strategies like personal communication to use of mass media suit different types of messages and level of farmers. Reach and impact potential of message transfer, two negatively correlated indicators, are of primary importance and differ between diffusion approaches, i.e. generally, the higher the reach, the smaller is the impact and vice versa. Mass media often suits simpler messages while intensive interactions through farmer field schools can be more effective strategy for complex message.

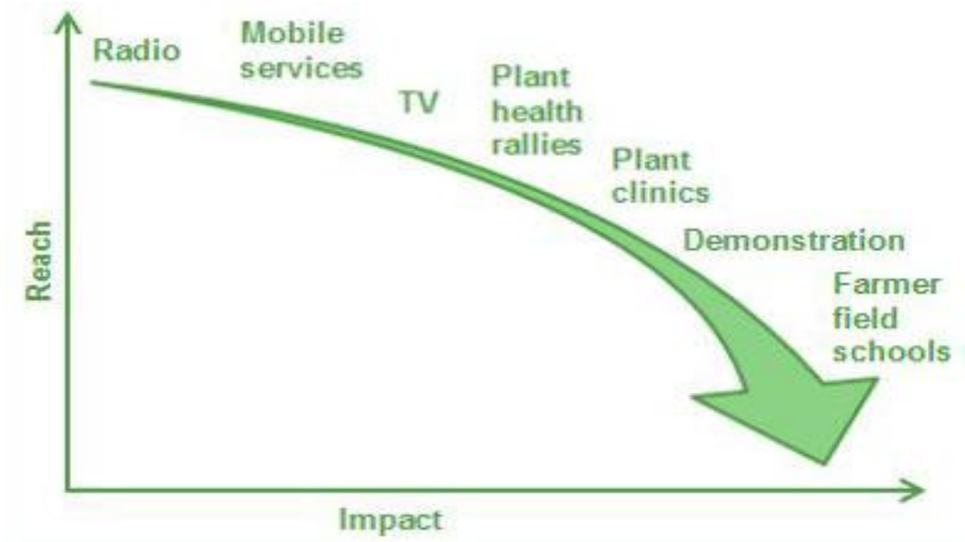

Fig. 1: Impact and reach of Technology Transfer Methods

Some of the traditional as well as innovative extension approaches which can be specially used for diffusion of CA Technlogies are discussed below:

1. **Awareness programmes/Campaigns, Exhibitions:** Major constraints of national extension systems are shortage of field extension personnel and limited resources to reach large numbers of farmers in India. To address this, extension can be more efficiently performed using mass media like awareness camp, kisan mela, exhibitions etc. Diffusion with mass media can also be run by non-extension players (e.g. radio or television) with technical inputs through SMS from extension workers, for awareness creation or simple information delivery on conservation agriculture related issues.
2. **Training on CA Technologies:** Training and capacity building of intermediaries/extension personnel is very important to update their knowledge related to various CA technologies available, their socio-economic impacts and

consequences on farming system . Being operational at field level, extension service providers should be familiar to the local conditions and should know how to read the scientific data or interpret it. Trained extension functionaries can organize "field school related to CA technologies" and establish weather services for farmers.

3. **Plant Health Clinics:** These clinics allow direct information exchange between extension workers and farmers on "any problem and any crop". The various crop problems brought to plant clinics can be related to either abiotic factors (e.g. nutrient deficiency, water logging, chemical misuse, etc.) or biotic factors (e.g. pathogens, insects, rats, etc.). Plant doctors should be knowledgeable about plant diseases and pests and farming conditions, speak the local language and know what inputs are available in the market as medicines. Sri Lanka, as an example, has already implemented the plant clinic approach in 16 out of 25 districts, with over 290 operating plant clinics.

4. **Farmers Field School on CA Technologies:** The Farmer Field School (FFS) is a participatory, non-formal extension approach based on experiential learning that puts farmers and their demands at the centre. In FFS, farmers can experiment experiment with new agricultural management practices, discuss and learn from their observations, which allows them to develop new practical knowledge and skills, and improve their individual and collective decision-making. For example, Climate Field Schools in Indonesia raised awareness of climate change and promoted solutions to cope with changing rainfall patterns, such as recording and interpretation of on-farm rainfall measurements and in-field water harvesting.

5. **Plant Health Rally approach:** This helps in quickly raising awareness about major agricultural risks or threats on important crops, to promote the use of improved agricultural practices, and to collect feedback from farmers on major issues which affect production viz. soil erosion, depleting water level etc. It is complementary to the plant clinic approach as it differs in terms of reach, impact and complexity of the messages that it can transmit. Plant health rallies are run by local extension workers. They are usually held in public spaces and are open to everybody. A plant health rally may be spontaneous, attracting people with a banner and other announcements, or may target farmers who have been specifically mobilized for the event.

6. **Contingency Crop Planning:** It is a document based on local weather and crops and includes the recommendations across the key aspects of crop management and cultural practices. This form of calendar is very useful in terms of crop planting, irrigation scheduling and plant protection measures for farmers. CA technologies like zero tillage or DSR can be integrated in this document.

7. **ICT Supported network:** ICTs played an important role as a medium of information and communication in climate change awareness, adaptation and mitigation strategies. Mobile phones, videos, radios etc. can be effectively used to address the issue of climate change by creating awareness among the farmers about the availability of different adaptation and mitigation strategies. e-Arik (e-agriculture) was an ICT-based project initiated in 2007 in Arunachal Pradesh, India, aimed to disseminate 'Climate-smart agricultural practices' and to achieve food security. Under this, a 'Village Knowledge Centre' was established with computer, internet link, printer, scanner,

phone and TV at Yagrung village. Project facilitators (agricultural professionals, a computer instructor and farmer) were appointed at the centre to help farmers access ICT-based agricultural information.

8. **Farmer to Farmer Extension (F2FE):** F2FE is the provision of training by farmers to farmers, often through the creation of a structure of farmer-promoters and farmer-trainers. It offers great promise for effectively scaling up conservation agriculture practices. The approach empowers farmers as change agents and helps to increase adoption because farmers are more willing to learn from their colleagues than from extension staff. F2FE programmes help to improve productivity, build resilience and reduce greenhouse gas emissions.

9. **Demonstration on different adaptation and mitigation practices:** Field Demonstration of various CA technologies and practices among farmers is a suitable approach to convince farmers about ill effects of traditional agriculture. These demonstrations can be laid out at experimental farms or at progressive farmers field of that area. Field day can also be observed where a group of farmers can be sensitized about issues of conservation agriculture under local prevailing agro-ecosystem.

Problems in adoption of CA Technologies

There are a number of problems encountered in adoption of conservation agriculture. Some of important ones are given below:

- The old mindset of farmers who were educated extensively and convinced about the intensive agriculture and use of external inputs.
- A complete shift from intensive tillage to zero or minimal tillage needs extensive educational programme by demonstrating the benefits accrued by conservation agriculture.
- Higher cost of machines and implements is a major problem in CA. Farmers in India are mostly small and poor, and therefore may not immediately shift from the existing or available machines to the conservation agriculture machines.
- Lack of access to information about the conservation agriculture to farming community is also a major hindrance. Farmers need complete information related to tillage practices, cultivation methods and improved varieties.
- Lack of skills development among farmers since new machines (zero till machine) and cultivation practices require skill development of the farmers. Most of the farmers lack skills in using zero-till machines and cultivation practices which prevents adoption of conservation agriculture practices.
- Lack of appropriate seeders especially for small and medium scale farmers is a limiting factor. Successful adoption will require accelerated effort in developing, standardizing and promoting quality machinery aimed at a range of crop and cropping sequences. These would include the development of permanent bed and furrow planting systems and harvest operations to manage crop residues.

- Burning of crop residues in many areas of India is another problem. For timely sowing of the next crop and without machinery for sowing under CA systems, farmers prefer to sow the crop in time by burning the residue. This has become a common feature in the rice-wheat system in north India. This creates environmental problems for the region.

Conclusion

Conservation agriculture technologies are the future of sustainable agriculture. There are potential benefits of conservation agriculture across different agro-ecological regions and farmers groups. These benefits range from nano-level (improving soil properties) to micro-level (saving inputs, reducing cost of production, increasing farm income), and macro-level by reducing poverty, improving food security, alleviating global warming. The need is aggressive demonstration and information dissemination programs and well complemented by skill development of the farmers. In addition, a massive training program for capacity development of farmers needs to be developed. Krishi Vigyan Kendras (KVKs) in partnerships with the research institutions engaged in conservation agriculture R&D, may take lead in this endeavour. Use of ICTs should also be promoted to diffuse CA technologies in an enhanced manner. Moreover, training of the extension staff to acquire new capacities in CA Technologies and linkage development with various stakeholders is need of the hour. Success stories from different approaches used for diffusion of CA technologies can be documented and replicated at similar kind of locations.

Conservation agriculture in Eastern India: A way forward for rice fallow management

Bal Krishna Jha
ICAR-RCER, Farming System Research for Hill & Plateau Region
Ranchi-834010 (Jharkhand)

Rice is the most important cereal crop of the developing world and the staple food of more than half of the world's population. India is having rice cultivation area of 44.6 million hectares with production of 132 MT and an average productivity of 2.96 t/ha (Pandian, 2009). One-fifth of the world's population depends on rice cultivation for their livelihoods. In Asia, about 90% of the area is rice grown and around 65% of the total populations in India consume rice and it accounts for 40% of their food production. India is the world's second largest producer of white rice, comprising of 20% of the world rice production. The world production of rice has risen steadily from about 200 million tones of paddy rice in 1960 to over 678 million tons in 2009. Rice-based production systems provide the main source of income and employment for more than 50 million households. The rice production in India contributes a major part of the national economy. Rice is also the main staple food crop of Jharkhand. The Jharkhand state ranks twelfth and produces about three per cent rice of total rice production of India. The Ranchi, Paschim Singhbum, Purb Singhbum, Lohardaga and Gumla are the chief rice producing districts and majority of the rice grown as rain fed with an average productivity of 2.97 t/ha. The achieving self-sufficiency in rice production and maintaining price stability are important political objectives in low-income countries because of the importance of this crop in providing national food security and generating employment and income for low-income people (Ghosh *et al.,* 2009). Since a large portion about 70 % of area under rice in India is drought prone rain fed (Kumar *et al.,* 2012).Therefore a suitable conservation agricultural technologies may play a vital role in utilization of such area in eco friendly and sustainable production of rice globally.

Growing more rice with reduced cost of production and maintaining soil health are the major concerns of rice farming globally (Rao *et al*., 2016). The suitable genotype of rice and good crop establishment is one of the vital components for efficient use of resources and desired level of productivity in rice. Establishing rice by manual transplanting is labour intensive and excessively puddling of soil increasingly difficult due to higher cost of operation and shortage of man power (Verma and Singh, 2016). The traditional method requires more tillage practices and too many time of repetition of tillage implements before sowing of seed. This tillage practice is very time consuming, expensive and needed hard labour. But in new concept of modern agriculture, the farming is tending towards the tillage practice should be minimum or no tillage practice required. Under these circumstances the zero tillage technology is economical, time saving and easy to operate and opportunity to utilize the soil moisture in succeeding Rabi crops after harvest of paddy. The new improved technologies of conservation agriculture will eventually lead to the farmers to discontinue the conventional tillage practices. The farmers' decision to adopt conservation agricultural practices of rice depend upon various factors. The studies on adoption of rice technologies indicate that the adoption behaviour of farmers is governed by a diversified set of factors such as their socio-psychological and economic factors, characteristics of innovations and quality of extension work (Bhagat, 1983; Mahant, 1989; Jha, 1991; Hugar *et al.*, 1992). The practically feasible and readily adoptable eco friendly technology to enhance production and productivity of the rice would be the conservation agricultural technology in near future.

The change in method of rice establishment is inevitable to improve productivity, profits and sustainability by adopting conservation agriculture practices too. Direct seeding of seed, zero tillage transplanting of paddy are some of the methods of crop establishment under conservation agricultural practices which require less water and less reliant on labour as compared to the conventional practice of manual transplanting (Rao *et al*., 2015).

As we aware that agriculture remains central to the Indian economy providing livelihood to the majority of its population. Though Indian agriculture have made spectacular progress for food self sufficiency, yet growing challenges of large management yield gaps, low water and nutrient efficiency, imbalance and inadequate use of external production inputs, diminishing farm profits, deterioration of soil health, environmental quality coupled with climate risks are major concerns. Feeding a growing population with increasing dietary preferences for resource-intensive food products is a major challenge facing humanity. Moreover, with no scope for horizontal expansion of farming to produce needed food; improving agronomic productivity and achieving high and stable yields under changing and uncertain climate are important to feeding the growing population. Increasing climatic variability affects most of the biological, physical and chemical processes that drive productivity of agricultural systems. The productivity and stability of agricultural systems depends upon measurable factors and processes controlled by climate and non-climate drivers of production paradigm. It is therefore vitally important to develop strategies and practices to sustainably increase food production while increasing farm income, protecting natural resources and minimizing environmental footprints. In most part of India, the agronomic yield of food staples can still be doubled or tripled through bridging management yield gaps by a widespread adoption of conservation agriculture (CA) based sustainable intensification (SI), yet conserving and protecting natural resources. Conservation agriculture based resource conservation technologies has proved to produce more at less costs, reduce environmental pollution, promote conjunctive use of organics (avoids residue burning), improve soil health and help adapting to climatic risks. Like any other tillage and crop establishment technology, it may not be a panacea for all present day ills, but has proven to bring out south American Agriculture out of its stagnant state almost 30 years ago, skyrocketing the cereals and oilseed production system. Thus, for addressing the issues of resource fatigue and bridging ‘management yield gaps’, Conservation Agriculture based sustainable intensification are cornerstone. Over past two decades, a efforts have been made on research on developing, adapting and scaling Conservation Agriculture (CA) based sustainable intensification (SI) under various programs, schemes and initiatives by ICAR, Indian NARS, CIMMYT and other CGIAR centers, developmental departments, NGOs, private sector and farmer organizations.

There are some good success stories around CA based technologies. However, the potential impact of CA has yet to be achieved as India accounts for 79% (11.65 m ha) of the total rice fallows of South Asia (15.0 m ha) as per the NAAS Policy Paper 64 (2013). The maximum rice fallow area is reported in MP + Chhattisgarh (4.38 m ha) followed by Bihar + Jharkhand (2.20 m ha), West Bengal (1.72 m ha), Odisha (1.22 m ha) and rest of Maharashtra, Assam, UP and AP (2.13 m ha).The CA being knowledge intensive with site /

location/situation specificity of application of component technologies (variety, machine, water, nutrient, weed, pest, etc.) on basic elements of CA (minimum mechanical disturbance of soil, rational organic soil cover and efficient crop rotation), needs precise understanding on recommendation domain for its large scale adoption. The CA research has evolved over time and still evolving in view of benefits that CA can provide to address the growing challenges. Also, CA need a holistic system based approach and a multi-disciplinary team efforts and continuum of "Basic-Strategic-Applied Research-Participatory Adaptation & Co learning-Capacity Development-Last Mile Delivery".

The significant efforts have been made to advance CA research over a period of couple of decades through eco-regional programs like RWC, national initiatives like NATP, NAIP, ICAR platform on CA, NICRA, regional bilateral collaborative programs like CSISA, SRFSI, CCAFS, regional platforms like BISA etc. and involving large number of institutions and organizations. Though despite of all these, the uptake of CA in India has been slow but with science based evidence on multiple benefits in addressing growing complexity of challenges and to deliver several Sustainable Development Goals. Now a day, CA has emerged as one of the major frontiers of future farming. However, scaling CA based management practices in diversity of farm typologies and production ecologies for impact scale, it needs a collaborative approach of consortium of projects/programs/institutions involved in CA research for development in India. Keeping in view, there is need to examine the pros and cons of CA as why the adoption is slow, what are new research aspects as well to make synergies and complementarities of the on-going CA research in India by ICAR, CIMMYT, BISA and other centers.

The Consortia Research Platform (CRP) on CA was initiated by the ICAR with broad objectives of development, adaptation and refinement of location specific CA practices for enhancing productivity of rice-fallow eco-systems. The project is being implemented at ICAR-RCER, Patna, Buxar (Bihar), Ranchi (Jharkhand) and Jashpur (Chhattisgarh) with major objective to develop, demonstrate and validate CA-based crop management technologies for improving the productivity of rice-fallows in rain fed ecosystems of Eastern region**.** Besides, lots of studies have been undertaken by various organizations to improve the productivity and profitability of rice-fallows. The efforts initiated by ICAR-RCER, Farming System Research Centre of Hill and Plateau Region, Ranchi as Consortia Centre on conservation agriculture with sub objective to evaluate CA practices in rice fallows, selection of appropriate rice varieties and management practices for successful introduction of *Rabi* crops and evaluation of suitable winter season oilseeds and pulses and varieties for rice-fallow system at farmer's field of village Chene, Ranchi (Jharkhand) located at Lat: 23°17'2.59"N, Long:85°26'9.84"E and village Kandora, Jashpur (Chhattisgarh) located at Lat: 22°45'46.58"N & Long: 84° 0'42.76"E. The treatment comprised of farmers puddle transplanted Rice (FP-TR), conservation agricultural methods as zero tillage direct seeded rice (ZTDSR) and zero tillage transplanted rice (ZTTR).

Research outcomes of conservation agriculture

The lot of studies has been undertaken by various organizations to improve the productivity and profitability of rice-fallows. The salient findings with economic analysis and monetization of CA carried out at ICAR-RCER being enumerated herewith. The research output under Bihar condition resulted the PTR recorded grain yield (5.18 t/ha) found better as compared to ZTDSR (3.58 t/ha) and UPTR (2.53 t/ha). During initial years, no significant effect of residue was recorded in paddy and succeeding winter crops like chickpea (3.88 t/ha) and safflower (3.85 t/ha). The yield of chickpea (2.5 t/ha) was higher after UPTR while safflower yield (1.7 t/ha) was higher in ZTDSR. Comparatively higher seed yields of winter crops was recorded in 30% residues retention as compared to no residue. The system annual productivity (SREY) was higher in rice-chickpea (12.2 t/ha) followed by rice-lentil (11.6 t/ha) under the PTR. The Utera system effectively used the soil moisture (121 mm) and recorded higher SREY (6.4 t/ha) as compared to ZT with straw mulch @ 5 t/ha (5.8 t/ha) and ZT (5.6 t/ha).

Similarly, under Jharkhand condition, the farmers practice of puddled transplanted rice (PTR) recorded highest yield of 5.35 t ha^{-1} and followed by zero tillage transplanted rice (ZTTR) of 4.23 t ha^{-1} and least was recorded in (ZTDSR) direct seeded rice (4.16 t ha^{-1}) Jha *et al*.,(2019). The similar finding of superior performance of alternate systems of rice establishment on crop and water productivity of in rice was reported by Murthy *et al.* (2015). However, the harvesting index was found highest in zero tillage transplanted rice (0.52) and least in direct seeded rice (0.48). Rao *et al.*, (2015) also reported the similar findings among different establishment methods direct sowing by drum seeder resulted lesser grain yield, however, it was at par to dry direct sowing and transplanting.

Among the genotypes trial, Lalat recorded consecutively maximum grain yield of 4.78 t ha^{-1} followed by Naveen (4.67 t ha^{-1}) and least in IR-64 (4.28 t ha^{-1}). The highest harvest index (0.51) was recorded in IR-64 and genotype Naveen and Lalat recorded the same value of harvest index. The Lalat and Naveen genotypes recorded significantly higher grain yield over IR-64 irrespective of conservation agriculture practices. An economic analysis of the pooled data revealed that farmers practice produced higher grain yield of 5.35 t ha^{-1} which is 28.60 % higher yield than direct seeded rice. This may be attributed to high tillers, high vegetative biomass production and high numbers of filled grains per panicle. The result obtained is in conformity with Samant *et al.*, (2015). The Lalat recorded the higher grain yield (4.78 t ha^{-1}) in comparison to Naveen (4.67 t ha^{-1}). These results are in conformity with Tripathi *et al.*, (2013). The economics analysis of CA revealed that the farmers practice revealed higher gross return of Rs. 81,855 ha-1 with a benefit- cost ratio of 2.72 and net return of Rs.51,785 ha^{-1} as compared to the direct seeded rice which gave the net return (Rs.38,128 ha^{-1}) and benefit-cost ratio (2.49) and least was recorded in zero tillage transplanted rice of net return of Rs 36,899 ha^{-1} and BC ratio 1.13. In mustard, effect of straw mulch was insignificant while the yield was highest in ZTDSR (0.3 t/ha) over farmer’s practice (PTR). Linseed yield (0.2 t/ha) was higher under mulch and recorded 5.0 and 16.7% higher yields under ZTT-M and DSR-M, respectively. Among the CA practices the soil organic carbon varied from 0.49 to 0.55 % which was slightly higher than farmers’ practice (0.42%).

Among rice establishment methods under Chhattisgarh condition, PTR recorded highest yield (3.1 t/ha) followed by DSR (2.4 t/ha) and ZTT (2.1 t/ha).The Rice genotypes viz., Lalat, IR-64, Naveen and Sahbhagi were evaluated with different CA practices, IR -64 yielded grain yield of 2.8 t/ha was significantly highest in FPT. The organic carbon in post harvest soils of paddy varied from 0.4-0.5% among three establishment methods. After DSR, Linseed with straw mulch showed highest yield (2.7 t/ha) over DSR-NM and PTR plots.

Monetization of eco-system services & economic analysis of CA in rice-fallows:

Rice–fallow areas are those *Kharif* paddy grown areas that kept fallow in *Rabi* season due to lack of irrigation, late harvesting of long–duration high yielding rice varieties, moistures stress at sowing during the *Rabi* crops, water logging and excessive moistures in November/December, and nuisance like stray cattle and blue bulls. This system covers ~11.7 million ha in India and mostly (82%) concentrated in the Eastern states i.e. Chhattisgarh, Jharkhand, Upper Assam, Bihar, Eastern Uttar Pradesh, Odisha and West Bengal. There is great scope in converting rice fallows into productive agro-ecosystems through appropriate crop based interventions involving suitable varieties and appropriate resource conservation technologies (RCTs). Pulses such as chickpea, lentil, lathyrus and blackgram and oilseeds such as safflower and linseed -through rotation or relay with rice - are the candidate crops for efficient utilization of conserved and scarce resources including soil moisture.

In rice-fallows, reduced tillage has increased the yield of pulses (lathyrus, greengram, blackgram, field pea) by 33–44% over conventional tillage (Kar and Kumar, 2009). Similarly, retention of rice stubble/mulching and ZT sowing of pulses significantly enhanced productivity of pulses in rice fallows (Ghosh *et al.* 2016). Retaining 30% rice residues on soil surface and ZT sowing with Happy Seeder increased yields of succeeding lentil, chickpea, safflower, linseed and mustard by 3.1, 11.7, 19.1, 14.4 and 12.3%, respectively (Unpublished results, CRP on CA Project at ICAR RCER, Patna). Similarly, *Utera* cropping performed better than ZT (with or without mulch), and produced the maximum seed yield due to advantage of early sowing and better utilization of residual soil moistures. Among different crops, lathyrus followed by linseed and lentil recorded the maximum yields and profits (Mishra *et al.* 2016). ZT after rice harvest also facilities timely planting of winter pulses, and helps to escape negative effects of terminal drought and rising temperature in spring-summer in rice–fallows. Results of the farmers participatory trials on ZT lentil and chickpea in Eastern–IGPs during 2009–10 showed that using ZT with reduced seed rate (30 kg/ha for lentil and 80–100 kg for chickpea), deeper seed placement (5–6 cm for lentil) improved crop establishment, crop productivity and reduced wilts incidence (Singh *et al.* 2012).

A survey on farmers' participatory adoption of ZT seeded lentils in rice–fallows (200 ha) of Nawada, Bihar showed that ZT planting of lentils together with the suitable improved agronomic packages resulted in higher yields (13 %) and a reduced cultivation cost by ` 3800/ha, thereby increasing farm profitability of Rs. 10,000/ha (Singh *et al.* 2012). In lowlands having high moistures after rice harvest, draining excess water at physiological maturity of rice by providing drainage channels at appropriate intervals creates a favourable soil condition for ZT of winter pulses (Layek *et al.* 2014). But in case of a dry soil at rice harvest, NT along with standing stubbles/residue retention @ 5 t/ha along with life saving irrigations could give a reasonable lentil yields (Das *et al.* 2013). Mulching with paddy straw/ water hyacinth was found to increase productivity of groundnut sown after rice harvest (Chaudhary *et al.* 2014). At Indian Institutes of Pulse Research Kanpur, ZT–drill for small farmers having low purchasing power was developed for line sowing in rice–fallow, which helped in moisture retention as least disturbances of soil occurred. Use of NT drill, seeding was performed timely at reduced cost. Experiences from several location in IGPs showed that ZT farmers saves on preparatory operation by Rs. 2500/ha and reduced diesels of 50–60 l/ha (Sharma *et al.* 2005).

The monetization of different cropping systems and economics studied under conservation agriculture practices at Jharkhand and Chhattisgarh were also studied. The cropping system followed under CA during kharif-rabi-summer in Jharkhand was Rice-linseed-green gram and Rice-mustard-cowpea. The above cropping systems are practiced under farmer's practice, ZTDSR and ZTTR. The economic analysis of cropping systems confirmed that the highest net return of Rs 51, 785/ha in farmer's practice with benefit-cost ratio of rice was highest 2.72. Similarly, the ZTDSR and ZTTR showed net profit of Rs 38,128/ha with B-C ratio of 2.49 and Rs 36, 899/ha with rice benefit-cost ratio of 2.33, respectively. The winter crop linseed showed highest gross return of Rs 14,948/ha with benefit-cost ratio of 1.02 in DSR-non tillage, while mustard showed gross return of Rs 13,700/ha with benefit-cost ratio of 1.0 in DSR-non tillage in comparison to farmer practice.

The summer crop green gram showed highest net return of Rs 6,065/ha with benefit-cost ratio of 1.27 in farmer's practice, while cowpea showed highest net return of Rs 92,432/ha with benefit-cost ratio of 3.87 in farmers practice. Among the two cropping systems, Rice-mustard-cowpea performed better in all CA practices under Jharkhand condition.

The cropping system followed under CA during *kharif-rabi*-summer in Chhattisgarh was Rice-lentil-black gram, Rice-safflower-sesame, Rice- mustard- cowpea and Rice –linseed –green gram. The above cropping systems are practiced under farmer's practice, ZTDSR and ZTTR. The economic analysis of cropping systems confirmed that the highest net return of Rs 16,861/ha in farmer's practice with benefit-cost ratio of rice was highest 1.56. Similarly, the ZTDSR and ZTTR showed net profit of Rs 10,658 /ha with B-C ratio of 1.42 and Rs 3,606/ha with rice benefit-cost ratio of 1.13, respectively. The winter crop of lentil showed highest gross return of Rs13,551/ha with benefit-cost ratio of 1.02 in farmer's practice, while mustard showed gross return of Rs 14,379/ha with benefit-cost ratio of 1.24 in farmer's practice. The linseed crop showed highest gross return Rs 18,011/ha with B-C ratio of 1.23 in DSR-non tillage, while safflower showed gross return of Rs 27,494/ha with B-C ratio of 2.11 in farmer's practice. The summer crop green gram showed highest net return of Rs 4,713/ha with benefit-cost ratio of 1.21 in farmer's practice, while cowpea showed net return of Rs 79,546/ha with benefit-cost ratio of 3.47 in farmers practice. The black gram showed highest net return of Rs 3,348/ha with B-C ratio of 1.15, while sesame showed highest net return of Rs 18,405/ha with B-C ratio of 1.86 in farmer's practice. Among the four cropping systems, Rice-mustard-cowpea performed better in all CA practices.

Conservation agriculture road map

The joint workshop of ICAR-CIMMYT held at July 9-10, 2018 at NASC Complex, Pusa New Delhi outlined the policy paper on road map of CA (Jat et al.,)as enumerated below:

1. ***Conservation Agriculture (CA) addresses several major challenges*** confronting agriculture in India including climate change, water scarcity, soil health deterioration, low farm profitability, environmental pollution and its adverse impacts on ecosystem and human health. As such, CA contributes to at least 8 of the UN's Sustainable Development Goals (SDGs) and should be valued by policy makers accordingly.

2. Several well-executed research programs have generated significant knowledge of CA performance over past 2 decades. However, due to temporal, management, and geographic factors, response cannot be generalized. There is a need to ***better aggregate and map knowledge of CA across sites in order to define recommendation domains*** that consider soil, climate, cropping systems and socio-economic conditions of different regions of the country.

3. While ***strengthening the long-term CA research platforms*** as sites of learning as well as new scientific insights and evidence generations and developing adapted component technologies (water, nutrient, genotypes x environment x management interactions) for CA, the ***on-farm research-cum-demonstration with farmers' participation*** *involving Krishi Vigyan Kendras (KVKs)* is essential for validating CA performance on a broader spatial scale, including identification of adoption bottlenecks.

4. ***Commercial availability of scale appropriate machinery*** is one of the critical factors for success of CA. Hence, CA mechanization priorities need to be defined and strengthened in the regions having week manufacturing capacity and distribution channels. Special emphasis should be made on establishing CA mechanization hubs in rainfed ecologies and eastern India.

5. ***Soil biology and pest (including insects, pathogens) dynamics under CA*** needs a thorough investigation due to change in hydro-thermal, carbon and nutrient regimes of the soil in presence of crop residue cover and non-disturbance of soil. Changes in community structure and dynamics of microbial mediated processes under CA need to be evaluated to harness the benefit.

6. By synthesizing all the evidence generated on CA across the diversity of production system and ecologies over past 2 decades, a strong case need to be made for a new ***'National Initiative on Conservation Agriculture (NICA)'*** to be sponsored by Ministry of Agriculture & Farmers Welfare for evidence based promotion of CA in India. Emphasis is to be laid on CA for rain fed agriculture. Under proposed ***'National Initiative on Conservation Agriculture'*** some strategic sites should be identified and established with ICAR-CIMMYT collaboration as permanent demonstrative units on CA under ***deficit, limited*** and ***adequate*** water availability situations for irrigation with a provision of both ***in-situ*** and ***ex-situ*** water conservation/harvesting. These sites should represent diverse soil types and climatic conditions for a major production system of the region.

7. ***Scalable and sustainable business models*** should be developed for promoting adoption of CA in large scales through motivating and attracting youth in agriculture and empowering women for creating effective custom hiring centers as well as manufacturing hubs. Enhanced capacity development of all stakeholders involving farmer's service providers-scientists-to policy makers should be an integral part of such models.

8. ***The CA should be the part of course curriculum*** of undergraduate and post-graduate courses in all the Agricultural Universities. The Education Division of ICAR may take appropriate action to initiate such courses. In all the universities as well as ICAR research institutions and KVK farms, there should be large-scale demonstrations of CA based systems for training of young researchers. The practical crop production program at undergraduate level by the students should be mandated for CA-based production system.

9. There is a need to ***establish a learning platform/ CA-Community of Practitioners (CA-CoP)*** with a mechanism for regular interactions, knowledge sharing and capacity development.

10. A ***'Technical Working Group on Conservation Agriculture (TWGCA)'*** involving key researchers from ICAR, SAUs, CIMMYT, other CG Centers and other organizations (like BISA, IPNI) should be established as **"*The India CA Center*"** with defined roles and responsibilities should be established to promote CA in India.

The Center should be mandated to work on:

(i) Mapping CA research and development initiatives,
(ii) Defining recommendation domains of CA-based management systems,
(iii) Identifying research gaps and address pertinent questions and concerns related to CA,
(iv) Acting as knowledge repository and sharing center,
(v) Serving as catalyst for capacity development of stakeholders,
(vi) Developing science-driven policy guidelines and advisories for out scaling CA,
(vii) Developing proposals and raising funding for CA research and development,
(viii) Acting as facilitator for south south collaboration,
(ix) Developing framework for tracking adoption and social impact of CA and
(x) Monitoring and evaluating CA adoption and its impacts.

Conclusion, constraints, research gaps & way forward for CA

It can be concluded that farmers traditional practices is yielding better than conservation agriculture practices however it would be better to adopt conservation agricultural practices which gave comparable yield, economic returns and environment conducive. Among conservation agriculture practices, direct seeded rice proved as productive and emerged more remunerative than zero tillage transplanting system. However, for adoption of CA, the farmers have the pre occupied mindset that tillage has direct relation to crop production and the seeding or sowing is not possible without tillage practice. They opined that tillage operation in seeding/transplanting as more number of plowing is cause of high yield in crops and less number of plowing low yield. However, in modern technology the researcher's emphasizing that the minimum disturbance of soil in case of seeding. According to minimum soil disturbance concept, the zero tillage technology introduced between farmers. The recent past few years, due to globalization, it is necessary to put low cost of agricultural produce. Due to increase of input cost of produce and low selling price, the zero tillage technology is adaptable. The zero tillage technology is very valuable and may be very wildly accepted and easy technology in near future. The use of zero tillage save, the fuel, time of sowing, seeds, water, fertilizer and man power. However, for promotion of CA, the lack of improved varieties and quality seeds, poor plant stand (low moisture), weed menace, no use of fertilizers, terminal drought, prevalence of diseases, delayed planting (late harvest of rice), poor crop management, lack of mechanization in CA practices, capacity building Cum awareness and socio-economic constraints (Animal grazing) are the major constraints. The way forward for promotion of CA would be to reduce yield loss during initial years, assessment of economic gains through CA, environmental impact assessment of CA practices, effective use of residual soil moisture using CA practice, development of CA compatible crop varieties and selection of region specific cropping sequences for CA practice.

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Management of low temperature stress in *Boro* rice

N. Bhakta

ICAR-Research Complex for Eastern Region, Patna (Bihar)

Boro rice has been traditionally grown during winter season (Oct-Nov to May-June) in the deeply flooded areas of West Bengal, North East Bihar, Eastern Uttar Pradesh and Assam in Eastern India and in the Sylhet, Mymensingh and Faridpur districts in Bangladesh.

In Bihar *boro* rice (summer rice or *garma dhan*) is grown in 80000-100000 ha area mainly in the districts of Katihar, Kishanganj, Purnea, Supaul, Araria and Madhubani in the agro-climatic Zone-II.

Table 1. Area, production and yield of *boro* (summer) rice in Bihar

Year	Area (000 ha)	Production (000 tonnes)	Yield (t/hectare)
2016-17	84.323	224.329	2.660
2015-16	81.302	200.983	2.472
2014-15	82.265	181.555	2.207
2013-14	92.207	215.952	2.342
2012-13	105.117	285.833	2.719

Source: Directorate of Statistics and Evaluation, Department of Agriculture, Govt of Bihar

Among the rainfed rice ecosystems the flood-prone deep water areas are more vulnerable than the others. The wet season rice crop in these areas is generally damaged by floods and submergence at different crop growth stages. The rice crop also suffers from drought, especially during early stages of the same season. The farming situations around these areas comprise of flowing or still water conditions and flooding at different times. The situation varies greatly depending upon intensity of rainfall, drainage facility, onset of flooding, rate of water rise, etc. The rice production in this ecosystem is very poor and uneven. Due to change in environment with special reference to rainfall pattern and amount, the wet season rice crop faces the problems of submergence at early stage due to flood and drought at panicle initiation stage. Such extremely diverse situation compelled to farmers to search an alternative for their sustenance and livelihood which is mainly based on rice cultivation. The *boro* rice system of cultivation emerged from such crucial situation and now it has become a boon for victims of natural vagaries prone area. There is an unlimited and annually rechargeable source of water under the earth in the vast area under flood prone rainfed lowland and deep-water ecologies remaining fallow after harvest of monsoon rice in eastern India.

Boro rice is grown in low lying areas in the flood prone ecosystem in dry season. It takes advantage of the residual water in the field after harvest of dry season paddy. *Boro* is the most productive season for growing rice. It possesses an inherent high yield potential due to availability of good sunshine during growing season, good water control, less risk of crop failure (due to no flood), high input use efficiency and less incidence of insect-pests and diseases. Farmers are encouraged to take up its cultivation in the season when irrigation facilities are available.

Boro rice is grown during Nov-Dec to May-June. The crop growth stages like seed germination, emergence, seedling establishment and early vegetative growth are subject to low temperature stress during the winter months. In eastern India, minimum temperature goes well below 10^{o}C during Mid December to Mid January. Minimum temperature falls down to as low as $6\text{-}10^{0}$ C during seedling stage, 15^{0}C in the vegetative stage $15\text{-}20^{0}$ during PI stage and $35\text{-}40^{0}$ C during harvesting that are detrimental for obtaining potential yield. The critical temperature for different growth stages in rice crop is given below in Table 2.

Table 2. Response of the rice plant to varying temperatures at different growth stages. (Yoshida 1981)

Growth Stage	**Critical temperature (^{0}c)**		
	Low	**High**	**Optimum**
Germination	10	45	20-35
Seed emergence and establishment	12-13	35	25-30
Rooting	16	35	25-30
Leaf elongation	7-12	45	31
Tillering	9-16	33	25-31
Initiation of panicle primordial	15	-	-
Panicle differentiation	15-20	38	-
Anthesis	22	35	30-33
Ripening	12-18	30	20-25

Leaf yellowing in *boro* rice due to cold

Cold injury in *boro* rice seedlings (severe cold)

Thus, the main environmental factor limiting *boro* rice cultivation is the cold stress. Cool water and air temperature affect the seedling growth, tillering ability, plant height and crop duration and cause yellowing of leaves and seedling mortality (Pathak *et. al.* 1999). The traditional *boro* rice varieties are tolerant to cool temperature during early vegetative stage but they poor yielder due mainly to their tall stature, weak culm, loose panicle, coarse grain, red kernel, presence of awn, etc which are not preferred by the farmers. There is no cold tolerant high yielding variety of rice ideally suitable for the *boro* season. Rice varieties like Gautam, IR 64, Krishnahamsa, Chandrama, Naveen, CRHR-7, Shatabdi, Kshitish, Joymati, CR *Boro* Dhan 2, Dhanlaxmi, Richharia, Prabhat, etc have been released for *boro* season. However these varieties have only the moderate level of cold tolerance. Besides these some rice hybrids like Arize 6444, Arize 6444 Gold, Arize Tez, Arize 6129, etc are also grown by farmers during *boro* season. These varieties/hybrids lack the desired level of cold tolerance and hence these are affected by low temperature stress in the nursery and early vegetative phase coinciding with the winter months of December and January. However, affect of cold injury in *boro* rice at seedling stage can be reduced by following suitable agronomic and cultural management practices.

Management of cold stress in *boro* rice

Site selection for nursery

As *boro* rice is invariably grown under transplanted condition and seedlings are raised under wet seedbed method. Site selection of nursery plays a great role in raising healthy seedlings. It is observed that seedlings raised in lowlands are healthier than those raised in uplands. While selecting site for nursery, places under shade should be avoided. It is observed that the number of albino seedlings due to cold is very low in places receiving light as compared to those grown under shade.

Selection of seeds

Healthy seeds with high seedling vigour are expected to overcome the cold stress effectively. Heavier seeds having a specific gravity of 1.06 or more are to be selected by discarding the floating seeds in salt solution. This solution is prepared by adding 60 g of common salt per liter of water. Selected seeds are washed immediately with normal water and then dried. An alternative to this cumbersome practice is to collect healthy seeds during threshing time itself. In manual threshing method, the bold seeds are easily shattered by first two beating operations and these should be considered for seed purpose. This process is effective in separating out the partially filled and diseased grains.

Sun drying of seeds before soaking

Time required for sprouting (from soaking to sprout initiation) is usually longer (8-12 days) in *boro* season compared with *kharif* season (3-4 days). This period can be reduced by pre-heating the seed lot under sun for 4-5 hours. Sun drying the seed before soaking is observed to result in faster and uniform sprouting.

Sowing time in nursery

The intensity of cold gradually increases from early November to mid January and hence, advancing sowing time to early-November is advantageous. Early sowing has the advantage of higher survival of sprouts by avoiding their desiccation and drying due to cold wave. Further, seedlings already attain a height of 8-10 cm before of onset of cold injury. Hence, ceasing of seedling growth during cold stress does not interfere with timely uprooting and transplanting. Moreover, 15-20 days old seedlings are physiologically mature enough to endure better against cold stress compared with younger seedlings or sprouts.

Use of polythene tunneling

High yielding semi-dwarf rice varieties are unable to attain optimum seedling height in spite of early sowing in this season. Hence, uprooting of seedlings from nursery and transplanting in main field becomes difficult as well as time and labour consuming. To overcome the low temperature stress in nursery, polythene tunneling is useful. During cooler period (Mid-December to mid-January) *boro* rice nursery is covered with polythene tunnels during night time. In this practice, polythene tunnel is removed daily in the morning hours and covered in the evening. There is increase in temperature inside the polythene tunnel as compared to the outside temperature. An observation on weekly mean minimum temperature during *boro* 2015-16 at ICAR-RCER, Patna revealed that it was higher by 2.0 to 3.0 ^{0}C inside the polythene tunnel as compared to the ambient minimum temperature.

Fig. 1. Raising *boro* rice nursery in open as well as under polytunnels

Water management in nursery

Effective water management practices can reduce the effects of low temperature stress to rice seedlings. Wherever there is facility for controlled irrigation and drainage exists, nursery should be irrigated daily in the afternoon. The water should be allowed to stand on the field throughout the whole night and early morning. The cool water should be drained out from nursery in morning. In absence controlled drainage facility, standing water should be maintained to reduce the cold stress.

Removal of dew

Removal of dew drops from rice seedling tips daily in the morning with the help of a rope or stick lessens the adverse effects of low temperature stress.

Application of compost and balanced nutrients

NPK should be applied in the nursery bed @ 10:10:10 kg/ha as basal followed by top dressing with N @10kg/ha after 2-3 weeks of germination. Application of compost @ 1kg/ m_2 also helps in mitigating the cold stress. Yellowing of leaves due to cold injury may get disguised as deficiency of nitrogen.

Care of seedlings between uprooting and transplanting

Leaving the uprooted seedlings of *boro* rice even for few hours (2-3) on dry field results in desiccation and drying. The seedling uprooted for transplanting should always be kept in fields with standing water. This practice helps in development of winter hardiness in seedlings leading to their better survival in main field

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Diversifying Crop Rotations with Nitrogen Fixing Legumes

A. K. Choudhary

ICAR Research Complex for Eastern Region, Patna (Bihar)

Legumes are plants belonging to the family Fabaceae (or Leguminosae). The term also applies to their fruits or seeds. Legumes are grown agriculturally for their edible seeds (grain legumes or pulses), for oil extraction (oilseeds), for vegetable purpose (vegetable legumes), for livestock (forage legumes), as seed spice and soil-enhancing green manure. However, most commercially cultivated legume species serve two or more purposes simultaneously, depending upon their degree of maturity when harvested. Most of such legumes contain distinct strains of symbiotic bacteria called *Rhizobia* within root nodules of their root systems. These bacteria have the special ability to fix atmospheric molecular nitrogen into ammonia (NH_3), converting it further into another form (NH_{4+}). This arrangement means that the root nodules are sources of nitrogen for legumes, making them relatively rich in plant proteins. All proteins contain nitrogenous amino acids. Nitrogen is therefore a necessary ingredient in the production of proteins. Hence, legumes are among the best sources of plant protein. When a legume plant dies in the field or gets harvested, all of its remaining nitrogen that became incorporated into amino acids inside the remaining plant parts (roots) is released back into the soil. Thereafter in the soil, amino acids are converted to nitrate (NO_3^-), making the nitrogen available to other plants, thereby serving as the fertilizer for the succeeding crops. Legumes are notable in that most of them have symbiotic nitrogen-fixing bacteria in structures called root nodules, which begin to develop after 2-3 weeks of sowing followed by their degeneration at/after completion of flowering. For that reason, they play a key role in crop rotation. In many traditional and organic farming practices, crop rotations involving legumes is common. By alternating between legumes and non-legumes (cereals/millets), sometimes planting non-legumes two times in a row followed by a legume, the fertility status of the soil gets improved to produce a good succeeding crop.

In India, leguminous crops including pulses and oilseed legumes (Table 1) presently account for only one-third (47 mha) of the net cultivated area (> 140 mha). Grain legumes and oilseed legumes together have not only contributed to food and nutritional security, but have also aided to soil health and environmental sustainability. According to Dwivedi *et al*. (2017), a legume-rich diet has health benefits for both humans and livestock. However, grain legumes constitute only a minor part of the dietary requirement of millions of poor vegetarians of South- Asia where legume crops are greatly under-used. Food security and soil fertility may be substantially enhanced by greater grain legume usage and increased improvement of a range of grain legumes. The current lack of coordinated focus on various classes of legumes has compromised human health, nutritional security, soil and environmental sustainability.

Table 1. Agriculturally important legume species

Classes of legumes	Common name	Botanical name
Pulse crops	Chickpea Lentil Field pea Grass pea Rajmash Broad bean (faba bean) Pigeonpea Mungbean Urdbean Cowpea Moth bean Horse gram Rice bean	*Cicer arietinum* L. *Lens culinaris* Medik. *Pisum arvense* L. *Lathyrus sativus* L. *Phaseolus vulgaris* L. *Vicia faba* L. *Cajanus cajan* (L.) Millsp. *Vigna radiata* Wilczek *Vigna mungo* (L.) Hepper *Vigna unguiculata* (L.) Walp. *Vigna aconitifolia* (Jacq.) *Macrotyloma uniflorum* (Lamb.) Verds. *Vigna umbellata* (Thunb.) Ohwi & H. Ohashi
Oilseeds crops	Soybean Peanut	*Glycine max* L. *Arachis hypogaea* L.
Forage crops	Egyptian clover (berseem) Alfalfa (lucerne) Sweet clover Vetches Guar (cluster bean)	*Trifolium alexandrinum* L. *Medicago sativa* L. *Melilotus spp.* *Vicia spp.* *Cyamopsis tetragonoloba* (L.) Taub.
Seed spice crop	Fenugreek	*Trigonella foenum-graecum* L.
Vegetable crops	Garden pea Scarlet runner bean French bean (string bean) Sword bean Jack bean Fava or broad bean Lablab (sem) bean Winged bean	*Pisum sativum* L. *Phaseolus coccineus* L. *Phaseolus vulgaris* L. *Canavalia gladiata* L. *C. ensiformis* (L.) DC *Faba sativa* Moench *Lablab purpureus* (L.) Sweet *Psophocarpus tetragonolobus* (L.) DC
Root crop	Yam bean	*Pachyrhizus erosus* Rich. ex DC.
Green manure crops	Sunn hemp Sesbania (Dhaincha) Subabul	*Crotalaria juncea* L. *Sesbania cannabina; S. rostrata; S. sesban* *Leucaena leucocephala* (Lam.) de Wit

Current Crop Rotations and their Side Effects

More than twenty cropping systems are practiced in India. Rice-wheat and rice-rice are the major cropping systems practiced in an estimated 120 districts and 50 districts of the country, respectively (Khoury *et al*. 2014). The introduction of high-yielding semi-dwarf varieties of rice and wheat was necessary to ensure food and nutritional security for an ever growing population of South Asia especially Bangladesh, India, Nepal and Pakistan. The rice-wheat cropping system (RWCS) of the Indo-Gangetic Plains (IGP) of South Asia is the creation of the so-called green revolution. Although undoubtedly brought about food security in the IGP regions of India, this crop rotation, however, is labour, water, capital and energy intensive, and its profitability is directly related to the availability of these inputs

(Bhatt and Yadav, 2015). The extensive RWCS has displaced the soil-rejuvenating high-protein grain legumes from the system to a large extent. The area under leguminous crops in the north-west and north-east plains of India now stands at an all-time low. The persistence of cereal-cereal cultivation over decades is now showing its ill effects on soil health in terms of soil structure, poor drainage, and declined productivity *per se* (Kataki, 2014). The heavy use of chemical fertilizers and liberal use of irrigation to both rice and wheat over years has made this rotation unsustainable, primarily due to increase in soil salinity and poor response to added fertilizers (Dahiya *et al*. 2002). Another cereal-cereal cropping system in which rainy season rice is followed by a second crop of rice is quite common in the areas characterized by tropical climate with distinct dry and wet seasons. These areas include southern parts India and sub-tropical areas of Eastern Gangetic Plains (EGP) with mild winter climate. The overall productivity of rice-rice cropping system is not only low (Mangal Deep *et al.* 2018) but has also deteriorated soil health and human dietary pool (Dwivedi *et al*. 2017).

In recent years, an increasing trend of malnutrition has been observed among South Asian populations depending entirely on rice and wheat, with micronutrient deficiency (Fe, Zn and Vit-A) being the major cause of malnutrition. This micro-mal- nutrition amongst children and adults is a “hidden” emergency in South Asia including India. As nitrogen-fixing legumes are rich source of proteins and minerals, the diversification of the RWCS and rice-rice cropping system with grain, oilseed and vegetable legumes is likely to alleviate widely prevalent protein and micro-nutrient malnutrition among the south Asian peoples. In addition to this, the diversification will also improve soil health and system productivity alike.

Established Facts vis-à-vis Diversifying Crop Rotation

A mega study performed across 150 countries has shown that crop total diversity has narrowed over the past 50 years. Several factors including policy decisions like minimum support price (MSP) and assured purchase by the government agencies are attributed to this loss of crop diversity. This has resulted in more or less a uniform dietary composition across the world. A study carried out in Malawi has revealed that farm production diversity was consistently and positively correlated with dietary diversity (Remans *et al*. 2011). Farm production diversity was consistently and positively associated with dietary diversity, and this association was significantly greater in women-headed households than in those led by men. Legume, vegetable and fruit consumption was strongly associated with greater farm diversity, with more diverse production systems contributing to more diverse household diets (Remans *et al*. 2011; Jones, 2016). This research highlights the relationship between production and dietary diversity, which leads to improved human health and wellbeing (Kumar *et al*. 2015). As a result, the energy density of the cereal supply remained constant between 1961 and 2011, but the protein, iron, and zinc contents in the global cereal supply declined by 4%, 19%, and 5% respectively, with an overall decline of the nutrient-to-calories ratio (DeFries *et al*. 2015). Thus a more diverse farm policy is required to stimulate more production of leguminous crops across the world.

Sustainable agriculture and human nutrition and health are closely related. However, these two aspects are often dealt with in isolation. Developing and developed nations face qualitatively different problems (Dwivedi *et al*. 2017). For instance, in EGP regions where there is greatest population pressure per unit area, a large proportion of subsistence small farm holder is coping with poverty, soil erosion and low quantity and diversity of crops on their land and in their diet. However, most industrialized nations with large-scale intensive farming systems have compacted soils, food surplus and a large proportion of extremely processed food in malls and super-markets. In both the situations, the ultimate aim is to improve soil fertility and to move towards affordable and sustainable nutritious foods. An interdisciplinary approach integrating human health and environmental health (eco-nutrition) has been exemplified in the Millennium Villages project in Africa in which nitrogen-fixing plants or trees in the farm system were included as the key elements to serve as important sources of free N for soil fertility (up to 200 kg/ha) and protein for human consumption and health because it replaces animal sources of proteins as animal-based proteins have a higher environmental impact than plant-based products (Dechelbaum *et al*. 2006). Under sustainable and resilient farming system initiative (SRFSI) project in EGP, several scenarios were analyzed to improve the current narrow rice and wheat systems by various possible options including cropping system diversification that included legumes or vegetables in the cereal rotation. The integration of legumes in the rotation resulted in higher productivity and farmers' income over the prevailing practices. Experiments conducted at the ICAR Research Complex for Eastern Region have established distinct advantage of system productivity that included legumes (pigeonpea, urdbean and soybean) in the crop rotation (Anonymous, 2018). Experiments have revealed that diversification of rainfed upland rice system with vegetable legume (cowpea) and pulses (pigeonpea, black gram and horse gram) is more profitable in the eastern plateau and hill region. Even in foxnut-based cropping system, integration of legumes (fox nut-water chestnut-berseem) from 2012-13 to 2014-15 significantly improved system productivity and fertility status (organic carbon, N and P) of aquatic low land ecosystem (I S Singh; Pers. Comm.).

Way Forward

Various options to diversify crop rotations with nitrogen fixing legumes are dis- cussed below briefly:

Diversification in upland ecology

After the so-called green revolution, the semi-dwarf varieties of rice supplanted urdbean, mungbean, pigeonpea and many other legumes from the cropping system in the uplands of north-west and north-east plains of India. RWCS usually predominates in the upland ecosystem of IGP. This situation warrants diversification of this crop rotation. In this context, pigeonpea-wheat rotation, wherein deep rooted pigeonpea replaces the water-sucking paddy, may be the ideal choice with respect to profitability and sustainability. A number of early (UPAS 120, Pusa 991, Pusa 992 and PA 16) and extra early (Manak, ICPL 88039, etc) maturing pigeonpea cultivars have been bred that may help stabilize the pigeonpea-wheat rotation (Choudhary and Nadarajan, 2011). Similarly, improved varieties of mungbean (Virat, Samrat, Meha, IPM 02-3, IPM 02- 14, SML 668, SML 832, Pant Mung 5 & 6) and urdbean (Azad Urd 1 & 3, Uttara, IPU 02-43, Pant Urd 31 & 40, WBU 108 & 109) can be fitted in the rainfed mixed or inter- cropping systems involving maize or long-duration pigeonpea in upland ecosystem especially in north India. Another legume which has a very high potential for giving maximum return in upland situation is soybean. Almost all high yielding cultivars of soybean have sympodial pod-bearing habit which results in high yield compared to mungbean and urdbean. Thus, soybean-wheat rotation also holds high promise in such a production system.

Low land ecology

Under low land ecology, farmers frequently encounter waterlogging or submergence condition during the rainy season (July-September) in both north-east and north-west plains. They have no choice but to grow rice as legumes are highly sensitive to waterlogging and partial or complete submergence. However, such pieces of land are usually planted with wheat in the succeeding winter season. There exists ample scope to grow cool season grain legumes instead of wheat. This rice-legume rotation may be more rewarding in terms of nutritional security and soil health sustainability. A number of varieties of chickpea (Pusa 372, Pusa 547, Pusa 1103, Pusa 3043, GNG 1581, JG 11, JG 16, etc), lentil (Pusa Vaibhav, Pusa Masoor 5, HUL 57, KLS 218, IPL 406, IPL 220, etc), field pea (HUDP 15, GDFP 1, Swarna Mukti, etc) and faba bean (Swarna Suraksha and Swarna Gaurav) are available which can be grown after harvest of rice crop with relatively less input resources (fertilizers and irrigation water) as compared to wheat. Diversifying rice-wheat rotation with rice-grain legume system may also lead to sustainable crop intensification in low land ecosystem as cool season legumes usually mature earlier than wheat.

Wetland Ecology

The wetland production ecosystem is usually characterized by prolonged sub mergence from June-July up to the end of November. Such areas (chaurs, mauns and shallow ponds) are usually planted with fox nut (*Euryale ferox* Salisb.). Some progres- sive farmers also take a second aquatic crop 'water chestnut' (*Trapa bispinosa*) after the harvest of fox nut in August/September. Water chestnut gets harvested by the end of December. Thereafter, forage legumes (berseem or lucerne) may be planted to sustain integrated farming system. Out of the eight crop rotations assessed at Research Centre for Makhana (2012-13 to 2014-15), fox nut-water chestnut-berseem rotation has been found highly promising from soil fertility view point.

Diversification of rice-fallow system

Around 11.7 mha area distributed over the north-east, central and coastal peninsular India is occupied under the typical rainfed rice-fallow production system (DAC, 2011). The extensive utilization of rice fallows for pulses cultivation has been mostly restricted due to limited residual soil moisture available to sustain these crops after harvest of rice (Pande *et al*. 2012). Under such a situation, efficient crop management practices and selection of crop and varieties can play a major role. In the north-East plains which experience relatively severe winter, pulse crops such as grass pea, lentil and chickpea may be sown in *paira*/*utera* system. Retention of preceding rice stubble (30 cm) may act as the soil mulch to prevent rapid moisture loss. In case of non-adop- tion of paira/utera system, the succeeding pulse crops should be sown immediately just after harvest of rice following zero or minimum tillage in order to better utilize the residual moisture. In the central zone, grass pea and chick pea could be the major pulse crops. The coastal peninsular zone that is characterized by bimodal rainfall pat- tern during the kharif and mild winter in the succeeding crop season, rice fallows may be cultivated with urdbean and mungbean. However, selection of appropriate pulse varieties will be a key factor under all the aforesaid conditions. The varieties must have early growth vigour, early flowering and early maturity with at least moderate level of tolerance to co-occurring drought and heat stresses (Table 2).

Table 2. List of suitable varieties of pulses for rice-fallows in India

Rice fallows	Crop	Variety
North-east plain zone (Central and eastern UP, Bihar, Jharkhand, Assom, WB and Odisha*)	Chickpea	Pusa 372, Pusa 547, Pusa 3043, GCP 105, JG 14, JG 16, GNG 1581
	Lentil	HUL 57, KLS 218, Pusa Masoor 5, IPL 220
	Grass pea	Ratan, Prateek, Mahateora
Central zone (Madhya Pradesh, Chhatisgarh, Maharashtra)	Chickpea	JG 6, JG 11, JG 14, JG 16, Digvijay
	Lentil	JL 3, IPL 81, Pusa Ageti Masoor, RVL 31
	Grass pea	Ratan, Prateek, Mahateora
Coastal peninsular zone (Andhra Pradesh, Telangana, Tamil Nadu, Karnataka)	Chickpea	JG 11, JG 315, Samrat, ICCC 37
	Urdbean	LBG 709, LBG 752, LBG 787, TU 94-2, ADT 4 & 5, DU 1, COBG 653, TBG 104
	Mungbean	Yadari, Sri Rama, TM 96-2,VBN(Gg) 3, CO(Gg) 8, LGG 407, LGG 450

Source:* Project Coordinators' Reports (MULLaRP; Chickpea);Rice fallow of coastal Odisha can be planted with suitable varieties of Urdbean

Legume as a green manure crop in a cereal-cereal rotation

In RWCS, farmers are left with no choice to fit a grain legume either between rice and wheat or after the late harvest of wheat in both north-east and north-west plains. Since these two crops are components of high input agriculture, continued practice of growing them in succession adversely affects the fertility status and physical properties of soil. In order to replenish the fertility level, it is necessary to fit nitrogen fixing green manure crop in the rotation after wheat. Farmers can grow sunn hemp, dhaincha, subabul, mungbean, cowpea, soybean or even pigeonpea as a green manure crop (Table 3). Most annual legume green manure crops should be terminated up to early flowering stage. This achieves a balance between minimal soil moisture use and maximum N fixation. For drier areas, legume green manure crops should be terminated before the end of June, to allow as much time as possible for soil moisture recharge before the establishment of the next crop. To avoid disease and weed control problems, growing another pulse crop variety before or after a green manure in rotation should be avoided.

Table 3. Biomass production and nitrogen fixed by the green manure crops

Green manure crop	Fresh biomass (t/ha)	Dry biomass (t/ha)	Termination stage (days after sowing)	Amount of nitrogen fixed (kg/ha)
Cowpea	9-10	3-4	40-60	140-150
Pigeonpea	9-10	5-7	45-60	> 45.0
Dhaincha	--	1.5-4	45-50	100-135
Soybean	--	5-7.4	45-60	> 65.0
Sunn hemp	5-19	5.5-6	50-60	108

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Soil and Residue Management in Conservation Agriculture

K.K. Rao, Kirti Saurabh, S. Kumar, Abhishek Kumar Dubey and N. Raju Singh

ICAR-Research Complex for Eastern Region, Patna (Bihar)

India has attained a record food grain production of 264.4 million tonnes in 2013- 14 and hence the crop residues, a by-product of crop production system, has increased-proportionally. Total plant nutrient removal by different crops is significantly higher than nutrients addition through fertilizer in India, causing in continuous soil fertility depletion. Soils of India are generally low in soil organic matter and poor in fertility. This situation leads to multiple nutrient deficiencies in soils of cereal crop production systems. Rice-wheat (RW), rice-rice (RR), pearl millet-wheat (PmW), soybean-wheat (SW), maize-wheat (MW), cotton-wheat (CW), and rice-maize (RM) are the major cereal-based production systems of India. Among these, rice-wheat occupies an area of over 10 million ha (Mha) spread over Indo-Gangetic Plains (IGP), followed by rice- rice (5.89 Mha). Low levels of soil organic matter, appearance of multiple nutrient deficiencies due to their over-mining from soils and poor management and non-recycling of crop residues (CRs), leading to their burning are some of the major reasons for declining crop productivity, particularly in rice-wheat system. Recycling/ retaining crop residue on the soil surface will improve nutrient cycling and, ultimately, soil and environmental quality can be markedly enhanced. Adopting the principles of conservation agriculture (CA) together with best management practices would improve system productivity and overall resource-use efficiency, resulting in a higher profit- ability as well as long-term sustainability of different crops and cropping systems.

Crop Residue Availability in India

It is estimated that, a gross quantity of 686 million tonnes crop residues are available in India on annual basis from 39 crop residues generated by 26 crops (Hiloidhari *et al*. 2014). Out of the total residue produced in India, cereal group (rice, wheat, maize, pearlmillet, barley, small millets, sorghum) contribute the highest amount of 368 million tonnes (54%) followed by sugarcane 111 million tonnes (16%). At individual crop level, rice contributes the highest amount of 154 million tonnes gross residues followed by wheat (131 million tonnes). Gross residue potential is the total amount of residue produced while surplus residue potential is the residue left after any competing uses (such as cattle feed, animal bedding, heating and cooking fuel, organic fertilizer). Considering the surplus portions of residues available from the selected crops, annual national potential is about 234 million tonnes/year, i.e. 34% of gross residue generated in India is available as surplus. Huge amounts of residues are available either for retaining in fields to enhance productivity and fertility of the soil but in many areas of Asia the crop residues produced in rice-based cropping systems have been considered a nuisance by farmers and disposed through burning in fields. Because of large data gap and differences in estimation procedure, precise estimate of biomass availability in India is non-existent and the only statistics that available are on crop production and of forest coverage.

Crop Residue Management and Soil Health

Soils of India are generally low in organic matter content and are being consistently depleted of their limited reserve of nutrients by crops. The quantities of nutrients removed by crops in a cropping system are greater than amount added through fertilizers. Removal of all the straw from crop fields leads to K mining at alarming rates because 80-85% of K absorbed by rice and wheat crops remains in straw. The long-term sustainability of a cropping system depends on its carbon inputs, outputs, and carbon-use efficiency. Long-term straw application will build soil organic matter level and N reserves, and also increase the availability of macro- and micro- nutrients, and influences the microbial population and activity in the soil and subsequent nutrient transformations (Yadvinder Singh *et al*. 2005). Thus, indiscriminate removal of crop residues can adversely impact soil properties, soil organic matter (SOM) dynamics, water and wind erosion and crop production. Many studies from the US indicate that about 30-50% maize stover can be removed for alternative uses without causing severe negative impacts on soil (Graham *et al*. 2007). However, it is still uncertain where, when and how much residue can be removed sustainably.

Cereal residue retained at soil surface reduces soil erosion by buffering the impact of raindrops and reducing wind speed at the soil surface. Crop residues increase the water available in the soil for plant use by enhancing rainfall infiltration and reducing evaporation losses. Retention of cereal residues on soil surface or their incorporation in the long-term increases organic matter inputs into the soil, reduces the loss of plant nutrients, and increases nutrient-holding capacity and soil biological activity. The loss of nutrients from residue removal depends on residue type, amount of residue removed, climate, soil organic matter, rate of residue decomposition, tillage, and other management practices. Residue removal will have a marked effect on soil productivity in a short-term on soils poor in organic matter.

Residues retention improves soil physical (structure, infiltration rate, plant available water capacity), chemical (nutrient cycling, cation-exchange capacity, soil reaction), and biological (SOC sequestration, microbial biomass C, activity and species diversity of soil biota) quality (Bijay Singh *et al*. 2008; Yadvinder Singh *et al*. 2005). Hydraulic conductivity and infiltration rate (final infiltration and the total infiltration) are higher in residue retention compared to conventional tillage due to the larger macropore conductivity as a result of the increased number of biopores that is commonly observed. The retention of rice residue in wheat may help reduce the adverse effects of hard pan in the rice-wheat system and benefit the wheat crop (Yadvinder Singh and Sidhu, 2004).

Crop residues are also known to enhance nitrogen fixation in soil by asymbiotic bacteria. Mulching provides better environment for the growth and activity of micro-organisms which can help in improving biological nitrogen fixation owing to increase in nodulation in leguminous crops. Crop-residue retention increases the population of aerobic bacteria by 5-10 times and of fungi by 1.5-11 times compared with removal or burning of residue (Beri *et al*. 1995). Various enzymatic activities such as nitrogenase, dehydrogenase and phosphatase are increased over residue removal treatment. Rates of C sequestration are highly influenced by soil type and climate. The critical level of C-input requirement for maintaining soil organic carbon at the antecedent level has been calculated as 2.47 t/ha/year for rice-based systems (Srinivasarao *et al*. 2013). Gupta *et al.* (2007) reported that an incorporation of crop residues increases inorganic andorganic P fractions, reduces P sorption, and increases P releaseAbout 50-80% of micronutrient cations (Zn, Fe, Cu and Mn) taken up by rice and wheat crops can be recycled through incorporated residue. Crop-residue management influences avail- ability of micronutrients, such as zinc and iron in rice (Yadvinder-Singh *et al*. 2005).

Crop Residue as a Source of Plant Nutrients

Crop residues are good sources of plant nutrients and are the primary source of organic matter (as C constitutes more than 40% of the total dry biomass) added to the soil, and constitute important component for the stability of agricultural ecosystems. They can play an important role in the cycling of nutrients despite the dominant role of chemical fertilizers in crop production. About 30-40% of the N, 25-35% of the P, 70- 85% of the K and 35-45% of the S absorbed by cereals remain in the vegetative parts at maturity. Typical amounts of nutrients in rice straw at harvesting are 5-8 kg N, 0.7-1.2 kg P, 15-25 kg K, 0.5-1 kg S, 3-4 kg Ca and 1-3 mg kg per tonne of straw on a dry weight basis. Rice straw contains 50-100% higher concentration of K than wheat straw. Maize stover contains more N and K than wheat straw. Besides NPK, 1 tonne of rice and wheat residues contain about 9-11 kg S, 100 g Zn, 777 g Fe and 745 g Mn. Residues of 7 leading crops in all the continents contained about 18.8 million tonnes of N, 2.9 million tonnes of P, and 24.0 million tonnes of K. Nutrient concentration in crop residues depends on the soil conditions, crop management, variety, season etc. Removal of crop residues for various off-farm purposes (except for composting and use as fodder), potentially have adverse effects on nutrient supply representing an economic loss in the short term, but it will have a long-term negative effect on soil quality, water quality, and agriculture sustainability as demonstrated by many studies (Bijay Singh *et al*. 2008). In order to replace harvested residue nutrients lost due to resi- due removal, additional nutrient (NPK) fertilization will be needed in the long-term. Just like fertilizers, nutrients released from crop residues into the soil are susceptible to losses such as leaching, denitrification, immobilization and fixation. The efficiency of nutrient uptake by crops from fertilizers or residue release is generally thought to be similar (for example, 30-50%). The method of residue placement (buried by tillage or left on the surface in no tillage) can impact nutrient cycling and efficiency.

Burning of Crop Residue: A National Issue

The increasing constraints of labour and time under intensive agriculture have led to the adoption of mechanized farming in rice-based cropping systems leaving large amounts of crop residues in the fields. Of the total crop residues burned globally, cur- rently India contributes 33.6%.One tonne of crop residue on burning releases 1,515 kg CO_2, 92 kg CO, 3.83 kg NOx, 0.4 kg SO_2, 2.7 kg CH_4, and 15.7 kg non-methane volatile organic compounds (Andreae and Merlet, 2001). These gases and aerosols consist- ing of carbonaceous matter lead to adverse impacts on human health in addition to contributing to global climate change. Estimated emission from open-field burning of crop residue and assuming 25% of the available residue is burned in the field, the estimated emissions in 2000 from open-field burning of rice and wheat straw in India were 110 Gg CH_4, 2,306 Gg CO, 2.3 Gg N_2O, and 84 GgNOx (Gupta *et al*. 2004).

Crop Residue Management Options

In-situ incorporation

While soil incorporation of crop residues is beneficial in recycling nutrients, ploughing requires energy and time, leads to temporary immobilization of nutrients (N), and the high C:N ratio needs to be corrected by applying extra fertilizer N at the time of residue incorporation (Yadvinder Singh *et al*. 2005). A crop grown im- mediately after the incorporation of residues suffers from N deficiency caused by microbial immobilization of soil and fertilizer N in a short-term. The duration of net N immobilization and the net supply of N from crop residues to a subsequent crop depend on decomposition period prior to planting next crop, residue quality, and soil environmental conditions. Generally, crop yields decrease with the incorpora- tion of cereal residues immediately before planting of the next crop over the residue removal or burning (Beri *et al*. 1995). Rice straw can be managed successfully *in-situ* by allowing sufficient time (10-20 days) between its incorporation and sowing of the wheat crop to avoid N deficiency due to N immobilization (Yadvinder Singh *et al*. 2005). However, incorporating rice residue before wheat planting is challenging for farmers because of the short interval between rice harvest and wheat planting and it is costly. The practice of rice-residue incorporation before wheat planting can also delay sowing by 2-3 weeks.

In-situ mulching

Rice-wheat based systems

Emerging crop-residue management option in the IGP to avoid burning is to mulch with rice straw in no-till (NT) wheat and other crops. The loose rice residues generated during combine harvesting hamper no till seeding for the subsequent wheat crop due to straw accumulation in the seed drill furrow openers and poor traction of the seed-metering drive wheel due to the presence of loose straw. Until recently, the availability of suitable machinery was a major constraint to direct drilling into heavy rice stubbles. The development of a new generation of machines for seeding into rice residues commenced with the design and development of the Happy seeder. Happy seeder works well for direct drilling in standing as well as loose residues, provided the residues are spread uniformly.

Conservation Agriculture and Crop Residue Management on Surface

CA-based crop management technologies, such as NT with residue retention and judicious crop rotations, are gaining more attention in recent years with the rising concern over degradation of natural resources, mainly soil and water, and to offset the production costs. Furthermore, intensive tillage systems results in decrease in soil organic matter due to acceleration of the oxidation and breakdown of organic matter and ultimately degradation of soil properties. To harness the full potential of conservation agriculture in rice-wheat system not only residue will have to be used as soil surface mulch in wheat but also rice will have to be brought under no-till. The potential benefits of NT can be fully realized only when it is practiced continuously and soil surface should remain covered at least 30% by previous crop residues. Agronomic productivity and profitability are high with use of crop residues in conjunction with no-tillage in conservation agriculture (Jat *et al*. 2014).

Managing wheat straw in direct-seeded rice and the rice straw in wheat increased system productivity and water use efficiency in the rice-wheat system under permanent NT system (Gathala *et al*. 2013). Removing 50-60% of cereal residues for animal feeding, remaining portion could still be used as mulch in ZT or permanent raised bed systems for saving irrigation water and improving the water productivity. There is an obvious need to know the minimum straw load needed for different crops and cropping systems on different soil types and agro-ecological region of the country. Ensuring good seed germination and crop-stand establishment are major challenges to be addressed with conservation agriculture and crop-residue management. Three machines (double disc opener drill, Turbo Happy seeder, rotary powered disc drill) are now available that are capable of seeding into full, surface retained rice residues.

Summary

Crop-residues offer a sustainable and ecologically sound substitutions for meeting the crop nutrient requirement, and improving soil and environmental quality. Rice residue can be incorporated into the soil 10-20 days before sowing of following wheat using suitable machinery without any adverse effect on the crop. Latest developments in machinery (Turbo Happy seeder) letting no-till sowing of wheat with rice residue as surface mulch, while maintaining yield, decreases tillage costs and saves time, avoids the need for burning. Nutrient management is more complex with crop-residue management because of higher residue levels and reduced options with regard to method and timing of nutrient applications. In fact, there is a need to develop complete package of practices (fertilizer, irrigation, weed control, pest management, etc.) for crop-residue management systems. Long-term studies involving multidisciplinary approaches are needed to study different issues associated with crop-residue management.

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Issues and constraints for doubling farmers' income in Indian perspective

Naresh Chandra

ICAR-Research Complex for Eastern Region, Patna, Bihar-800014

It is a general knowledge that in India, farmers have been suffering from perennial problem of low income and lower level of livelihood for long. It is also quite obvious that prosperity of farmers is a function of amount of money and asset in their possession. However, they can have more money/asset only when their occupation of agriculture becomes more productive and also profitable. Earlier in the distant past, the expectation of 'profit' from agriculture used to be a non-issue. It is the issue of food sufficiency/ security, and at the most farmers' livelihood improvement through yield augmentation which used to be the talking points for agriculture. However, recently it has been now widely believed and frequently expressed by the farming community and some concerned non-farming entities as well at various fora that occupation of traditional agriculture, source of livelihood for about 60% of Indian population, is no longer that profitable and resultantly losing its charm. As a matter of fact, this occupation seems to suffer from a syndrome of high input cost and low output return either owing to low yield or low output price, making it less profitable in average sense, but not unprofitable, as sometimes stated loosely by someone. Therefore, farmers in general and rural youths in particular, having expensive/fashionable needs to fulfill and aspirational goals and lifestyles to follow, are not getting attracted and enthused to undertake the work of farming. Rather, they are gradually getting disenchanted with and jettisoning this occupation, which used to be the mainstay of their livelihood earlier, because of its, inter alia, too low profitability and employment potential to meet their growing household requirements, and thus sustain their livelihood with reasonable dignity.

In order to enhance agricultural productivity/profitability, the option of adoption of modern agricultural technology is already there from the very beginning, and the same has got adequate, direct or indirect support of the Government, NGOs and other concerned agencies in various ways aimed at improving socio-economic conditions of the farmers. However, considering various types of constraints including those of labour, capital, irrigation water, farming risks and uncertainties, etc. confronted by farmers in food production and sale processes, having adverse impact on farm income, adoption of modern agricultural production technology as such, though claimed to be cost reducing and yield/income augmenting, is left with limited capacity to enhance farm income, if farmers choose to remain confined to their operation in agricultural production sector alone.

This has resulted in their gradual relative marginalization, compelling them to partially or fully leave this occupation and migrate to some other places in search of economically attractive avenues yielding greater returns needed to satisfy their increasingly growing needs, via exposure and demonstration effect, caused by techno-information led changing times towards consumerism and materialism witnessing onslaught of plethora of modern and fancy technological consumer goods in the market**.** However, it would be also worthwhile to mention here that contrary to the popular belief and findings of several studies, as reported elsewhere, migration of rural people as such should not be necessarily viewed as a distressed and inauspicious phenomenon. Many times, owing to inadequate availability of reliable, sustainable and quality physical, economic and social rural infrastructure required for their aspirational growth and development, it also takes place voluntarily in search of gainful employment and better quality of livelihood.

All these lead to raise a very serious and pertinent question how working in agriculture sector can be made attractive, profitable, and employment augmenting so as to meet the rising expectations of the farming community, and retain them in this very occupation of production of food required for their own families and also for the growing population of the nation.

The answer lies in adoption of multi-pronged approach to deal with this pressing problem of low agricultural profitability resulting into waning charm of agriculture among rural youths. The fact is that there is no problem which is insoluble. Every problem has some or the other solution and the same can be dealt with effectively sooner or later, if we genuinely want to solve it. If a problem has no solution, then it is not at all a problem. And in that case, we have to develop the habit of living and adjusting with the problem itself. Many times, it is also witnessed that we as a society tend to develop apathetic attitude towards honestly solving the problem itself, probably because of some vested interests in continuation of the problem.

So far as approaches/strategies to deal with low agricultural profitability are concerned, these should be adopted and executed seriously from both government and farmers' sides on equal footing, and these from both the sides should be considered equally important. Non-seriousness and laxity from either side may not yield desired result. Sustainable development of an individual/economy is not a unilateral process. It has always been a bilateral phenomenon, developer (government) and developee (farmers) being two parties, working together in symbiosis. Indifference from either side is detrimental to solution to the problem of low agricultural profitability. Therefore, realizing the fact and significance of bilateralism of efforts towards agricultural development, farmers must not remain in confusion that it is only the government's responsibility to meet their expectation of making agriculture profitable and improve their livelihood, but the onus lies equally on them also to make it more productive and profitable.

In the light of above backdrop, given below are some points pertaining to issues and constraints including solutions in an integrated manner for enhancing farmers' income.

1. It is said that farmers' economic condition is not good. But who is a farmer? Is anyone owning land and doing farming himself, or is anyone simply holding an agricultural piece of land and giving that on lease, and acting as absentee landlord, doing sharecropping, contract farming or working as agricultural labourer is a farmer? Can a politician/film star/celebrity/official/businessman or any other person engaged in non-agricultural occupation having cultivable land in a village be called a farmer? Revisiting the concept of the term "farmer" and redefining it afresh are needed for better targeting of the real farmer beneficiaries of Govt. policies and programmes/schemes.

2. Farmers, particularly better-off and aware ones, in order to obtain more and more advantage from Govt. policies and programmes/schemes usually tend to scale down their economic conditions as pathetic and rue their fate because of continued apathy of the Govt. towards them. But as a matter of fact, though farmers also appear to be partly responsible for their own condition of under-development and misery, they hardly tend to consider themselves also at fault for this. In the wake of this, therefore, farmers need to be educated/trained on the importance of their own personal role/effort and attitude in their own development, and categorically sensitized through mass media or any other means on the real issue that the "Sustainable development of an individual/economy is not a unilateral, but strictly a bilateral phenomenon**.** In fact, it is a function of, *inter alia*, joint aspiration for development together with sincere and sustained endeavour for the same by both, the developer (Govt.) and the developee (farmers), working together in symbiosis. Laxity on either part tends to derail/scuttle the process of sustainable development. The process of development cannot be broadbased, inclusive and sustainable, unless it is driven by both demand and supply".
3. Preparation of National Agricultural Land Use Plan taking comprehensively into account all kinds of backward and forward linkages with an eye on harnessing the synergy and comparative yield/income advantage of regional relative strengths, weaknesses, opportunities and threats (SWOT) in order to optimize locally available resource use efficiency, and also bring about effective implementation of the Plan.
4. Undertaking aggressive mass media advertisement campaign of agricultural development programmes/plans/schemes with full details, so that farmers, particularly ignorant small holders, may be adequately aware of and take advantage of them.
5. Taking up effective steps for addressing hitherto unresolved, but very crucial issues of agricultural land consolidation and other agrarian reform measures, where the same has not been undertaken**,** conducive to the accelerated growth of agriculture and its productivity on a sustainable basis.
6. Linking every village with all-weather quality motorable road to facilitate efficient input/technology procurement and output disposal in a profitable manner with ease and speed. This also has multiplier effect on the growth of economy in general and agrarian economy in particular.
7. Giving impetus to public capital investment for building/renovation and upkeep of agri-infrastructure such as canals, check-dams, water conservation reservoirs, electricity supply, technology extension network/institutions, etc. having multiplier effect on the rural economy.
8. Strengthening KVKs by making provision of adequate funds for building of requisite infrastructure, and filling up vacant posts by qualified personnel through fair selection procedure. Opening more number of KVKs and extending them to Block level, and integrating all programmes related to agricultural technology extension under a single umbrella of KVK to avoid duplicacy.
9. Farmers should be made to understand and undergo a paradigm shift from traditional "agriculture as a way of living" approach to "agriculture as a way of earning"

approach. Setting up of Farm Training Institution (FTI) in every district on the pattern of ITI to impart practical training on “modern and profitable agriculture” and award diploma in scientific agro-entrepreneurship--a crucial and indispensable characteristic to achieve something significant in life..

10. Credit being a crucial input in modern capital intensive agriculture, banks should be asked officially to organize Agricultural Loan Mela periodically (say every quarter) in the rural hinterland for on-the-spot loan application, processing and delivery, and also to enhance awareness among farmers about role of banks and credit in yield/profit augmenting modern agriculture, lending/borrowing ease, velocity and transparency. This will help lighten the farmers’ informal loan burden due to usurious rate of interest charged by local moneylenders and traders. However, farmers must also be educated and sensitized to the disadvantages of non-repayment of loan, and also the importance and advantages of sincere repayment, which they normally do not believe in and practice (essential for their long term sustainable development), hoping that the same would be waived off sooner or later by the politically sensitive Govt. before general election time.

11. Efforts should be made towards building of quality and sustainable infrastructure for value addition and wastage/loss minimization resulting from post-harvest mishandling/inefficient handling of farm produce, and promotion of agro-industrialization in PPP mode--a provider of forward linkage and key to inclusive and sustainable agricultural development in the long run.

12. Proper, fair and timely arrangement of procurement of farmers’ produce at procurement price announced by central Govt., and also further decentralization of procurement process for farmers’ convenience and speedy procurement.

13. Development of market linkage for farmers’ produce and also modern marketing yard with hi-tech facilities in each district where farmers can directly sell their produce to buyers at mutually agreed price, and consequently, get rid of clutches of middlemen who exploit them by offering as less price of produce as possible, making their enterprise of agricultural production relatively less remunerative or even unremunerative.

14. Making available timely, adequate, quality, affordable agro-inputs such as seed, planting materials, agro-chemicals, irrigation water, etc and capital, market, infrastructure, training and technology to farmers. Towards this end, the Govt. should set up a vibrant agricultural input and service delivery system in each Block of the state.

15. Taking effective and expeditious steps to control market malpractices/manipulations such as input hoarding, black marketing, profiteering, and supply of spurious agro-inputs, etc. causing hassle and economic harm to farmers and environment as well.

16. Appointing adequate number of staff qualified from agriculture background, providing them required facilities and necessary benefits, making them abreast of their role in the wake of latest development in agricultural technology by carrying out periodic capacity building and sensitization programmes on their role, importance and indispensability for the noble cause of development and welfare of farming

community, sense of commitment, discipline, work culture, service delivery, etc. through training/workshop, and making policies in participatory mode aimed at encouraging devotion of more time to field rather than office by agricultural development officials. For this, a Staff Training Centre should be opened at state level, engaging quality faculty of resource persons.

17. Keeping district-wise executable (workable) contingency plan with all logistic support ready to deal with any unforeseen situation arising mainly from drought (sub-normal or erratic rainfall) and flood, and subsequent mitigation of misery and devastation.

18. Keeping effort/investment on agricultural research pointedly linked with farmers' genuine problems. For this, "Agricultural Problem-Solution" interface meeting among key stakeholders such as representatives of farming community, research institutions and those of state line departments on a specified interval should be held on an institutionalized basis, so as to understand and appreciate new emerging problems of farming.

19. Appointing independent monitoring agency with specific task to identify critical bottlenecks and advise suitable ameliorative changes to be made in the ongoing agricultural development programmes/projects/ schemes/policies to make them more broadbased, inclusive and effective.

20. Laying focus on development of marketable rural skills, their upgradation and entrepreneurship, and linking the skill obtainers with banks for procurement of capital required for undertaking the skill based enterprise, if needed.

21. Taking utmost care while targeting genuine beneficiaries of a policy/ programme implementation. It has been reported that in many cases, in connivance with the programme implementation officials, ineligible persons happen to be too shrewd and manipulative to take advantage of the programme meant for the needy, thus depriving them (eligible persons) of programme benefits.

22. Controlling post harvest losses of food by building adequate number of storage and warehousing facilities. Food security for the growing population can also be achieved by reducing the post harvest losses resulting into more availability of food.

23. Innovative planning and accelerated execution of population control measures. For achieving food security, one can strategize to either increase the availability or access of food or decrease the number of mouths/stomachs. This will enhance the livelihood and per capita income of farm families.

24. In a nutshell, we need to have an administrative framework which ensures effective governance, convergence and coordination between various line departments. The Govt. has to be proactive and sustainably serious for and committed to agricultural and rural development, and hence it should accord adequate priority to creating and providing an enabling environment for the growth of agriculture and farmers' income--the primary sector of the economy-failing which the scope of growth of other contingent sectors also may be jeopardized, and thus that of overall economy will remain a far cry.

Disease management in major field crops

Abhishek Kumar Dubey, K. K. Rao, Santosh Kumar, Manisha Tamta, S.K. Dwivedi, Rakesh Kumar, K. Saurabh and J.S. Mishra

ICAR Research Complex for Eastern region, Patna-800014

Plant disease is an impairment of the normal state of a plant which modifies or interrupts its vital functions. The prevalence of plant diseases vary from season to season, depending on the crops and varieties grown, presence of the pathogen and environmental conditions.Crop yield loss from diseases may result in starvation, especially in countries where access to disease-control methods is limited and annual losses of upto 50 percent are not uncommon for major crops and sometimes losses are much greater, producing catastrophic effect. Some major disease outbreaks have led to famines and mass migrations in past. The devastating outbreak of late blight of potato in Ireland in 1845 brought about the Great Famine that caused starvation, death, and mass migration. Approximately one million died of starvation or famine-related illness, and 1.5 million migrated to other countries. In 1943, Bengal famine cause by rice brown spot about 2 million people died of starvation and other diseases aggravated by malnutrition. To meet the food demands of increasing human population, agricultural production is being augmented through changed agronomic practices and use of new crop varieties having narrow genetic base over large areas which is also a reason of disease outbreak. The world is also experiencing one of its regular climate change cycles which influences the environment on micro to macro scales that range from microclimate to global and hence affects the plant disease epidemics (Garrettt,2006). The classic plant disease epidemic triangle includes interactions between plant hosts, pathogens and environment. Integrated disease management is a multidisciplinary approach that seems promising to manage diseases effectively by integration of cultural, physical, biological and chemical strategies (Kumar, 2014). For the effective and economical control, knowledge of following aspects of disease development is essential.

1. Identification of the cause of the disease
2. Mode of perennation and dissemination of the infectious agent of the disease
3. Host- pathogen interaction and mode of secondary spread
4. Effect of environment on pathogenesis

The conventional approach to manage the disease involves the immunization and prophylaxis

Immunization: It includes

a. Induction of resistance by genetic manipulation and systemic acquired resistance

b. Chemotherapy which involves use of systemic fungicide and antibiotics

Prophylaxis measures: It includes

a. Legislation –quarantine, seed inspection and certification

b. Protection- using chemical and cultural method

c. Eradication- crop rotation, sanitation, removal of collateral and alternate host and chemical

d. Avoidance- choice of geographical area, selection of field, time of planting, disease escaping varieties and selection of planting material

Different components of integrated disease management

1. Cultural method:

Cultural methods of disease management may be classified as pre-planting and post planting cultural methods

A. Pre-planting Cultural Practices

a. Deep summer ploughing

Deep summer ploughing leads to exposure of pathogen propagules to high temperatures and physical killing of the pathogen. Summer deep ploughing and covering field with plastic mulches increase the temperature of soil resulting in death of pathogens. It is also very effective in reducing populations of nematodes and increasing crop yield (Mathur et al., 1987).

b. Crop rotation

Cultivation on same field year after year results in the enrichment of pathogen populations. So crop rotation with unrelated crops is very effective method to manage soil borne diseases (Katan, 2003).

c. Planting on a raised bed

In poorly drained soils, this practice is very effective.It is helpful in preventing certain diseases such as Southern blight. This practice is advisable for growing some leguminous crops.

d. Flooding

The harmful effect on soil borne pathogen may be related to lack of O2, increased CO2 or various microbial activities under anaerobic conditions like production of toxic substances to the pathogen (Bruehl, 1987). Flooding results in high CO2 content in the flooded soil, CO2 stimulates germination of conidia but prevents the formation of chlamydospores so that the fungus dies out when the organic matter is exhausted. Management of Panama wilt disease of bananas caused by *F. oxysporum f. sp. Cubense*is a classical example of disease management by flooding (Stover, 1962). Rice blast (*M. oryzae*) is less severe on flooded paddy rice than on upland or non-irrigated rice because fewer hours of dew occur in paddy than in upland rice

e. Fire and flaming

Hardison (1976) defined this technique as thermo sanitation and described many examples of diseases management by fire and flaming. The basic idea behind use of Fire and flamingis to achieve thermal killing of the pathogens' resting structures which is done by burning the dry plant residues in the field. Burning of rice stubble and straw is common practice throughout the world. However burning of crop residue causes serious environmental impact. Recently air quality over Delhi region was found to be severely affected due to burning of crop residue in western region. So Fire and flaming practices should be avoided.

f. Sanitation

The principal aims of sanitation are to prevent the introduction of inoculum into the field or eliminate the inoculum that is already present in field (Palti, 1981). Weeds around field act as pathogen reservoir during the off season or may play role of alternate host for pathogen and when main crops come in field they act as source of inoculum for disease occurrence. Volunteer plants present in field also act as source of inoculum. So previous year crop residue, volunteer plant and weeds should be removed.

g. Time of seeding

Time of sowing also play important role in disease avoidance. Delayed planting of wheat will help escape the chances of wheat streak mosaic virus. Early spring planting of cotton may effectively help escape cotton root rot.

h. Intercropping

It is practice of growing a crop or crops between the rows of another crop. The intervening plants pose physical barriers to the dissemination of aerial pathogens or their vectors

i. Others- Depth of sowing, Crop density, direction of sowing also influence disease incidence

B. Post-planting cultural practices:

Post planting cultural practices includes

a. Irrigation and water management,

Some pathogens require high moisture content in soil while some are favoured by dry conditions. Water logging condition in field results in severe soil borne pathogen infection. It alters the moisture content of the soil and consequently influences its aeration and temperature and these in turn affect the incidence of diseases through their impact on biotic and abiotic processes in the soil or foliage. Irrigation can have a major influence on the spread of some pathogens and on disease development.

b. Roguing of diseased plants

Removal of diseased plant reduces the spread of a destructive disease. Virus diseases are examples where roguing is worthy of consideration.

c. Fertilizer usage

Fertilizer applications and crop nutrition, soil nutrient status may influence the susceptibility of plants to attack by pathogens. In general, high nitrogen use enhances foliage disease development. Potash on the other hand reduces disease development when it is in balance with other elements.

d. Trap and decoy crops

Trap (or catch) crops are susceptible plants. The pathogens infect the crop which must be destroyed before the life cycles of the pathogens are complete. Decoy crops stimulate the germination of resting structures or seeds of other pathogens, but the pathogens are unable to establish a compatible relationship with the decoy crop host and eventually die.

2. Physical Methods

Physical Methods in Management of Plant Diseases are Eco-friendly innovative. This method includes the physical agents like hotwater or hot air or steam to eliminate the seed or soil borne infection especially internally seed-borne diseases like loose smut of wheat. Physical methods are used for reduction or elimination of primary inoculums that may be present in seed or planting material:

a. Hot Water Treatment of seed

Hot water treatment is widely used for the control of seed-borne pathogens. Eg. Treatment of wheat seed at 52°C for 10 minutes for control of loose smut or 55°C for 10 min for Pearl millet Downy mildew, 54 °C for 8 hr for Red rot of sugarcane

b. Hot Air Treatment of seed

It is less injurious and easy to operate but less effective as compared to hot water treatment. Singh (1973) claimed complete control of red rot in some varieties of sugarcane by hot air treatment of 54ºC for 8 hours. Similarly, grassy shoot disease of sugarcane has been controlled by hot air at 54ºC for 8 hours (Singh, 1968)

c. Steam and Aerated Steam

The use of aerated steam is safer than hot water and more effective than hot air in controlling seed borne diseases. It is widely used in managing sugarcane diseases. As a gas, it moves readily through soil and on condensation into liquid, they release much more latent heat. Steam is passed through perforated pipes at a depth of 15 cm to sterilize the upper layers of soil. It is mostly practiced under glass house and green house conditions.

d. Solar Heat Treatment

This technique is widely used in India to eliminate the pathogen of loose smut of wheat. Luthra in 1951, devised this method to eliminate the seed borne infection of *Ustilago tritici*. In this method, the seeds are soaked in cold water for 4 hours in the forenoon followed by drying the seeds in hot sun for four hours in the afternoon on a bright summer day.

e. Soil Solarization

In this management practice, the solar energy is preserved with the help of transparent polyethylene sheet to increase soil temperature (10-15°C above normal temperature) enough to kill the most of the soil-borne pathogens and weeds also (Akhtar, *et al.,* 2008). Many fungal diseases viz., damping-off, root rots, wilts and blights caused by *Pythium* spp., *Phytophthora* spp., *Fusarium* spp., *S. rolfsii*, *R. solani*, *Sclerotinia sclerotoirum* have been successfully managed by soil Solarization.

f. Drying Stored Grains

In presence of sufficient moisture, a variety of microflora already accompanying harvested grains cause decay. Such decay, however, can be avoided if seeds are harvested when properly mature and then allowed to dry in the air or are exposed to sun. Maize downy mildew pathogen is seedborne. If the maize seeds are properly sun dried, the inoculum gets inactivated.

3. Use of Biocontrol

Biological control is nothing but ecological management of community of organisms. It involves harnessing disease-suppressive microorganisms to improve plant health. Disease suppression by use of biological agents is the sustained manifestation of interactions among the plant (host), the pathogen, the biocontrol agent (antagonist), the microbial community on and around the plant and the physical environment (Chandrashekara, 2012).

Mechanisms of biological control include **Direct Antagonism (**Hyperparasitism/predation**), Mixed-antagonism (**Antibiotics, Lytic enzymes, unregulated waste products, Physical/chemical interference,**) Indirect antagonism (**Competition and Induction of host resistance**).** *Trichoderma* and *Pseudomonas* based bioformulations are mostly used in soil borne disease management. Biocontrol may be used as seed dressing, seedling treatment, furrows application or field application.

4. Chemical method

Fungicide research has developed a range of products with novel modes of action during the last two decades. Truly novel compounds have been released and have reached an advanced stage of development, which include phenylpyrroles, anilinopyrimidines, strobilurin analogues etc which affects respiration, cell membrane components, protein synthesis, signal transduction and cell mitosis. Plant diseases, which were not managed satisfactorily by the previous traditional fungicides, can now be well managed by the newly developed chemicals which are mostly systemic in nature (Nabi et al., 2017)

5. Modern tool in plant disease management

Various biotechnological tool *viz*.,Mapping of disease resistant gene using DNA marker, marker assisted pyramiding of resistant genes, development of transgenic, application of RNA interference/ post transcriptional gene silencing and other tools are also being used in plant disease management (Kumar 2014).

Some important diseases of major field crops and their management

1. **Rice**
   a. **Brown Spots (*Helminthosporium oryzae*)**

   Management: 1) Use of resistant varieties and disease free seed in healthy soils 2) Sanitation and crop rotation, 3) adopt seed treatment with Carbendazim(12%) + Mancozeb (63%) combination 75 WP @ 2 g/kg 4) spray propiconazole 25 SC @ 0.25% 5) Spray with biocontrol agent like P. fluorescens@ 10g/lit (Talc based bioformulation)

   b. **Rice blast (*Magnaporthe oryzae*)**

   Management: 1) Early planting, 2) Cultivation of resistant varieties, 3) Use of healthy seed, 4) Spray Tricyclazole 75 WP @ 0.6g/litre

   c. **Bacterial blight (*Xanthomonas oryzae*)**

   Management: 1) Cultivation of resistant varieties 2) Avoid field to field irrigation 3) Hot water treatment for 30 min at 52-54°C 4) Seed treatment with streptocycline @1.5 g/10 kg seed 5) Spray streptocycline Sulphate @ 150 PPM. 5) Spray with biocontrol agent like P. fluorescens@ 10g/lit (Talc based bioformulation)

2. **Wheat**

   a. **Wheat rust**

   Management: 1) Grow Resistant cultivars 2)spray plantavax @0.1% 3)Plant early-maturing cultivars

3. **Maize**

   a. **Bacterial Stalk Rot :** *Dickeya zeae*

   Control:1) use resistant varieties 2) avoid water logging

Charcoal-Rot : *Macrophamina phaseolina*

Management: 1) Regular irrigations particularly during flowering time 2) Use resistant varieties 3) Seed treatment with Carbendazim 2g/kg seed

4. **Pigeon Pea**

   a. **Pigeon peawilt : *Fusarium udum***

Management: 1) Practice long term crop rotation 2) rotating pigeon pea with sorghum and tobacco 3) Solarize the field in summer to help reduce inoculums 4) Seed treatment with Thiram2g/kg seed 5) *Trichoderma* @ 5—8 kg/ha (With compost), 4 kg in 1000 kg compost 6) Seed dressing with *Trichoderma* 8 g/kg of seeds along with stickers

5. **Pigeonpea sterility mosaic**

Management: 1) Plant resistant varieties 2) Control mites by spraying 0.1% Oxydemton methyl (Metasystox) 3) Start spraying as soon as first affected plants are seen in the field 4) Destroy volunteer/ratooned plant

6. **Chickpea**
a. **Ascochytablight: *Ascochyta rabiei***

Management: 1) Remove and destroy the infected plant debris in the field 2) Treat the seeds with Thiram 2 g or Carbendazim 2 g or Thiram + Carbendazim at 2 g/kg 3)Exposure of seed at 40-50°C reduced the survival of *A. rabiei* by about 40-70 per cent 4)Spray with Carbendazim at 0.2% 5) Follow crop rotation with cereals.

b. **Root rot: *Rhizoctonia solani***

Management: 1) Treat the seeds with carbendazim or thiram at 2 g/kg or seed pelleting from *Trichoderma viride*at 4 g/kg or*Pseudomonas fluorescens*@ 10 g/kg of seed.

c. **Wilt- *Fusarium oxysporum***

1) Practice long term crop rotation 2) rotating pigeon pea with non host crop 3) Solarize the field in summer to help reduce inoculums 4) Seed treatment with Thiram2g/kg seed 5) *Trichoderma* @ 5—8 kg/ha or Seed dressing with *Trichoderma* 8 g/kg of seeds along with stickers

7. Sugarcane

a. **Red rot of sugarcane: *Colletotrichum falcatum***

Management: 1) Healthy Sett selection 2) Crop rotation with paddy 3) Avoidance of irrigation water from infected field 4)Growing of resistant /tolerant varieties 5)treat the sett with 0.1% carbendazim

b. **Ratoon stunting**

Management:1) Healthy Sett selection 2) Avoidance of ratooning 3) Disinfecting cutting knives with antiseptic solution of 5-15 lysol or 50-70% ethanol or Agallol 4)Hot water treatment 50°C/2hr or 52°C/30 min 4) Grow resistant cultivars

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Mushroom production for doubling the poor and marginal farmers' incomes

Sudarshan Maurya

ICAR-Research Complex for Eastern Region, Farming System Research Centre for Hill and Plateau Region, Ranchi, Jharkhand

Agricultural wastes management is the primary concern in today's world to keep the environment clean. Disposal of agricultural waste of the farmers fields in National Capital Region (NCR) and near by the states likewise Punjab, Haryana and Western Uttar Pradesh by burning of straw causes serious air pollution in New Delhi and NCR. The burning of paddy straw also practiced in the Bihar, Jharkhand and Eastern Uttar Pradesh. To overcome this burning issues can be addressed by generation of wealth from the waste by Mushroom cultivation using agricultural wastes can helps in reducing the risk of environmental pollution as well as it converts good manure after mushroom cultivation as well as it can helps to the farmers for doubling their agricultural income. Mushroom belonging to fungi species, is a nutritious vegetarian delicacy and a good source of high quality protein (20-35 per cent on dry weight basis) as well as good source of quality proteins like lysine, they also contains many vitamins like B- Complex, D3 and mineral rich like iron and calcium, selenium etc., Mushroom is completely fat (cholesterol) and carbohydrates free and also rich in anti–oxidants, anti-cancerous and anti-diabetic properties as well as it has possesses several medicinal properties.

The global mushroom production in 2013-2014 was 35 million tonnes, which is growing at a rate of around 8 percent. China still in leading mushroom producers which contributes 60 per cent of the world production. Other major mushroom producing countries for are Poland, France, Italy, Indonesia and Germany. India with 5 percent contribution ranks eighth in the global mushroom production. The mushroom consumption is mainly concentrated in six countries known as G-6 (USA, Germany, UK, France, Italy and Canada) consuming 85 per cent of world consumption. The varieties of mushroom cultivated internationally are shiitake (22%), button (15%), oyster (19%), black ear mushroom (18%), Flammulina (11%), paddy straw mushroom (5%) and milky/others (10%). India's production, Punjab, Haryana, Himachal Pradesh, Uttar Pradesh, Rajasthan, Maharastra and Jammu & Kashmir are the major mushroom producing States. Punjab, Haryana and Himachal Pradesh account for nearly 80 percent of the country's mushroom production. Punjab is the leading mushroom growing state contributing to 36% of the total production followed by Hariyana (35%), Himanchal Pradesh (9%). In India, mushroom has been a non-traditional cash crop grown indoors, both as a seasonal crop and under the controlled environmental conditions. Button and Shitake mushroom are cultivated in temperate or sub-temperate region while Oyster, milky, paddy straw mushroom is cultivated in the sub-tropical and tropical regions of India. 6-7 crops of button mushroom can be harvested per year under controlled conditions, while for seasonal button mushroom; one or two crop is harvested in a year.

Conversion of agricultural wastes into valuable protein and presents huge potential for generating additional of source income and employment by adopting mushroom cultivation.

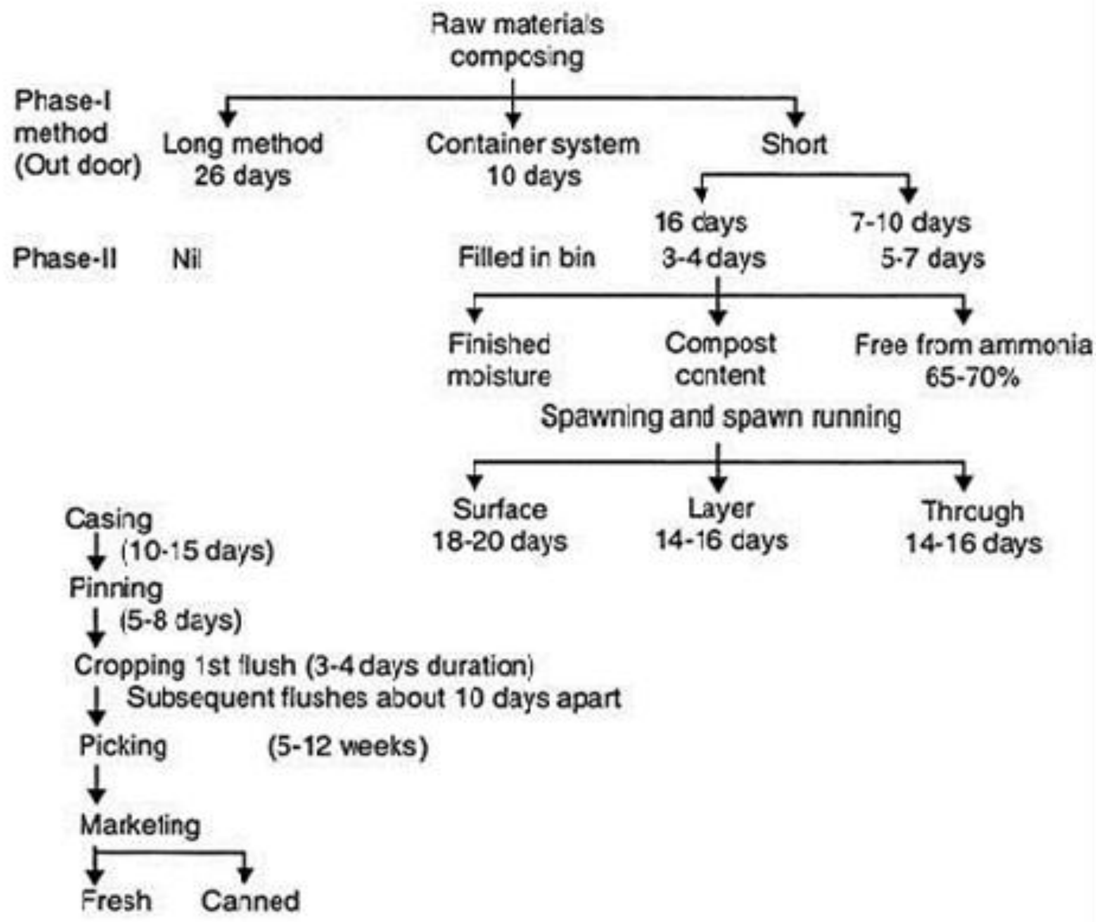
In India, the full potential of mushroom cultivation is yet to be unleashed. ICAR-Research Complex for Eastern Region for Farming System Research Centre, Hill and Plateau Region, Ranchi Jharkhand, Agricultural universities, KVKs of Bihar and Jharkhand regularly providing trainings and advisory for growers and opportunities to mushroom entrepreneurs, unemployment's in rural youth for upliftment of their social livelihood and doubling of farmers income by mushroom cultivation in Eastern Region of India.

Mushroom cultivation now established technologies and government of India, incorporated for promotion of mushroom cultivation in various extension and community development in National programmes like Kisan Kalyan Yojna, Farmers FIRST, Biotech Kisan and Mera Goan Mera Gaurav. It has potential to help in eliminating protein malnutrition among weaker section of the society, primarily dependent on cereals, and offer remunerative rural and urban employment opportunities. Among different agri-based enterprises, mushroom cultivation is one of the best enterprises which has the vast potential to doubling farmers and this enterprise can easily be adopted by any category of farmers irrespective of their landholding size and can be done at cottage and small scale level besides large scale farming. Mushrooms can be grown at a very low cost and in relatively short period as compared to conventional crops. Mushroom cultivation is a strong means to diversify livelihoods and strengthen the resilience of farmers. As we know, agricultural wastes are rich in lignocellulosic components which are difficult to breakdown, but can effectively utilized by the microbes of mushroom viz., *Agaricus* species, *Pleurotous* species *Lentinula edodes Volvallella volvacea* and *Ganoderma* and *Calocybe* species.

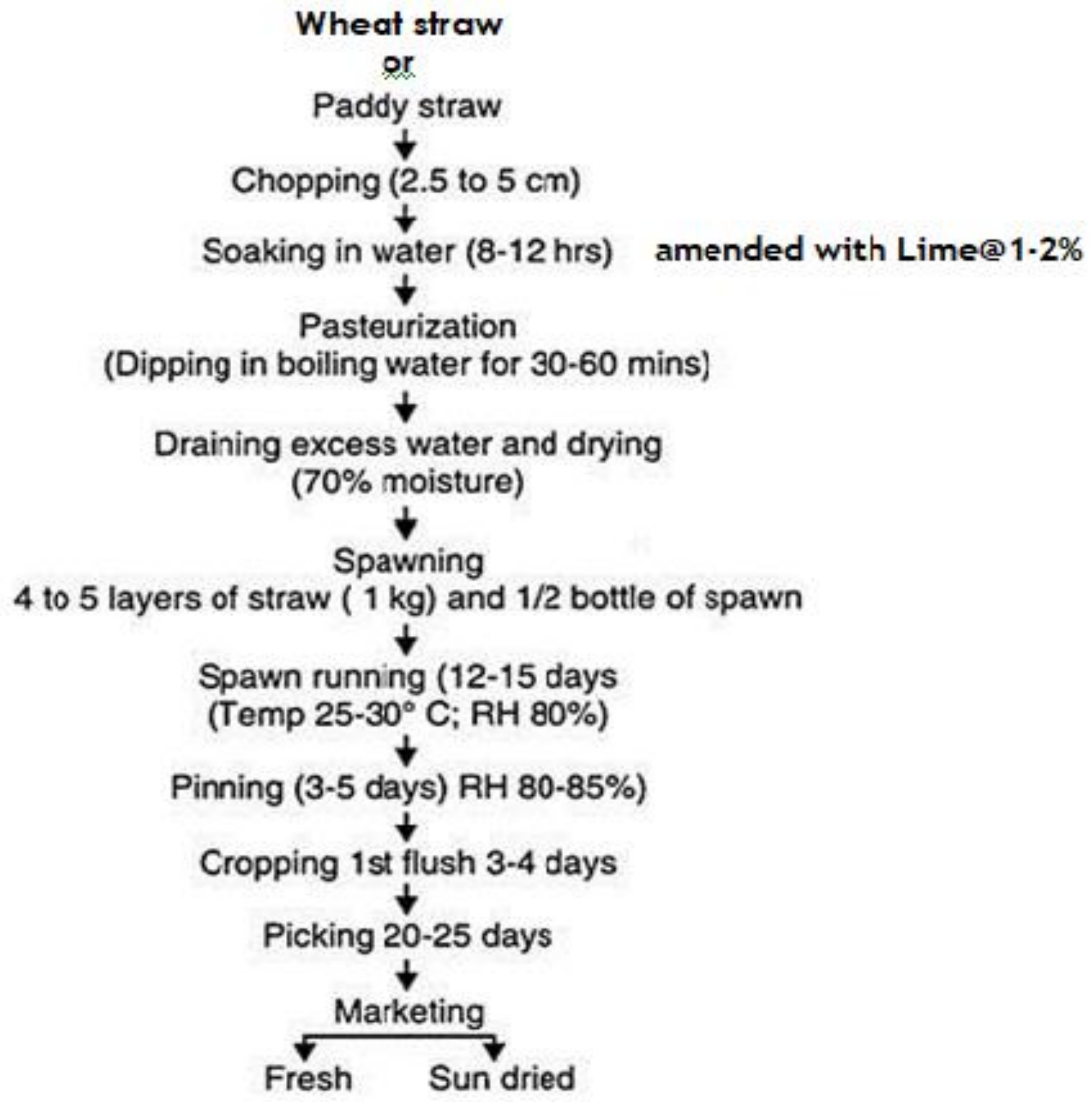
In India, presently five varieties of mushroom are widely cultivated by the growers and entrepreneurs, namely, i). White mushroom (*Agaricus bisporus*) cultivated in natural and controlled condition (Scheme 1. Steps of button mushroom production) ii). Oyster mushroom (*Pleurotus sajor-caju*) (Scheme 2. Steps of Oyster mushroom production). iii). Milky mushroom (*Calocybe indica*) (Scheme 3. Steps of Milky mushroom production) iv). Paddy-straw mushroom (*Volvariella volvacea*) (Scheme 4. Steps of Paddy straw mushroom production) and v). Shitake mushroom.

Oyster mushroom is the third most cultivated edible mushroom around the Globe. It's also very much popular in rural and urban India. In Jharkhand and Bihar its very much popular because of their simplest production technology and availability of huge quantities of agricultural substrates and growers are growing oyster mushrooms in their thatched houses, mud or brick houses in the rural and peri-urban areas of the Jharkhand and Bihar. It has very short production cycle and one production cycle completed in 35-45 days after spawning. The biological efficiency of *Pleurotus* species are more than 70-75% on the basis of their dry weight. It's a very good and reliable rural enterprise of the farmers which have potential to doubling their income because of their huge demand and premium sale price in the locality.

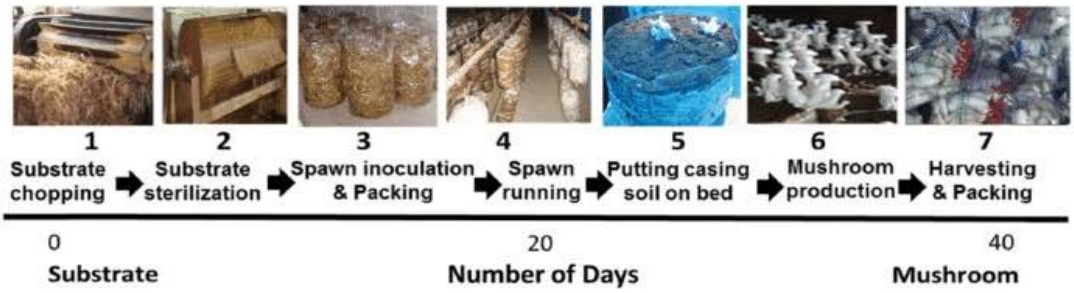
Scheme 1. Button mushroom cultivation



Scheme 2. Oyster mushroom cultivation



Scheme 3. Milky mushroom cultivation



Scheme 4. Paddy straw mushroom

Paddy straw bundles Sterilization ➡ Spawning and covering of substrates ➡ Spawn run ➡ Fruiting

Total life cycle (10-15 days)

Use of Solar energy in agriculture

Atiqur Rahman
ICAR-Research Complex for Eastern Region, Patna (Bihar)

There are about 81% of farms in India are small of size less than 2 ha (CDR, 2015). Smallholders are facing a series of challenges arising from increased competition for land and water, rising farm inputs cost and climate change (Sridhar, 2007).There are the regions, particularly eastern region, which are having the distinction for its fertile land, excellent environment and vast potential of groundwater reserve. However, the food production and productivity is still risky and of low return due to erratic rainfall and lack of assured irrigation (Lobell *et. al*., 2008). To save the crops from long dry spells, farmers are solely dependent on groundwater. In absences of grid electricity farmers are bound to use diesel pumps. The ever-increasing diesel price reduces the profitability and forces the smallholders to migrate the villages in search of labour work. This trend is a threat to food security commitment to the growing populations.

In India, particularly in Eastern region, there are significant numbers of pockets where depth of groundwater level about 10 m bgl (CGWR, 2018) with depth fluctuation decreases to ±2 to ±4 m. This shallow groundwater depth requires no sophisticated equipment for extraction. This very region also blessed with immense solar energy potential. The average incidence solar radiation is ranging between 6.4 – 3.5 kWh/m^2/day. The region is also rich in bright sunshine days. The number of bright sunshine days per year is ranging between 250 - 300 days. These many favourable conditions along with other strategic benefits are making the solar radiation as a year round reliable source of energy for the agricultural uses. However, despite these facts most of the water irrigation structures are diesel operated (Rahman and Bhatt, 2017). This makes the smallholders' irrigation in eastern region under siege. The an energy squeeze is of three dimensional, i.e., the deteriorated farm power supply, embargo on new electricity connections for operating irrigation pumps and many-fold increase in diesel price. This energy squeeze undermines the adoption of broad range precision irrigation technology and therefore the stable and profitable production, as major part of the year remains dry frequent long dry spells during rainy season.

1. Solar energy water pumping and pressurised irrigation

One of the potential uses of solar energy in agriculture could be for groundwater abstraction and operating pressurised irrigation system. In general, farmers traditionally prefer surface irrigation, which requires more energy and resulting into overexploitation of groundwater. Thus, the solar powered water pumping coupled with pressured irrigation system would be the most appropriate options for environmental conservation and protection of overexploitation of groundwater, as combustion of 1 liter of diesel produces 2.7 kg carbon dioxide. In addition to water use efficiency, pressurised irrigation technology also increases fertilizer-use efficiency and crop yield. Since, different crops differ in their water requirement and requirement fluctuates with crop growth; therefore, the choice of crop succession and combination are of decisive importance in sizing of solar pumps. Further, the investment cost of solar pups are high; therefore, uninterrupted crop rotation and continuous crops of high value such as fruit, vegetables, spices etc. are to be grown to reduce system's payback period. Solar water pumping is most effective option particularly in those locations where grid electricity is not available, and if available, there are frequent power cuts and voltage fluctuations.

In solar photo voltaic water pumping system the main components are the solar array, power conditioning unit and the solar tracking mechanism. If water source is a deep well then submersible pumps are preferred. However, if water source is a shallow well then surface pump is a better option. Since, water required to irrigate a given land area depends on number of factors such as nature of crop, crop growth cycle, type and condition of soil, land topography, application efficiency, crop growth cycle etc. which needs quantification of lifted groundwater volume on daily basis and also season wise. Based on this the sizing of solar pumping system can be done. Mathematically, for given water volume, the energy requirement of and the pumping depth can be connected as: E= ρ gVd, where:

E : hydraulic energy in joules (J)
V : required volume water in (m^3)
D : - head of water (m)
ρ : density of water (1000 kg/ m^2), then:

$$E = \frac{9.81 \times V \times d}{1000} \times 1000000 J$$

Or

$$E = \frac{9.81 \times V \times d}{1000} MJ$$

Suppose the daily water requirement is 150 $m^{3,}$ then to lift 150 m^3 of water from a depth of 20 m and if pipe head loss is supposed to be 10% of total head, then required hydraulic energy is:

$$E = 9.81 \times 150 \times 22/1000 = 30.29 \text{ MJ} = 8.41 \text{kWh}$$

If pump is to be operated for number of hour equal to number of peak sunshine hours (say 6 hours), then the flow rate (Q) in liters per second (lps) is:

$$Q = 150 \times 1000/6 \times 3600 = 6.95 \text{lps}$$

The hydraulic power (P), required to lift a given quantity of water depends on the length of time, the pump requires. As power is defined as the rate of doing work or the expending energy, therefore, hydraulic power could be obtained from energy by replacing volume with rate of water flow, i.e.,

$$P = \rho g Q d, \text{watt}$$

or

$$P = 9.81\, Qd = 9.81 \times 6.95 \times 22 \cong 1500 W$$

If η is the efficiency of the pump, then $\text{motorpower} = P/\eta$ then with a typical pump efficiency of 70%, generally pumps have, then the mechanical power required would be of 1500/0.7 = 2150 W. Therefore, the pump size should be of ≈ 3 H.P. To operate this capacity pump 3000 Wp solar array is required. There are some configurations of pumping and delivering water into the fields to irrigate crops. In one configuration, abstracted water is injected directly into a piped irrigation network, into an open channel, or into an overhead tank. The overhead tank serve as an energy store for pressure needed for pressurised irrigation. In another configuration, water is stored in a pond and a surface pump is used to delivers water from pond to irrigation fields. This type of a solar system developed at the research farm of ICAR-Research Complex for Eastern Region, Patna (Fig 1). Under this configuration, abstracted water per day is high compared to previous configuration, as groundwater abstraction unit is already decoupled with field delivery unit and therefore total dynamic head (TDH) is substantially reduced. This type configuration enables farmers to get more water per day even with a low capacity-pump and could extract groundwater even from deeper depth. Here more cropped area are irrigated per day. Further, as delivery unit is abstracting water out of a storage tank; therefore, it encounters very low suction head and therefore offers a very high delivery head. Here, farmers can integrate pressurised irrigation system with the delivery unit and can operate drip as well as sprinklers. Availability of high delivery head at delivery pump also facilitates the farmers to deliver water at distantly located fields or for selling water to neighbouring farmers. The storage pond is serving as reservoir for low insolation period and used for fish farming, duck farming and also growing aquatic crops like chestnut etc. In most of the part of country, the groundwater use is high due to long dry season and frequent dry spells in rainy season. Farmers, in general adopt surface method of irrigation, which leads overexploitation of groundwater. Therefore, awareness and dissemination of solar energy pumping system fitted with pressurised irrigation technologies is required to avoid groundwater depletion and ecosystem damage.

Fig 1: Solar photovoltaic groundwater pumping system model for small farms.

Fig 2: Solar photovoltaic operated drip irrigation.

In Eastern region of India solar radiation intensity is ranging from 6.4– 3.5 kWh/m^2/day and a 3.0 hp solar pump operated by 3000 Wp solar array abstract groundwater between 170-100 m^3/day (Table1). The discharge of a 2.0 hp surface pump delivers water from pond to field is between 2800-12000 lph during 8.30 am to 2.30 pm and offers pressure heads, ranging between 1.0-1.6 kg/cm^2. This much available pressure is sufficient to operate pressurised irrigation system successfully (Fig.2).

Table 4 : Water output from 3HP solar pump and irrigable area

Water yield (m^3) per day on a cloud free day				Irrigable area (m^2) per day on a cloud free day			
Sep-Nov	Dec-Jan	Feb	Mar-June	Sep-Nov	Dec-Jan	Feb	Mar-June
150- 130	100-110	120-140	170-155	2350-2250	1650-1850	2000-2350	2850-2550

2. Solar energy use in fishpond aeration

In general, farmers are culturing fishes in small earthen ponds with very high stocking density. The water of these ponds is very turbid and lead thermal stratification. The thermal stratification and high stocking density lead dissolved oxygen deficiency (Nnaji *et. al*., 2003). In such scenario dissolved oxygen management is crucial, as low oxygen concentration reduces feed intake, lead high feed conversion ratio, slowdowns the growth and increases stress and susceptibility to the diseases (Oakes, 2011). However, aeration through artificial surface agitation is a good method to add atmospheric oxygen into the water column of pond. An aerator could be of a sprayer type, a paddle wheel or an air diffusion type. These aerators require energy for operation. The energy source in terms of fossil fuel is costly and also the unavailability of electricity makes the farmers to content with low productivity. In this scenario solar powered aerator could be an appropriate option. The simplest model of a solar aerator is the sprayer type (Fig. 3). This type of aerator sprays pond water high in to the air and relatively high speed of water jets with surrounding air led breaking of jets into small droplets. This manifold increase in surface area accelerates oxygen diffusion at water droplets-air interface. This aerator increases the dissolved oxygen level of top layer *vis-à-vis* breaks thermal stratifications. The dissolved oxygen level of bottom layers are also increases due to mixing of top oxygenated water with low oxygenated bottom water layers. Though, it is to be operated during day time as no battery bank is involved, but the continuous operations over the day saturate the bottom layers which act as reserves oxygen for the following night.

Fig 3. Spray type solar aerator for fishpond.

3. Solar energy use in dairy management

Rearing high producing dairy cattle is necessary for profit maximization. These high producing dairy cattle needs plenty of water per day, as total water content of the bodies of adult dairy cattle is ranging between 56 – 81 percent of body weight, and loss of even 20 percent of total body water could be fatal (Murphy, 1992). In addition to this, the increase in environmental temperature due to climate change further enhances the water requirement, as cows consume 50 percent more water when thermal heat index is above 80 units (Pennington and Van Devender, 2004). Therefore, maintaining plentiful supply of water is crucial to enhance resilience of dairy cattle against the climate variability. The availability of Thermal environment is a major factor that negatively affects the milk production, hormone management and fertility of dairy cattle in a significant way (Jóźwik *et al*., 2012). The key factors are the ambient temperature, humidity and the wind velocity (Broucek, 2009). High temperature and low humidity dehydrate mucous membranes thus increasing vulnerability to viruses and bacteria. The temperature range of -0.5 to +20°C has little effect on milk production of cow, but temperature range 24 -27°C, is a critical maximum temperature for cows (Broucek, 2009). Therefore, the most challenging task in dairy cattle management is to maintain appropriate microclimate such as air temperature and humidity. Some of the management practices include the use of humidifiers and shade. Solar energy can be utilized in development of humidifiers (Fig4). If we use solar motor to derive a compressor, a good working pressure can be generated for humidification. In general, 100 psi pressure is required for developing fine droplets. For humidification clean water is required to avoid nozzle choking. Further, the washing of cattle shed and cattle bathing are the important activities in dairy management. For such type of activities, pressured water is required. A solar system could be designed for these purposes to convert stored water into a pressured water jet. A backyard pond can be also be used for this purpose (Fig 4).

Fig 4. Solar water supply and humidification of animal shed

In livestock and dairy operations often have substantial air and water heating requirements. Many livestock like pig and poultry are raise in enclosed buildings, therefore, temperature control and air quality is a matter of concern in maintaining animal health and growth. The indoor air need to be replaced regularly to remove moisture, toxic gases, dust etc. For this, solar system of appropriate design could be installed in animal houses.

4. Solar drying

Sun drying of crops and grains is the most widely used application of solar energy. There are simple and least expensive solar drying techniques are available for fast and safe dryings, as open dryings are subject to damage by birds, rodents, wind, and rain and contamination and takes several days to get required moisture level. Available solar crop driers are simple, more effective and hygienic (Fig 4). The basic components of a solar dryer are an enclosure or shed, screened drying racks or trays, and a solar collector. The heated air in the collector moves, by natural convection or a fan, up through the material to be dried. The size of the collector, and rate of airflow needed, depend on the amount of material being dried, moisture content of the material, humidity in the air, and the average amount of solar radiation available during the drying season.

Fig 5. Solar dryer

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Crop diversification for climate resilient farming and food security

Rakesh Kumar, Kirti Saurabh, Manisha Tamta, JS Mishra, and Hansraj Hans
ICAR-Research Complex for Eastern Region Patna-800 014

India has made impressive strides on agricultural front during last three decades. Much of credit for this success should go to several million small farming families that form of Indian agriculture and economy. During last 30 years, India's food-grain production nearly doubled from 102 MT in triennium ending 1973 to nearly 200 MT in triennium ending (TE) 1999. Virtually all of increase in production resulted from yield gains rather than expansion of cultivated area. Availability of food-grains per person increased from 452 gm/capita/day to over 476 gm/capita/day, even as country's population almost doubled, swelling from 548 million to ~1000 million. Increased agricultural productivity and rapid industrial growth in recent years have contributed to a significant reduction in poverty level, from 55% in 1973 to 26% in 1998. Despite impressive growth and development, India is still home to largest number of poor people of world. With ~250 million below the poverty line, an India account for ~1/5th world's poor. About 25% children suffer from serious malnutrition that highest toll in this country. More than 50% of pre-school children and pregnant women are anaemic. The depth of hunger among undernourished is also high. India has high population pressure on land and other resources to meet its food and development needs. Natural resource base of land, water and bio-diversity is under severe pressure. Massive increase in population (despite slowing down of rate of growth) and substantial income growth, demand an extra ~2.5 MT of food grains annually, besides significant increases needed in supply of livestock, fish and horticultural products. Under assumption of 3.5% growth in per capita GDP (low income growth scenario), demand for food-grains (feed, seed, wastage and export) is projected in 2020 at the level of 256 MT comprising 112 MT of rice, 82 MT of wheat, 39 MT of coarse grains and 22 MT of pulses. Demand for sugar, fruits, vegetables, and milk is estimated to grow to a level 33 MT, 77 MT, 136 MT and 116 MT respectively. Future increases in production of cereals and non-cereal agricultural commodities will have essentially achieved through increases in productivity, as possibilities of expansion of area and livestock population are minimal. To meet the projected demand in 2020, country must attain a per hectare yield of 2.7 tons for rice, 3.1 tons for wheat, 2.1 tons for maize, 1.3 tons for coarse cereals, 2.4 tons for cereal, 1.3 tons for pulses, 22.3 tons for potato, 25.7 for vegetables, and 24.1 tons for fruits. Average yields of most crops in India are still rather low.

Accent on Diversification of Agriculture

Agriculture has always been backbone of Indian Economy and despite concerted industrialization in last six decades; agriculture still occupies a place of pride. It provides employment to ~60% of total workforce in country. The significance of agriculture in India arises also from the fact that the development in agriculture is an essential condition for the development of national economy. Agriculture provides employment to ~60% of total workforce in country. The significance of agriculture in India arises also from fact that development in agriculture is an essential condition for development of the national economy. In face of shrinking natural resources and ever increasing demand for larger food and agricultural production arising due to high population and income growth, agricultural intensification is main course of future growth of agriculture in region. Research for product diversification should be yet another important area. Besides developing technologies for promoting intensification, country must give greater attention to development of technologies that will facilitate agricultural diversification particularly towards intensive production of fruits, vegetables, flowers and other high value crops that are expected to increase income generate effective demand for food (Kumar et al. 2019a,b).

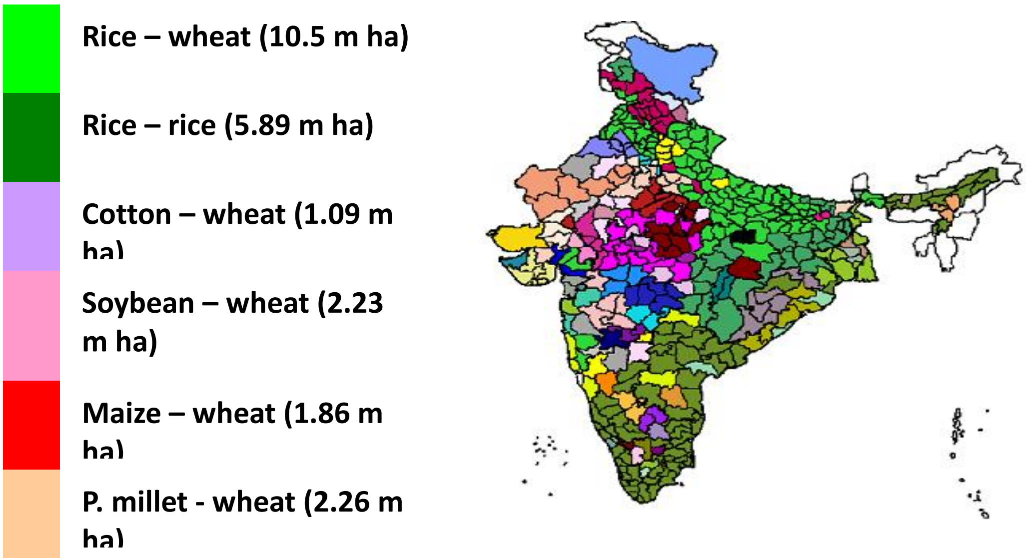

Fig.1. Major cropping system in India

Basics of Crop Diversification

Excess nutrient mining from top soil and detracting crop productivity with monocropping of nutrient exhaustive crops are twin problems affecting the future of hill agriculture in organic management condition. Limited water availability in eastern region again accelerated condition of low crop productivity, income and intensity. Water use efficiency (WUE) is yield of harvested crop produce achieved from available water to crop. WUE of major crops in eastern India varies from 0.28 to 1.40 kg m^{-3} with wide differences among crop species. Improving WUE in eastern Indian agriculture especially in rainfed ecosystems will require an increase in crop water productivity and reduction in water losses from crop root zone. Climate change may have negative penalties for agricultural production in fragile rainfed ecosystem; hence, there is a need to build resilience into agricultural system. Implementation of increased crop diversification may be the rational and cost-effective method to cope with climate change. Crop diversification can improve resilience in a variety of ways: by suppressing the pest outbreaks and dulling pathogen transmission and by improving the soil fertility and input use efficiency (IUE). Crop diversification may enhance the ecosystem services and climate resilience, which reduces production risk under aberrant weather condition.

Crop diversification advocated inclusion of crops of diverse behaviour of growth, development and input requirement, have zero/minimum competition and resulted in higher land and water productivity at a given time and space. This practice for resource conservation and utilization based template created by using diversified crops in systematic manner. This interlaces farmers to the land, available resources and generates employment and income throughout the year. Diversification/intensification of existing cropping pattern is unique as it focuses on assisting farmers in creating a situation where they are managing their own natural resources in a sustainable productive ways. Nutrient self-sufficiency is a desirable attributes of diversified sustainable cropping. Under organic production system, nutrients applied to preceding crops exhibits considerable residual effect on succeeding crops. Hence, the nutrient management has to be addressed in system-mode and not on individual crop basis. Therefore, organic farming must be practiced in system mode for higher production, productivity and profitability apart from more efficient nutrient use. Furthermore, unless organic crop production is undertaken throughout the year the desired profitability levels will be difficult to achieve. Crop diversification is imperative for increasing cropping intensity and soil resource management for sustained organic crop production. To prevent the runoff and soil erosion and to meet all requirements in terms of feed, fodder and soil cover, efforts must be made to obtain them from diversified cropping system only.

Concept of Diversification

Diversification may be defined as production of a variety of diverse goods, services often as a protection against effects of tumble in demand for a particular product. With regard to agriculture, diversification may be viewed as a process with different stages. Initially, diversification is at cropping level, where there has been a shift away from monoculture. At second stage, farm has more than one enterprise and may produce and sell crops at different times of year. At the subsequent stage, diversification is understood as being mixed farming. Finally, activities beyond agriculture are incorporated into meaning of diversification and it incorporates use of farm resources for non-agricultural activities. Such activities could include on-farm processing, provision of non-agricultural products and services on-farm. In concise way, agricultural diversification infers diversification of crop production and shifting of agricultural employees to other allied activities i.e. dairy, poultry, fisheries and non-agricultural sector. Shift from crop farming to non-farm employment is essential in order to raise income and to reconnoitre alternate opportunities of sustainable livelihood.

Diversification across ecological, spatial and temporal scales serves as the device for maintaining biotic interactions among various components and in turn, ecosystem services that provide critical inputs to agriculture. Across ecological scales, a diversified production system includes genetic diversity within crop or animal varieties, varietal diversity within a single crop/animal species, intercropping of multiple species, integration of pet animal components and non-crop plantings and semi natural communities of plants i.e. hedgerows, riparian buffers and pastures. With reference to the spatial scales, diversified systems promote agro-biodiversity through innovative practices in composting, intercropping, agro-forestry, crop rotation, cover cropping and fallowing. Similarly, around field boundary hedgerows, border plantings of Napier, Congo signal, broom and other grasses. Across temporal scales, asynchronous tilling, planting/sowing, intercultural operations, irrigation, harvesting, crop rotations, fallowing contribute to the maintenance of landscape-scale heterogeneity.

Crop Diversification

Crop diversification is a novel archetype of sustainable agriculture. It is a need based, demand driven, regional specific and house hold food-security goal seeking incessant and dynamic concept and involves temporal, spatial, value totalling and resource complementary approaches. It is a shift from less profitable and unsustainable crops or cropping systes to more profitable and sustainable crops/cropping systems. Crop diversification means to increase total productivity in terms of quality, quantity and monetary value in specific and/or diverse agro-climatic situations. It mainly depends on land typology, farming experience, capital resources, location, access to agricultural technologies, market demand and price, transportation costs and general information access.

Table 1. Examples of crop diversification and potential benefits

Type of diversification	Nature of diversification	Potential benefit
Improved structural diversity	Makes crops within field more structurally diverse	Pest suppression
Genetic diversification in monoculture	Cultivation of mixture of varieties of same species in a monoculture	Disease suppression, Increased production stability
Diversify field with fodder grasses	Growing fodder grasses alongside of food/pulse/ oilseed/vegetables	Pest suppression, opportunity to livestock farming
Crop rotations	Temporal diversity through crop rotations	Disease suppression, Increased production
Polyculture	Spatial and temporal diversity of crops	Insect, pest disease suppression, climate change buffering
Agro-forestry	Growing crops and trees together	Pest suppression and climate change buffering
Mixed landscapes	Development of larger-scale diversified landscapes through mixture of crops and cropping system with multiple ecosystems	Pest suppression, climate change buffering and increased production stability
Micro-watershed based diversification	Integration of crop with other farming components for year round income and employment generation, besides sustaining soil	Insect, pest and disease suppression, climate change buffering and increased production, employment and income

Why Crop Diversification Approach?

Low cropping intensity, poor on–farm input management, late maturing poor yielder crop cultivars and fatigue soil fertility are the main culprits for lower agricultural productivity in the region. Furthermore, winter fallowing is common practices in eastern India due to low rain water availability and short duration nutrient responsive cultivars of *rabi* crops. A family of 6–7 members requires ~2 ha cultivable area in sloping hills to sustain their livelihood (Babu *et al*., 2016). The sloping lands are 3-4 times less efficient than the plains in meeting caloric and protein needs of their populations. They can sustain only 3–4 persons and 1 head of cattle/ha/year through crop intensification as compared to 9–10 persons in plain areas. The key socio-economic descriptors of these farms are their small size, often managed by women and provide only a portion of total family income. Complex nature of fragile agro-ecosystem makes it crucial for sustainability issue to be given priority for maintaining farm productivity and ensuring food and economic security. To tackle these challenges crop diversification approach can be employed for harassing maximum benefits from available resources with least negative impact. Present cropping intensity in Eastern India is about 140 per cent and there is ample scope for further intensification. A multidisciplinary scientific approach is more important in mountain areas than in less fragile environments. Choice of crops is vast: ranging from cereals like maize and paddy to vegetables, fruit crops, spices, condiments, medicinal and aromatic species. Although, current understanding with crops and market orientation are major determinants in choice of crops, environmental causes should also be taken into consideration (Kumar et al. 2018). In this connection, crop with dense canopies for conserving soil by reducing runoff should be grown during rainy season and crops with lesser water requirement should be preferred during post rainy season. Species having narrow upright leaves are less suitable for growing on steep slopes, hence, sole cropping of maize is discouraged and its intercropping with restorative crops like local beans and other legumes is recommended. In general, small scale diversified systems mostly depends on home-grown resources with diverse crop arrangements, are reasonably productive and stable, exhibits a high returns per unit of input, labour and energy. An agro-ecological approach to improve agricultural production systems must ensure that promoted systems and technologies are suited to the specific environmental like low, medium and high altitudes and socio-economic conditions of resource deprived farmers, without excess reliance on external inputs and risk. It is assumed that diversified cropping systems with pulses, oil seeds and vegetable crops can enhance soil water conservation, improve soil health, and increase system productivity. Introduction of new cultivated species and improved varieties of crop is a technology aimed at enhancing plant productivity, quality, health and nutritional value and/or building crop resilience to diseases, pest organisms and environmental stresses. Therefore, crop diversification approach should blend with traditional agricultural knowledge and modern agricultural science, featuring resource-conserving yet highly productive systems like intercropping, mixed cropping, multiple cropping. Under organically managed condition of crop diversification refers to addition of new crops or cropping systems to agricultural production on a particular farm taking into account different returns from value-added crops with complementary marketing opportunities. In searching for alternative, non-winter fallowing farming strategies in EIGPs, we determined that diversifying cropping systems with annual pulses, vegetables, oilseeds and other regional specific crops along with appropriate agronomic manipulations increase systems productivity, soil health while decreasing negative impact (Singh et al. 2018). Need of crop diversification is summarized hereunder:

Crop diversification: single window for multi-benefits

- Enhancing natural resources sustainability
- Maintaining agro-ecological balance
- Opportunities for employment generation, hence reduces social evils
- Minimizing risk coverage and reducing the magnitude of risk due to mono-cropping
- Higher profitability and also the resilience/stability in production
- Year round income generation, hence, crop diversification acts as a bank ATM
- Reduces dependence on external input requirement for sustaining family needs
- Soil restoration
- Enhances opportunity of cropping in aberrant weather situations

Approaches of Crop Diversification for Eastern India

Present cropping intensity in region is very low (140%) and there is scope for further intensification. Diversified crop production can play a pivotal role in protecting livelihood security by reducing poverty through increased household income mainly through increased agricultural production. Crop diversification approach should be goal oriented, hence, on basis of achievable targets crop diversification approaches divided into following groups.

A. **Horizontal diversification:** It is generally of two types

Crop intensification: Addition of more number of crops in existing cropping system as a way to enhance overall productivity of a farm. The defined objective like use of gap between two crops, utilize the space available in fields and bunds, as a way to improve overall productivity of a farm or region's farming economy like blackgram/pigeon pea in bunds of rice crops. Some other notable examples are Maize+beans (Intercropping/mixed cropping), Maize-Pea (Sequential cropping), Alder+Large cardamom (multi-tier cropping), Cucurbits+ ginger/turmeric (vertical cropping).

Crop substitution: It is primary approach to crop diversification in production agriculture. Substituting less suitable crops with more suitable alternate crops *e.g*. substitution of pea to vegetable pea/vegetable crops during *rabi* season in irrigated ecosystem. Similarly, high risk crops like tomato, potato may be substituted with short duration pulses and oilseeds crops especially in rainfed condition.

- High water requiring crops should be substituted with less water intensive crops *e.g*. cultivation of maize instead of rice during *kharif*.
- In case of rainfed condition, on moisture retentive soils after harvest of *kharif* crop *i.e*. rice some minor crop requiring less moisture like vegetable pea, lentil should be grown.

B. **Vertical diversification:** Post harvest management, stakeholders add value to products through processing, regional branding, packaging, merchandising to enhance market values.

C. **Land based approach for crop diversifying existing cropping system:** Crop should be selected on the basis of land configuration *e.g*. on slopy lands an alternate cropping of erosion promoting and erosion resisting crops like legumes should be adopted. Similarly, on terrace risers fodder crops like Napier, medicinal and aromatic crops like Citronella and lemon grass, perennial legumes should be grown. Well-drained fertile land should be utilized for important food and vegetable crops. Similarly, pulses should be promoted in less fertile land.

D. Varietal diversification: Low yielding, less input responsive, susceptible to various insect pest diseases varieties should be substituted with HYVs for profit maximization.

E. Crop diversification for nutrient management: For proper and uniform use of nutrients from soil, crops with fibrous root should be followed by those, which have a taproot system. Similarly, leguminous crops should be rotated with non-leguminous crops because leguminous crops had inherent ability to fix atmospheric N into soil and add more organic matter to soil. Apart from this, legumes have more affinity for divalent cations as compared to non-leguminous crops. Furthermore, legumes require less nitrogen while non-legumes need more of N. Hence, nutrient requirements of these crops are different and lower similar crop components and such combination helps farmers in reducing cost of cultivation. Sustaining need of food, fodder, cash and maintaining fertility and productivity of soil deep rooted cash crops, shallow rooted grain crops and restorative crop should be rotated in a given piece of land. Similarly, more soil exhaustive crops should be succeeded by less exhaustive crops. Antagonistic/synergistic effect of preceding crops on succeeding crop should be considered for obtaining maximum yield and quality produce.

F. Crop diversification for pest-management: Intercropping in widely spaced crops not only reduces weed infestation but enhances overall productivity. Cultivations of crops with different botanical relationship in a same piece of land reduce weed, pest/diseases pressures.

G. Crop diversification for risk reduction: Enterprise diversification should be prompted; it is a self-insuring tactic to protect farm against uncertain risk. Similarly, staggered planting of high value crops is advocated for getting premium price in local market. Furthermore, selection of crops should be demand based, for realizing higher prices. Area allocation for a particular crop should also be constant from year to year.

Points to be remembers during recommendation of Crop diversification strategies

- Diversification approach should promote the substitution of low yielding traditional cultivars with high yielding varieties. However, traditional cultivar with unique characteristics should also be promoted.
- Crop diversification approach should follow principles of crop rotations. Similarly, water loving crops during rainy season and water repellent crops during winter seasons should be recommended.
- Diversion of high water requirement crops with less water requiring crops.
- Legumes intervention should also take into consideration, at any given time legumes must occupy at least 30% of total cropping area. Legumes are N-fixing and can also be good source of mulching from the crop residues.
- Crops having both domestic/international demand should be included in cropping systems
- Inclusion of crops with comparative advantages
- Rational choice of varieties of crops in system
- Inclusion of energy efficient crops
- Systems with high productivity, profitability and sustainability should be selected

- Cultivation of speciality crops like rice bean, horse gram, pillipasara should be promoted in cropping system mode
- Same cropping sequence should not be repeated in the same field in gram/cow pea and the field must be rotated every 2-3 years.
- Conservation tillage and irrigation practices should be adopted in diversified systems for improving soil quality and conserving soil moisture.
- Cover cropping, *in-situ* residue/biomass management, water and nutrient saving technologies, rain water harvesting approaches for ensuring year round high value crop production should be adopted in diversified farms.
- Low cost plastic tunnels, low cost plastic rain shelters and greenhouse (low cost) for off season vegetable production should be recommended in vegetable based cropping systems. However, in year round vegetable production no more than 5-6 crops in a year should be promoted for maintaining the soil health.
- Recycling of all kinds of biomass and crop residues should be promoted in diversified cropping systems to reduce dependence of nutrient requirement from outside. Similarly, soil conservation measures should be adopted in year round production systems, to prevent soil and nutrients erosion.
- Integrated organic nutrient management strategies should be adopted in diversified production systems.
- Owners of diversified farms should be educated about the processing of farm produce, in general and for perishable commodities, in particular for minimizing the post-harvest losses and enhancing the farm income.

Challenges for crop diversification

Adoption of crop diversification increased under cash crops including spices, vegetables and fruits since last three decades. However, this has gained momentum in last decade favouring increased area under vegetables and fruits and also to some extent on commercial crops like ginger, turmeric, large cardamom, pulses/oilseed crops specially soybean. Crop diversification promotes cultivation of new crops/varieties that would fetch additional income compared to the traditional crops/varieties. Thus, the response towards diversification in present conditions is slow in many crops. The major problems and constraints in crop diversification especially in EIGPS are primarily due to the following factors:

- Majority of the cropped area (89%) is entirely dependent on rainfall and is affected by other biotic and abiotic stresses
- Sub-optimal use of critical production inputs like organic manures, biopesticides
- Small and fragmented land holding, very poor mechanization of agriculture
- Inadequate post-harvest technologies and inadequate infrastructure for post-harvest handling of perishable crop produce
- Inadequate supply of quality seeds and planting material of improved cultivars.
- Non-availability of agro-industry
- Decreased investments and interest in the agricultural sector
- Poor storage and other post-harvest facilities
- Remoteness of region
- Poor transport facilities and high transport costs
- Devastating roadside landslides causes closure of roads during monsoons

- Lack of market information on the price, demand and supply and proper market outlets, hence, farmers tend to sell the produce at a price offered by the middlemen.

Table 2. Alternate crop diversification in irrigated ecosystem of India

Kharif alternate crop	Rabi alternate crop	States
Maize, fodder *jowar*/maize, beans, blackgram, ginger, sunflower, minor millets	Barley, French bean, buckwheat, *toria*, mustard, cole crops, veg. pea	Hiamanchal Pradesh, J&K, Uttarkhand
Maize, fodder *jowar*/maize, arhar, horsegram, ricebean, sesame, minor millets, jowar,	Jowar, Bajra, minor millets, French bean, mustard, toria, safflower, linseed, Arhar bottle gourds, bitter gourds,	Jharkhand, Chhattisgarh
Maize cob, greengram, blackgram, sesame, sunflower, French bean, ricebean, colocasia, turmeric, cardamom, fenugreek, braccoli, Jobstear, Perilla	Buckwheat, mustard, toria, frenchbean, veg. pea, linseed, pumpkin, lentil, fenugreek, coriander	Sikkim, Meghalaya, Nagaland , Manipur

Fig. 2. Major millets suitable for climate resilient cropping in Eastern India

Table 3. Alternate crop diversification in irrigated ecosystem of India

Kharif alternate crop (Rice)	Rabi alternate crop (Wheat)	Summer alternate Crop (Mungbean)
Maize, soybean mungbean, urdbean	Mustard, chick pea, lentil, potato coriander, field pea, cowpea	Dual purpose cowpea, Cluster bean (fodder), sunflower
Arhar/mungbean /urdbean	Mustard, toria, chick pea, lentil, veg. peas, French bean potato	Cowpea (dual purpose), Ladys finger
September Arhar, Toria, urdbean, mustard	Maize, potato, cabbage, tomato, veg. pea mustard, toria, lentil, chickpea, rajma, coriander, cowpea, oat (multi cut), jowar fodder, Rajma	Urdbean, cluster bean (fodder), onion, cowpea, cucumber, tomato, bitter gourd, ladys finger, bottle gourd
Maize (green cob), Arhar, French bean	Mustard, toria, potato, veg. pea, broccoli, radish, cauliflower	Cowpea dual purpose Veg. French bean, squash, garlic, potato, onion, radish
Jute, Mesta	Potato, rapeseed, toria	Sesame
Soybean	Chickpea, berseem, mustard, toria, onion,	Onion, linseed

Research Initiated at ICAR Research Complex for Eastern Region, Patna

A long term study was initiated at the ICAR Research Complex for Eastern Region Patna, with keeping 10 different cropping system *viz.* transplanted rice (TPR)-wheat-mungbean (Farmers practices, FP), direct seeded rice (DSR)-wheat (ZT)-mungbean (ZT) (RCT), soybean-maize (ZT),DSR-mustard-urdbean, foxtail millet-lentil-fallow, pearlmillet-chickpea-fallow, finger millet-*toria* (ZT)-fallow, sorghum (grain) –chickpea (ZT)-fallow, maize (cob)-pigeonpea and sorghum (fodder)-mustard (ZT)-urdbean (ZT) during *kharif* of 2016 on clay loamy soil. Results revealed that significantly highest system productivity (SREY) was recorded with maize cob-pigeonpea (22.41 t/ha) followed by sorghum fodder-mustard-urdbean (15.97 t/ha) and soybean-maize (13.31 t/ha) (Kumar *et al*.2018). Based on this study, it may be concluded that to achieve the maximum productivity and net returns, cropping system i.e. maize cob-pigeonpea followed by sorghum fodder-mustard-urdbean can be adopted for irrigated ecosystem. Comparative study was undertaken at ICAR, Patna during *kharif* of 2016 to determine feasibility of growing of Bajra cultivar (Proagro-9001 and 9450) under the upland rainfed condition of Bihar. Results revealed that both lines are having high yielding potential and matures within 85-90 days with very limited agronomic management practices. Crop yield potential varies from 4.5-4.8 t/ha and Proagro-9001 matures one week earlier compared to Proagro-9450. Crop diversification through substitution of millets, fodders, pulses, oilseeds and maize as dual purposes (green cob/seeds) in RWCS is of utmost importance to sustain the productivity and profitability under climate change scenario.

Fig. 2. View of the crop diversification at the ICAR-RCER Patna

Research and developmental support for crop diversification

Future agriculture will be much more knowledge and skill based rather than traditional subsistence agriculture. In the wake of globalization and opening up of global market, there will be much more opportunity for entrepreneurship development in agriculture. This also calls for paradigm shifts in research and technology development and also transfer of technology for successful crop diversification. The research system not only needs to address the issues connected with continuance and indulgence and knowledge in areas of emerging technologies but also create a cadre of scientists through the continuous upgrade of skills and human resource development. The researchers also need to popularize technologies, impart knowledge and skills to the extension functionary's for the transfer of technologies to the farmers. This knowledge-based farming will call for much more interaction between the researchers, extension workers and farmers. The fruits of the innovative technologies should reach the farmers at the earliest and also spread in the quickest possible time.

Conclusion

Diversification/intensification of rice based system along with crop management practices under both the irrigated and rainfed ecosystems may enhance the profitability, resource use efficiency and soil health. Therefore, crop diversification of rice based system through substitution of millets, fodders, pulses, oilseeds and maize as dual purposes (green cob/seeds) in RWCS is of utmost importance to sustain the productivity and profitability under climate change scenario in Eastern India.

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Strategies for improving C/N dynamics for climate resilient farming in conservation agriculture

Kirti Saurabh, Rakesh Kumar and J S Mishra

ICAR-Research Complex for Eastern Region Patna-800 014

Climate change impacts on agriculture are being witnessed all over the world, but countries like India are more vulnerable in view of the huge population dependent on agriculture, excessive pressure on natural resources and poor coping mechanisms. The warming trend in India over the past 100 years has indicated on increase of 0.60°C. The projected impacts are likely to further aggravate field fluctuations of many crops thus impacting food security. There are already evidences of negative impacts on yield of wheat and paddy in parts of India due to increased temperature, water stress and reduction in number of rainy days.

Despite impressive gains in cereal production from 50 million tonnes in 1947 to about 253 million tonnes in 2017-18, there remain two serious but inter-related problems. One, expected food demand of 300 million tonnes of cereals by 2030 which must be met from the shrinking land resource base. Two, there are severe problems of degradation of soil and water resources leading to reduction in use efficiency of inputs, pollution of surface and ground waters and emission of greenhouse gases (GHGs) from soil into the atmosphere. Most intensive cereal based production systems are showing declining trend in grain output. Significant negative impacts have been projected with medium-term (2010-2039) climate change, eg. yield reduction by 4.5 to 9%, depending on the magnitude and distribution of warming. Since agriculture makes up roughly 15% of India's GDP, a 4.5 to 9.0% negative impact on production implies cost of climate change to be roughly at 1.5% of GDP per year. Enhancing agricultural productivity, therefore, is critical for ensuring food and nutritional security for all, particularly the resource poor small and marginal farmers who would be affected most. In the absence of planned adaptation, the consequences of long- term climate change could be severe on the livelihood security of the poor. A decrease in soil C is one of the causes of yield decline in India. In long-term experiments of India, decline in soil organic matter is the major cause of yield decline (Swarup et al. 2000) irrespective of cropping system and soil type. This eventually leads to deterioration of soil quality. The problem is further enhanced by reduced biomass productivity and the low amount of crop residue and roots returned to the soil. Low soil organic carbon content is also attributed to heavy ploughing, removal of crop residue & other bio-solids, mining of soil fertility.

Adaptation to climate vulnerability

Planned adaptation is essential to increase the resilience of agricultural production to climate change. Several improved agricultural practices evolved over time for diverse agro-ecological regions in India have potential to enhance climate change adaptation, if deployed prudently. Management practices that increase agricultural production under adverse climatic conditions also tend to support climate change adaptation because they increase resilience and reduce yield variability under variable climate and extreme events. Some practices that help adapt to climate change in Indian agriculture are soil organic carbon build up, in-situ moisture conservation, residue incorporation instead of burning, water harvesting and recycling for supplemental irrigation, growing drought and flood tolerant varieties, water saving technologies, location specific agronomic and nutrient management, improved livestock feed and feeding methods. It has been shown that adopting conservation agriculture (CA) practices has the potential to increase crop yields, reduce soil degradation and make agricultural systems more resilient to weather-induced stresses such as climate change. In addition, some have claimed that CA along with improved management of nitrogen fertilizer has the potential to mitigate climate change by sequestering organic carbon in soil.

Building resilience in soil

Soil health is the key property that determines the resilience of crop production under changing climate. A number of interventions are made to build soil carbon, control soil loss due to erosion and enhance water holding capacity of soils, all of which build resilience in soil. Good quality soil has the capacity to maintain key ecological functions such as the formation and decomposition of soil organic matter, preservation of large amounts of carbon and sequestering the excess carbon leading to mitigation of rising atmospheric CO_2 levels. A number of factors including the composition of soil microbial populations, climate, nature of material, soil type, type and age of vegetation, topography of land, etc. regulate the amount of carbon in soils (Jenny, 1941). Soil environment directly affects the types of microbial populations, as well as the rates of processes they perform. For example, soil microbial activity increases or decreases with temperature, which in turn affects rates of decomposition, and on other hand, microbial processes directly affect their environments as well, contributing to carbon and nitrogen cycles (Figure 1), which are important for plant health.

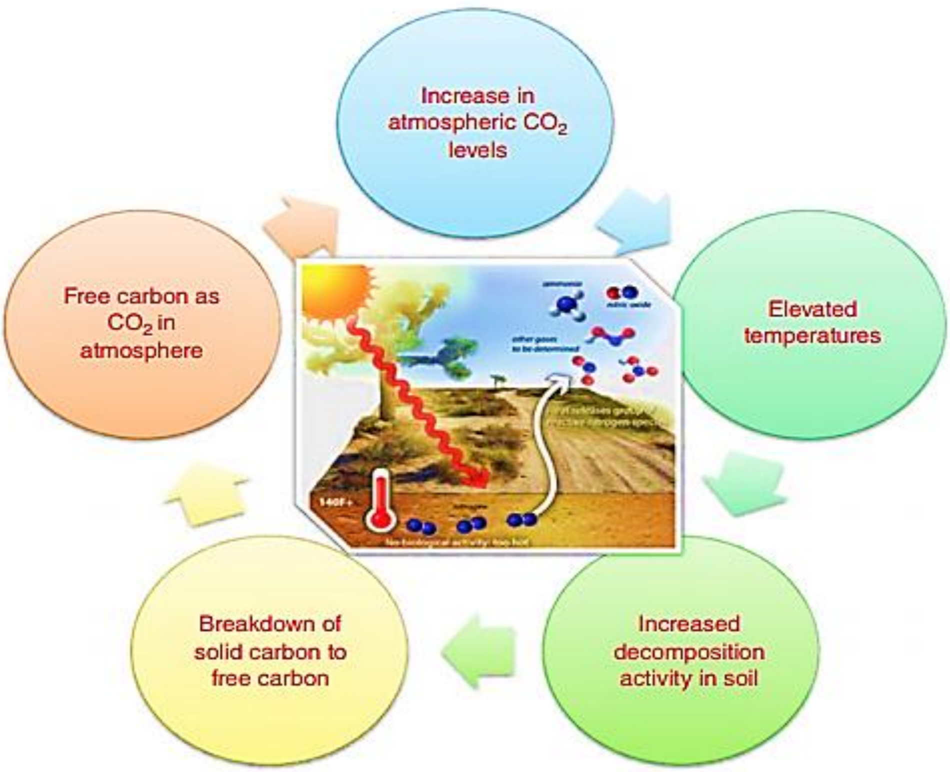

Figure 1. Impact of climate change on agriculture and soil organic matter

Carbon and Nitrogen Cycling in Agricultural Systems

Carbon uptake in crops occurs through photosynthesis and enters the soil as a residue of above- or below-ground biomass. The dead organic matter is colonized by a variety of soil organisms, which derive energy for growth from the oxidative decomposition of complex organic molecules. During decomposition, about half of the C is mineralized and released as CO2 (White, 2006). Marland et al. (2003) distinguished four sources of CO2 emissions in agricultural systems: (i) plant respiration; (ii) the oxidation of organic carbon in soils and crop residues; (iii) the use of fossil fuels in agricultural machinery such as tractors, harvesters, and irrigation equipment; and (iv) the use of fossil fuels in the production of agricultural inputs such as fertilizers and pesticides (Fig. 2). Soils can also be producers of CH_4, e.g., in wetlands or rice cultivation (Fig. 2).

The C and N cycles are linked through the reservoirs in crop and soil organic matter. Nitrogen can enter the soil from the atmosphere through dry and wet N deposition, fertilizers/manures and N fixation, while processes like ammonia (NH_3) volatilization and emissions of denitrification products (N_2, N_2O, NO) diminish the N content of the soil system. Mineral N in the soil can also be depleted through the uptake of nitrogen by the crop, whereas the return to the soil of the non-harvested crop will add to the organic nitrogen pool (Vlek et al., 1981). The processes of immobilization and mineralization are continuously causing changes in the mineral N reserves of the soil. Organically bound N can be converted microbiologically into inorganic mineral forms (mineralization), leading first to formation of ammonium (NH_4^+) and possibly ending up in NO_3^- (nitrification) (Van Cleemput and Boeckx, 2002). Where excessive wetting prevails, mineral nitrogen (particularly NO_3^-) may leach beyond the reach of crop roots (Fig. 1).

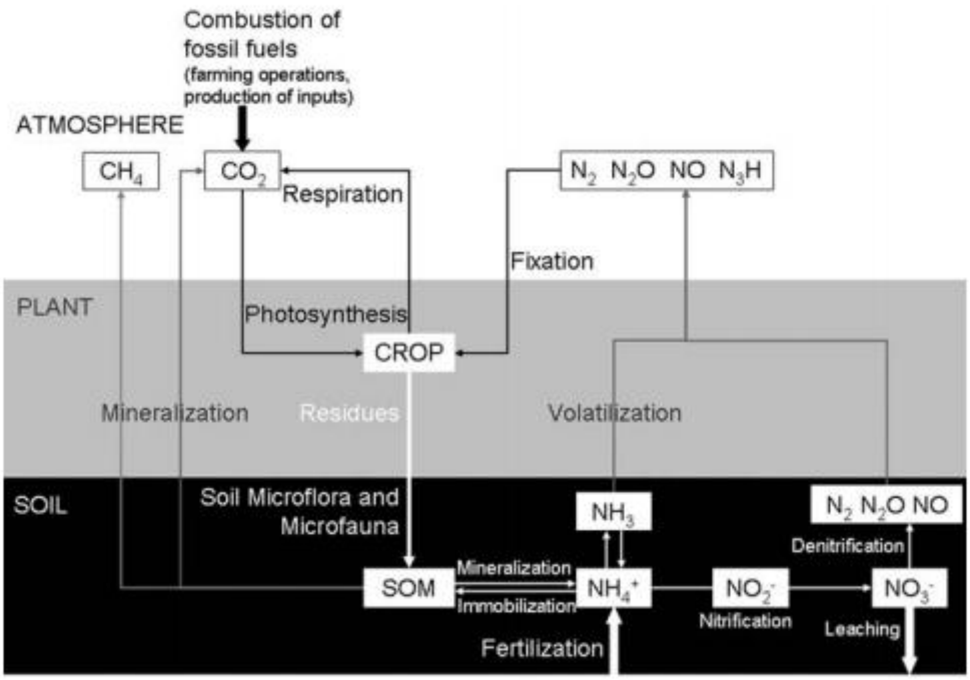

FIG. 2. Carbon and nitrogen cycle in agricultural ecosystems.

Nitrogen dynamics in agricultural systems are very much influenced by the large quantities added as nitrogen fertilizers. Since N supply to soils increases productivity and biomass accumulation in the short-term increased nitrogen input levels have been perceived as a strategy to favor soil C sequestration (Batjes, 1996). However, N application as fertilizers implies CO_2 emission costs. For example, 1 kg of N fertilizer leads to the emission of 0.86–1.3 kg of CO_2 in production, packaging, transport and application (Lal, 2004). Additionally, increases in soil organic matter might accelerate N dynamics and thus emissions of N_2O, a known greenhouse gas (Butterbach-Bahl et al., 2004). In summary, nitrogen affects the net greenhouse gas balance in four ways: (i) CO_2 is released from the energy and fossil fuel intensive production of nitrogen fertilizer; (ii) crop yield changes as a function of the nitrogen application rate; (iii) the application rate and CO_2 emissions associated with the energy-intensive production of agricultural lime depend on the rate of nitrogen fertilization, since increased use of N fertilizer can cause a decline in soil pH; and (iv) N_2O emissions vary with tillage practice and as a function of the nitrogen application rate (Marland et al., 2003).

Carbon levels in soil are determined by the balance of inputs, as crop residues and organic amendments, and C losses through organic matter decomposition (Paustian et al., 1997). Upon cultivation of previously untilled soils, this balance is disrupted and generally 20% to 40% of the soil C is lost, most of it within the first few years following initial cultivation (Davidson and Ackerman, 1993; Murty et al., 2002). Afterwards, the rate of decrease levels off, and some decades later a new, management dependent soil humus level is attained (Sauerbeck et al., 2001; Fig. 3)

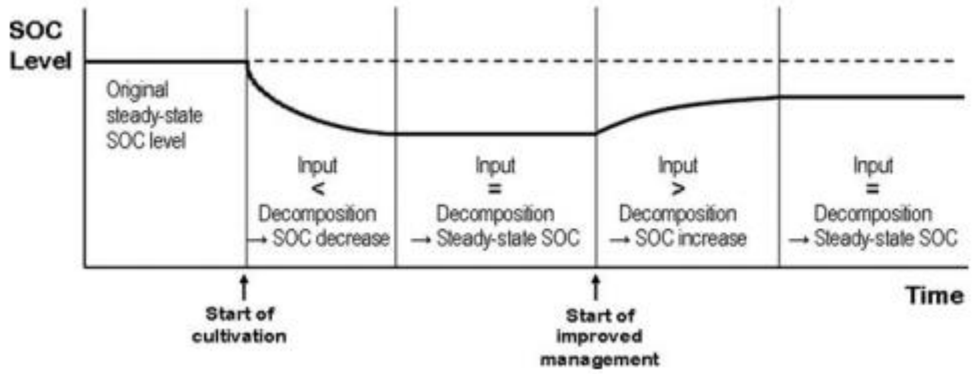

Figure. 3. Long-term soil organic carbon level changes depending on carbon input and decomposition in agricultural ecosystems.

Management to build up SOC requires increasing the C input, decreasing decomposition, or both (Paustian et al., 1997). Decomposition may be slowed by altering tillage practices or including crops with slowly decomposing residue in the rotation. The C input may be increased by intensifying crop rotations, including perennial forages and reducing bare fallow, by reducing tillage and retaining crop residues, and by optimizing agronomic inputs such as fertilizer, irrigation, pesticides, and liming. Following an improvement in agricultural management practices, soil organic carbon will gradually approach a new steady state that depends on the new suite of practices (Marland et al., 2003, Fig. 3). Estimates of the time necessary to reach the new steady state range from 20–40 years (West and Marland, 2002) to 50–100 years (Sauerbeck, 2001). It is important to remember that the use of agricultural inputs such as fertilizer, irrigation, pesticides and liming carry a 'hidden' carbon cost, so any effort to estimate the effect of changing tillage practice on the net flux of CO_2 to the atmosphere should consider both the C sequestered in soil and the emissions from fossil-fuel use in the affected system (West and Marland, 2002).

A simplified model of the regulation of nutrient flux in the agroecosystem is presented in Figure 4. This conceptual model depicts the flow of carbon and nutrients among organic residues, organic and inorganic pools in soil, and the plant. Pathways of loss are also included. Decomposition and mineralization of plant residue are mediated by both soil faunal and microbial populations. Some of the carbon and associated nutrients are mineralized immediately (pathway 1a) or are immobilized in the soil microbial pool (pathway 2a), later to be transformed into other soil organic pools via microbial by-products (3a). Recalcitrant plant material also may enter the soil organic pools directly (3b). The carbon and nutrients held in the various soil organic matter pools are subsequently decomposed and assimilated by soil biomass, resulting in

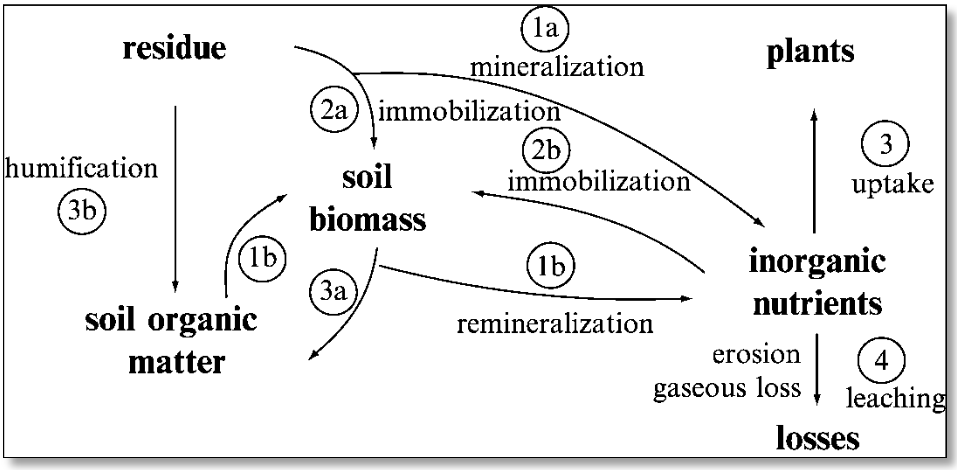

Figure 4. Conceptual model of nutrient pathways in crop residue amended soils (Myers et al., 1994).

additional mineralization (1b). The inorganic nutrients released by mineralization may be assimilated by soil biota via immobilization (2). Immobilization occurs simultaneously with mineralization, and the rate at which nutrients are available for plant uptake depends on the net balance between mineralization (1a plus 1b) and immobilization (2). The inorganic nutrients may also be taken up by plants (pathway 3), lost by leaching or volatilization (pathway 4), or remain in the soil (Myers et al., 1994). The size of the inorganic pool depends on the balance of the various processes that add to the pool (mineralization) and those that subtract (immobilization, plant uptake, and losses).

The proportion of N transferred from the residue to the plant and the rate at which it occurs are determined by the balance between the rates of the various processes represented by these flux pathways. This balance is regulated by a hierarchy of factors. Environment, which includes climate and soil, is an overriding control and determines the rate of the transfer between pools. The rates also vary depending on the quality of the decomposing substrate.

Carbon stock in different agro-climatic regions of India

Each soil has a carbon carrying capacity i.e., an equilibrium carbon content depending upon the nature of vegetation, precipitation and temperature. When the equilibrium is disturbed as for example by forest clearing, intensive cultivation etc., and soil carbon rapidly declines. In the cool and humid climates can have 6-7 per cent SOC content in their surface layers. In contrast, cultivated soils of the arid and semiarid tropics contain a low level of SOC and 0.2- 0.3 per cent of those in India. In tropical and sub-tropical areas, decomposition and the turnover of SOC tend to be faster.

The climate in combination with type of soil also influences the SOC content. It has been reported SOC in soils ranged from less than 1 per cent in sandy soils to almost 100 per cent in Doubling Farmers' Income – Volume V Sustainability Concerns in Agriculture 28 wetland soils. Of course, carbon stores in arid and semi-arid lands show high temporal and spatial variability, some parts acting as carbon sources and others carbon sinks. In arid and semi-arid zone tropical soils of India, nearly 50 per cent of the carbon is lost. Jenny and Rayachaudhury's classical study on Indian soils showed depletion to be as high as 60-70 per cent in many soils.

In the sub-humid (rainfall 1000-1500 mm), covers a major part of the IGP and parts of the southern peninsula, are rich in vegetation and therefore SOC content of these soils is relatively high compared to the semi-arid and arid bioclimate. The humid to per-humid (rainfall 1200- 3200 mm) bioclimatic system comprised of Arunachal Pradesh, Meghalaya, Mizoram, Manipur and the hilly areas of Tripura have cooler winter months and higher rainfall, which are favourable for higher SOC stock. In arid (<550 mm) and semi-arid (550-1000 mm) regions of Rajasthan having shrinking water resources, severe erosion, periodic drought, low biological productivity, summer fallowing have detrimental effect on SOC level.

Many of the arid zone soils are affected by high salinity and alkalinity and become barren. Waste lands in India are estimated at over 100 million ha (of which 70 per cent are badly degraded) and are extremely carbon depleted; organic carbon can be as low as 0.2 per cent. Several experiments in India show that extremely carbon depleted sites like salt affected soils have a relatively high potential for accumulating carbon in vegetation and soils if suitable tree and grass species are grown along with proper soil conservation measures to conserve rain water. The present carbon stocks of Indian soils covering 328.5 m ha calculated using organic carbon data of soil profile of 32 bench mark soils and 16 other sites characterised later for 22 agro-ecological regions of India is presented below:

Table 1 Current and potential stocks of organic carbon in Indian soils.

Soils	Area (m ha)	per cent of total area	Carbon content (kg/m^2)	Carbon stock (Pg)	per cent of total carbon	Carbon carrying capacity (Pg)
Red loamy	50.5	15.3	40.9	4.20	17.3	6.01
Red and laterite soil	20.8	6.3	19.2	1.99	8.2	3.22
Red and yellow soil	13.3	4.0	4.6	0.60	2.5	0.85
Shallow and medium black soil	33.0	10.0	8.2	2.71	11.1	3.57
Medium and deep black soil	26.6	8.1	15.9	2.45	10.0	3.3
Mixed red and black soil	39.2	11.9	34.3	4.75	19.5	6.51
Coastal alluvium derived soil	8.1	2.5	5.3	0.43	1.8	0.70
Alluvium derived soil	66.1	20.1	26.7	3.77	15.5	5.65
Desert saline soil	29.6	9.0	2.8	0.84	3.4	1.30
Brown and red hill soil	8.0	2.4	12.9	1.04	4.3	1.68
Shallow and skeletal soil	15.6	4.7	1.2	0.19	0.8	0.28
Brown forest and podzolic soil	17.7	5.4	7.7	1.36	5.6	1.87

Source: Gupta and Rao, 1994

The current total stocks are estimated at 24.3 Pg of carbon (Table 1). The potential stocks were also estimated by assuming that currently depletion is 50 per cent in surface and sub-surface and 10 per cent in rest of the profile. The potential stock was calculated to be 34.9 Pg and the difference of 10.6 Pg was taken to represent the potential for sequestering additional carbon in soil. Important strategies of soil C sequestration include restoration of degraded soils, and adoption of recommended management practices (RMPs) of agricultural and forestry soils. Potential of soil C sequestration in India is estimated at 7 to 10 Tg C/year for restoration of degraded soils and ecosystems, 5 to 7 Tg C/year for erosion control, 6 to 7 Tg C/year for adoption of RMPs on agricultural soils, and 22 to 26 Tg C/year for secondary carbonates.

Table.2 Depletion of soil organic carbon in cultivated and undisturbed soils

Region	SOC content		Percent reduction
	Cultivated(g kg^{-1})	Native (g kg^{-1})	
Northwest India			
Indo-Gangetic Plains	4.2 ± 0.9	$104. \pm 3.6$	59.6
Northwest Himalaya	24.3 ± 8.7	34.5 ± 11.6	29.6
Northeast India	23.2 ± 10.4	38.3 ± 23.3	39.4
Southeast India	29.6 ± 30.1	43.7 ± 23.4	32.3
West coast	13.2 ± 8.1	18.6 ± 2.1	29.1
Deccan Plateau	7.7 ± 4.1	17.9 ± 7.6	57.0

Source :Swarupet al., 2000 modified from Jenny and Raychaudhary (1960)

Carbon Losses

The soil organic carbon pool in 1m depth ranges from 30 t/ha in arid climates to 800t/ha in organic soil of cold regions with predominant range of 50-150 t/ha. The soil organic carbon pool represents a dynamic equilibrium of gains and losses. Losses and gains of SOM are influenced by land management practices such as cropping frequency, reduced tillage, and fertiliser/manure application and also by cultivation of perennial legumes and grasses. The depletion is exacerbated when the output of carbon exceeds the input and when soil degradation is severe.

A decline in SOC content is a common phenomenon when land use changes from natural vegetation to cropping, reasons being reduction in total organic carbon inputs, increased rate of decomposition due to mechanical disturbance of the soil, higher soil temperatures due to exposure of the soil surface, more frequent wetting and drying cycles and increased loss of surface soil rich in organic matter through erosion.

Low external input of chemical fertilizers and organic amendment causes depletion of SOC pool because nutrients harvested in agricultural products are not replaced, and are made available through mineralization of SOM.

Maintenance of soil structure in any soil type strongly influences soil C residence times, and thus management and disturbance can lead to substantial losses of soil C. Frequent disturbance to the soil (i.e., tillage) exposes protected organic matter and increases the rate of decomposition, decreased aggregate stability resulting in lower steady-state SOC storage. Excessive tillage and intensive cultivation in semi-arid region reduced soil organic carbon density from 60 kg km-2 under single cropping to 10.5 kg km-2 under double cropping.

Decrease in soil organic carbon pool may be caused by three, often simultaneous processes viz., mineralization, erosion, and leaching.

Mineralization: Most of the biomass produced in the natural ecosystem is returned into the soil. However the rate of mineralization in agriculture ecosystem often exceeds the rate of carbon accretion occurring through addition of roots and biomass. Higher soil temperature increases the rate of mineralization of SOC pool (Jenny and Raychaudhury, 1960). Because of high temperature, soils of tropical, subtropical, arid and semi-arid regions are expected to be contributing more oxidative products. Long-term cultivation reduced SOC storage, but losses varied depending on the climate in the order: tropical moist>tropical dry>temperate moist>temperate dry.

Soil erosion: Conversion of natural ecosystem to agricultural use generally leads to significant increase in the rates of soil erosion by both water and wind. In general, the ratio of C content of water and wind-borne sediments to that of contributing soil (C enrichment ratio) is always greater than one. Thus, the detachment of aggregates and redistribution of carbon rich sediments over the landscape may accentuate loss of carbon from soil to the atmosphere.

Leaching: The soluble fraction of SOC pool, called dissolved organic carbon (DOC), can be leached out of the soil profile with seepage water (Moore, 1998). While a component fraction of the DOC transported into the ground water may be precipitated and sequestered, a large portion may be mineralized and released into atmosphere as CO_2. Some soil has lost as much as 20-80 t C/ha mostly emitted into atmosphere. Crop cultivation is known to adversely affect distribution and stability of aggregates and reduces organic carbon stock in soil. In other words, the low SOC pool in soils of India is partly due to the severe problem of soil degradation.

Conservation agriculture as an option for c sequestration and N buildup

During the green revolution era, the approach of "more inputs–more outputs" has been followed, which is considered as ecologically intrusive and economically and environmentally unsustainable against suboptimal use of efficiency of inputs. The resource intensive agricultural production system practiced, especially during the post-green revolution era, have led to challenges like declining factor productivity, soil health deterioration, multiple nutrient deficiency, depleting water table at an alarming rate, loss of biodiversity due to monotonous crop rotations, etc., rendering the agricultural production system unsustainable (Jat et al., 2016). Therefore, intensification of the agricultural system through efficient resource use remains the only available option to enhance production with no additional land use, as competition for land and water is increasing from the non-farm sectors. This warrants a paradigm shift in agronomic management optimization, not only to produce more but with a higher efficiency of production inputs, while sustaining a natural resource base and reducing environmental footprints (Jat et al., 2016).

The green revolution paradigm also included the Asian green revolution; particularly in the irrigated rice–wheat cropping system of the Indo Gangetic Plains of South Asia, which boosted crop yield and averted a looming food crisis in the continent. It also resulted in negative retrogressions such as loss of soil organic matter, porosity, aeration, biota and consequently decline in soil health. Collapse of soil structure is due to mechanical compaction, reduced water infiltration, problems of water logging, loss of water as runoff and soil as sediment, less efficiency of inputs and loss of biodiversity (below and above soil surface) in the ecosystem. Breakdown of food-webs also reduces resilience and sustainability.

The decrease in soil carbon due to tillage occurs more rapidly in the tropics due to higher temperature. Soils under intensive tillage-based farming lose their original structure, thus depriving the soil microbial population of their habitat and organic matter. This loss of soil biodiversity, increased soil compaction, runoff, soil erosion, infestation by pests, pathogens and weeds, reflect the current degraded state of soil health globally (Montgomery, 2007).

Conservation agriculture systems utilize soils for the production of crops by reducing excessive mixing of soil and maintaining crop residues on the soil surface, thus minimizing damage to the environment. Conservation agriculture (CA) has following three principles:

1. Direct seeding or planting (no-till farming, viz. zero tillage, reduced tillage, etc.): The use of tillage methods like no-till, zero tillage with or without residue retention not only helps to mitigate the effects of high temperature stress, but also helps in conserving soil moisture and organic matter in the field, thereby maintaining good soil health.

2. Permanent soil cover (Enhancing and maintaining organic mulch cover on the soil surface): Covering soil surface by retaining crop residue or applying organic mulch is the second pillar of conservation agriculture. It helps protect soil against the deleterious effects of rain and sun, and provides soil microorganisms with a constant supply of food and microclimate for their optimal growth and development. Cover

crops or crop residues protect the soil surface, conserve water and nutrients, promote soil biological activity and contribute to weed and pest management. The crop residues are mainly from the previous field crop, so as to achieve 30% or more ground cover (Berger et al., 2012). Thierfelder and Wall (2008) suggested retaining crop residues as a major factor in the realization of benefits of conservation agriculture. Retaining crop residues and considerable nitrogen applications have shown to improve all the soil properties, viz. physical, chemical and biological (Ailincâi et al., 2012). Positive impacts on soil microbes and other macro-fauna which increase biological activity of the soil, have been reported under conditions of permanent soil cover with well-maintained crop residues (Thierfelder and Wall, 2008). An increase in soil microbial population, facilitated by crop residues, ensures high microbial decomposition of plant material, consequently increasing rate of build-up of organic matter, which leads to improved soil structure and therefore; higher crop yields (Rengel and Singh, 2010). Nitrogen, one of the main elements for nurturing crop growth, is indispensable for attaining high crop yields. If crop residues of legume crops are used, their decomposition releases nitrogen into the system and hence greater yields are obtained (Erenstein, 2003). Another factor which affects nitrogen availability to crops is ammonia volatilization which is affected by several environmental conditions such as higher temperatures and drier weather conditions (Olson-Rutz et al., 2011).

The crop residue/mulch conserves moisture and prevents direct heating of the soil surface, which significantly prevents or reduces nitrogen volatilization (Schwab and Murdock, 2005). For the full realization of benefits of CA, measures that protect crop residues from getting removed from fields need to be considered as part of the conservation agriculture farming system package.

3. Crop rotation/diversity (diversity of species): Diversity can be enhanced by both annuals and perennials, in associations, sequences or rotations, and may include trees, shrubs, pastures and crops, all contributing to enhanced crop and livestock nutrition and improved system resilience. Crop rotation/diversity offers a diverse "diet" to soil microorganisms, ultimately leading to a diverse soil flora and fauna. The roots excrete different organic substances that attract various types of bacteria and fungi, which in turn, play an important role in the transformation of these substances into plant available nutrients into the different soil layers. The roots are thus able to function effectively and are able to capture high amounts of plant nutrients and water without restrictions

- Crop diversity is also enhanced or maintained by intercropping. Intercropping improves the agronomic output and economic efficiency of a cropping system through effective use of resources in space and time as compared to monocrop. Intercropping emerged as an effective agro-technique to enhance crop production per unit area and time, particularly for farmers with small land holdings (Aziz et al., 2015). In the Indo-Gangetic Plains, earlier intercropping of mustard or chickpea with wheat was a regular practice, but with the introduction of farm mechanization, especially popularization of the combine harvester, its area has decreased drastically. Alternative crops to wheat, such as winter oilseeds and grain legumes are becoming more prevalent in the wheat zone. This warrants the need for farmers/producers to diversify the cropping system and harvest the benefits of sound crop rotations on wheat yield (Tripathi et al., 2016). Alternative crops can increase the yield of subsequent wheat crops by depriving soil-borne wheat pathogens of a host (Kollmorgen et al., 1983) and are often referred to as “break crops”. A better understanding of the magnitude and mechanisms of break-crop effects on wheat yield would allow management to maximize the potential benefits within a cropping sequence. Conservation agriculture ensures that water enters the soil so that plants never suffer water stress that may otherwise limit the expression of their potential growth; also excess water passes down to groundwater and stream flow and not over the surface as runoff. Conservation agriculture favors beneficial biological activity in the soil, maintains and rebuilds soil architecture, competes with potential in-soil pathogens and contributes to soil organic matter. Conservation agriculture also contributes towards capture, retention, chelation and slow release of plant nutrients. Moreover, physical or chemical damage to roots can be avoided by practicing conservation agriculture. Nitrogen leaching and runoff losses are also minimized under CA systems and thereby reducing the need for mineral N by 30–50 % in the longer run (Crabtree, 2010) and has potential to lower N_2O emissions as well.

Case study

A study was conducted under Cereal System Initiative for South Asia (CSISA) experiment of institute farm, Patna during 2015-2018,with seven treatments in rice-wheat-mungbean system: 1) RPTR-CTW: Random puddled transplanted rice (RPTR) - Conventional till broadcasted wheat (CTW); 2) LPTR-CTLW: Puddled line transplanted rice (LPTR)- Conventional tillage line sown wheat (CTLW); 3) MTNPR-ZTW: Machine transplanted non-puddled rice (MTNPR) fb zero-till wheat (ZTW); 4) MTZTR-ZTW: Machine transplanted Zero-till transplanted rice; 5)SRI-SWI: System of rice intensification (SRI) fb system of wheat intensification (SWI); 6) CTDSR-ZTW: Conventional till direct seeded rice (CTDSR) fb ZTW; 7) ZTDSR-ZTW: Zero-till direct seeded rice (ZTDSR) fb ZTW. Different tillage and residue retention practices significantly influenced TOC stock in different treatment plots at different depths. T7 (ZTDSR-ZTW) recorded significantly higher TOC stock (48.08 Mg C ha^{-1} soil) as compared to other treatments in the total depth of soil studied. On the contrary, T1 (RPTR-CTW) showed significantly lower C stock (30.27 Mg C ha^{-1} soil) than all other treatments. On an average, TOC stock in different treatments follows the order: T1 (30.27) < T3 (30.90) < T6 (33.04) < T2 (33.87) <T4 (34.20) < T5 (40.08) < T7 (48.08 Mg C ha−1 soil). Maximum accumulation of SOC (18.29 Mg C ha^{-1}) in top depth of soil was observed under T7 followed by T5 (14.87 Mg C ha^{-1}) SOC accumulation reduced in lower depths (Table 3). In 10–20 cm depth significantly low SOC was observed in S4 (10.07 Mg C ha^{-1}). In 20–30 cm soil depth significantly greater SOC accumulation was recorded in T7 (13.79 Mg C ha^{-1}). Therefore, we concluded that improvement in soil quality (soil carbon, nutrient retention, structure, microbial activity and soil enzyme activities) in intensively cultivated rice-wheat crop area, is feasible by implementing zero till technology, and by applying crop residues including leguminous species in cropping sequence. In particular, the combined treatment of ZT in rice and wheat, one third crop residue retention and planting of leguminous species (ZTDSR+ZTW) can be considered an effective technology, due to its rapid improvement of soil quality, for carrying out sustainable agriculture in the EIGP.

CSISA experiment at ICAR-RCER, Patna farm

Litter bag experiment for surface and sub-surface residue decomposition study

Conclusion

The climate change is one of the most potent environmental challenges that have great implications on global food production system. The faulty agricultural practices like continuous tillage and traditional method of rice cultivation add considerable amount of greenhouse gases to the atmosphere. Many resource conservation practices have been identified by the researchers which reduce the emission of greenhouse gases from agricultural lands. Therefore, to avoid the risk of climate change, resource conservation practices which mitigate the emission of greenhouse gases needs to be promoted to meet out the food demand of the ever increasing population in future.

Sustainable intensification through conservation agriculture-based agronomic management in Indian agriculture

R.K.Malik[1], J.S. Mishra[2] and SP. Poonia[3]
[1,3]CIMMYT-India, rk.malik@cgiar.org,
[2]ICAR Research Complex for Eastern Region, Patna

For the past 50 years, the growth in agriculture was the result of technological innovations in the form of green revolution. When combined with increased use of external inputs, the benefits were even greater. With the result, supply exceeded demand and real prices of food such as cereals went down and boosted the average income of farmers. However, the yield growth rate of many crops especially cereals have started declining. Reasons for declining in the productivity growth are multiple. The second generation problems especially problems related to insect pest build-up, soil health and water scarcity are important reasons for such a downtrend. We must raise the total factor productivity on small farms a lot faster. Sustainability and profitability in agriculture is the lifeline and future of Indian economy with more than 60% people living in rural areas. The challenges are enormous ranging from conservation of natural resources to investing in new technologies based on biotechnology.

Green revolution technologies

The green revolution is one of the most striking success stories of post-independence India. The success was reflected through more efficient dry matter partitioning to reproduction and therefore, higher harvesting index with significant gain in the yield potential. It is the combination of green revolution varieties and their responses to external inputs, which produced meaningful advances in agriculture productivity. More than 90% farmers have adopted semi dwarf wheat by 1997 (Pingali 1999). However, the share of new varieties of wheat and even rice (except hybrid rice) towards productivity growth has declined in the recent past. It is not easy to escape a general relationship between grain productivity and fertilizer nitrogen especially after the evolution of semi dwarf varieties. It is estimated that irrigated lands have expanded to reach 268 m ha with 80% in developing countries and much in Asia. This expansion is now slowing down (FAO 1998). In addition to nitrogen fertilizer, there has been a consistent increase in the use of external inputs including irrigation and pesticides. Thanks to green revolution, the higher food availability without using the extra land represents a success story in agriculture
Regardless of boundaries, the green revolution has propelled competitive advantage to growing population of developing countries with less or no dependence on developed countries for food supplies. The growth opportunities for crops like wheat in developing countries were even more than the developed countries (Table 1).

Table 1. World major wheat producers

Countries	1961	1970	1980	1990	2000	2003	%
	(Million tons)						
China	14.3	29.2	55.2	98.2	99.6	86.1	602

India	10.9	20.0	31.8	49.8	76.4	65.1	597
USA	33.5	36.8	64.8	74.3	60.8	63.6	190
Russian Federation*	56.7	91.3	92.2	101.2	34.5	34.0	60
France	9.6	12.6	23.7	33.4	37.4	30.6	318
Australia	6.7	7.9	10.9	15.0	22.1	24.9	372

*Before 1990 the numbers are given as for the USSR.

Source: FAO statistical database. 2004. Available from: http:/faostat.fao.org

It was not varieties alone which transformed the food production scenario, but the response of these varieties to external inputs that brought about a major change in the food production. The gross consumption of fertilizers increased 25 fold in developing countries to reach 91 m t in 2002, but only increased 2 fold in developed countries. The use and rates in the developing countries surpassed that in the developed countries in the early 1990s (Cassman *et.al.*, 2003). The green revolution has slowed sharply, as has yield growth, since the 1980s. The slow down or even reversal has been due to water table lowering due to ever deeper tube wells, micronutrient depletion, mono-culture, reducing bio-diversity and buildup of insect, diseases and weeds, development of resistance against pesticides and high concentration of pesticides or fertilizer-derived nitrates and nitrites in water courses. The amelioration of above factors adds to the cost of cultivation and therefore, a decline in the total factor productivity. The high proportion of agriculture dependent population in developing countries (Table 2) has to be backed by science based agricultural transformation especially when the yield growth in cereals has fallen sharply (Paroda 2004). To find solutions for such new emerging problems, we need to do two things:

1. Mobilizing savings by channeling them to most productive uses. The components that we need to target are saving in energy, labour, water and even inorganic nutrients.
2. Evolving technologies which can facilitate the efficient use of natural resources.

Seen from profitability point of view, it will be important to maintain natural resources. Sustainable intensification therefore, has become a critical component to growth in agriculture. These technologies require complementary innovations through multi-disciplinary, multi-institutional and farmer's participatory approach. This is important because the livelihood of more than a billion agricultural populations in developing countries will depend on technologies that raise outputs per labour-hour and per unit area at less cost (Lipton 2004).

Table 2. Dynamics of total and agricultural population in Asia (million people).

Year	China		India		Indonesia	
	Total Population	Agricultural	Total Population	Agricultural	Total Population	Agricultural
1950	557	491	358	269	80	60
1960	661	547	442	312	96	69
1970	835	651	555	375	120	75
1980	1004	742	689	442	150	81
1990	1161	835	845	492	182	93
2000	1282	854	1008	541	212	94
2001	1292	853	1025	545	215	93

Source: FAO statistical database. 2003. Available from: http://faostat.fao.org/faostat/collections?subset=agriculture

Soil degradation

Soil degradation encompasses several issues at various spatial and time scales. Acidification is the change in the chemical composition of the soil, which may trigger the circulation of toxic metals. Eutrophication may degrade the quality of ground water. Groundwater over abstraction may lead to dry soils. Atmospheric deposition of heavy metals and persistent organic pollutants may turn soils less suitable to sustain the original land cover and land use. A report submitted on behalf of UNEP in 1996 have shown various parameters of soil degradation (Table 3.)

Table 3. Degradation of Indian soils (Anonymous, 1996).

Classification of Indian soil degradation	Area (Mha)	Percent
Water erosion loss of top soil terrain Deformation	132.5 16.4	40.3 5
Wind erosion loss of topsoil terrain Deformation/overblowing	6.2 4.6	4.1 1.9
Chemical deterioration loss of nutrients Stalinization	3.7 10.1	1.1 3.1
Physical deterioration waterlogging	11.6	3.5
Land not fit for agriculture	18.2	5.5
Soils with little or no degradation	90.5	27.5
Soils under natural condition	32.2	9.8
Total	328.7	100.0

State of India's Environment (A Quantitative Analysis):[Report No. 95EE52, Submitted on behalf of United Nations Environment Programme (UNEP), Bangkok, South Asia Cooperative Environment Programme (SACEP), Sri Lanka], 1996

Nutrient mining

India has made remarkable progress in NPK consumption and production. The use has raised from 65,000 tons in 1951 to 17.36 M t (11.31 N + 4.38 P_2O_5 + 1.67 K_2O) in 2002 a raise of 267 times. Intensity of NPK use in India has grown from 0.56 kg/ha/year in 1951-52 to 90.1 kg/ha/year in 2001-02. This steep increase in NPK consumption translates into an average addition of 0.34 M t /year. With that impressive record, India ranks third in the world and shares 13% of the global fertilizer consumption. Indigenous production counts for about 95% N and 88% P. Entire amount of K use is met through imports (Tiwari, 2003).

Table 4. Soil fertility management and SOC content of soils in India (1971-1989). Adapted from Nambiar and Meelu (1996). NPKSM refers to nitrogen, phosphorus, potassium, sulfur and manure, respectively.

Treatment	SOC content (%)					
	Alluvial	Vertisol	Redloam	Laterite	Sub-mountain	Foot hill
Initial (1971)	0.21	0.59	0.45	0.27	0.79	1.48
Unmannered	0.27	0.63	0.30	0.43	0.74	0.54
NPK	0.30	0.56	0.35	0.56	0.96	0.86
NPKSM	0.40	1.11	0.38	0.80	1.57	1.45
CD (P=0.05)	0.03 Ludhiana	0.06 Jabalpur	0.01 Ranchi	0.12 Bhub	0.23 Palampur	0.08 Pantnagar

Over the years N consumption has increased progressively. Consumption of P has also increased till 1990-91 but the decline in 1992 due to the decontrol of P-fertilizers restricted its positive balance and widened the N:P use ratio from 2.7:1 to 3.9:1. The use of K in Punjab is almost negligible but its removal is 19 and 150% greater than that of N and P, respectively. Mining of soil K has thus progressively increased and the present K balance in all the zones is negative. Current status of S balance is negative with mining of 80 thousand tones S annually in the state S deficiency is a limiting factor in the production of oilseeds and pulses, and for cereals

Despite high crop requirement and low nitrogen efficiency there seems to be no mining for nitrogen phosphorus but potash is a worrisome issue. This data (Table 4) have been recalculated by Tiwari (2003) on the basis of assumption made by Katyal (2001).

Table 5. With these assumptions, N, P and K balance pertaining to 2020 (Tiwari 2003)

Nutrient removal (M t)	Nutrient additions* (fertilizers + manural sources (M t)	Effective nutrient additions** (M t)	Balance*** (M t)
Nitrogen (N) 11.87	24.30 (20.74)	12.15	0.28
Phosphorus (P) 5.27	7.82 (6.77)	7.82	2.55
Potassium (K) 20.32	12.22 (2.06)	12.22	-8.10
N+P+K 37.46	44.34 (29.58)	32.19	-5.27

* Pertain to projected fertilizer-nutrient consumption plus additions from natural sources. Figures in parenthesis are the projected fertilizer-nutrient consumption.

** Represent nutrient additions times respective efficiency factor for N (0.5), P(1.0) and K (1.0).

*** Calculated by difference between respective figures in columns 1 and 3.

Future research should be oriented to improve the soil fertility and arrest further mining of nutrients. The argument for decline in total factor productivity especially in rice-wheat cropping system is partly explained by soil health issues (Harrington et.al. 1992). These arguments show that:

1. The nutrient deficit in rice-wheat cropping system is the gap between crop removal and the addition of fertilizer through external source.
2. The deficit of nutrient is partly responsible for decline in the yield growth.
3. The deficit would increase farmers spending on inputs which in term would further decrease the total factor productivity.
4. Among many contingency plans that we are focusing on soil fertility are not considering any other agronomic management option except for all kinds of options within nutrient management including biofertilizers. This should change.

Another way of looking at this deficit is that farmers need to save somewhere and invest in integrated nutrient management for decreasing the deficit. This can only happen through direct savings (cost of cultivation) or indirect savings (through improving soil health). This argument is further justified by the fact that during the green revolution phase the fertilizer consumption in developing countries increased 25 fold while it increased only 2 fold in developed countries.

Water scarcity

The global water scarcity analysis has shown that upto two-thirds of world population will be affected by water scarcity over the next several decades (Wallace and Gregory 2002). More important, wherever in the world water is scarest, which is mostly in developing countries, irrigation for agriculture gobbles up at least 75% and sometime as much as 90% of the available water. (The Economist, 17 July, 2003). The agricultural community sees continued growth of irrigation as an imperative to achieve the goals adopted to reduce hunger and poverty. International Water Management Institute, Colombo, Sri Lanka estimated that 29% more irrigated land will be required by the year 2025, but productivity gains and more efficient water use might decrease this diversion to 17% (Rijsberman, 2004). Irrigation development has impaired the ability of many eco-systems to provide valuable goods and services and therefore more attention should be given on sustaining the existing sources of irrigation rather than alternative sources. Alcamo *et al.* (2000) projected an 8% increase in the amount of water that should be diverted to irrigation if more sustainable means of production are adopted. The difference between 17% increase and 8% decrease is on the order of 625 km^3 of water, which is close to 800 km^3 of water that is presently used globally for urban and industrial use. Therefore, there should be more emphasis on water conservation and improved efficiency of use and reallocation of water from one use to another, presumably shifting to a higher value use. Gleick (2003) calls for a soft path for water with a focus on overall productivity of water rather than seeking new supplies. That would mean a paradigm shift from supply management to demand management in the form of integrated water resources management. The most tangible proposals that have come out of this direction are: (a) to involve users more in the management of water, often through the establishment of forms of water user associations; (b) to price water and/or make it a trade-able commodity; and (c) establish river basin authorities that integrate the usually fragmented government responsibilities for water into a single authority responsible for a hydrographically defined area, river basin.

The number of tube-wells has grown exponentially in Northwest India. Pump irrigation now dominates gravity irrigation in many countries. In the field, the upper limit of water productivity of well-managed, disease free water limited cereal crops is 20 kg/ha/mm (grain yield per ha water used). If the productivity is less than this, it is likely that major stress other than water stress such as weeds, diseases, poor nutrition or poor inhospitable soil health so, greatest advantages will come from dealing with these first (Passioura, 2004).

A big reorientation of crop and water science is needed. Development of varieties, which can resist moisture stress through the use of biotechnology, is necessary for increasing overall water productivity. There are no immediate prospects of producing GM crops that could greatly improve water productivity. There are hundreds of patents that claim drought tolerance but it is hard to discern any of these likely to influence water productivity in the field (Passioura, 2004).

Reducing non-beneficial evaporation losses in the field will lead to water saving. Changing to non-ponding/non-puddled rice cultures may help solve such problems. The transplanting of rice under non-puddled conditions or under zero-tillage can be an alternative for improving water productivity in the medium soils. This has been successfully demonstrated in the NATP project at CCS HAU, Hisar. Zero-tillage has enabled farmers to sow their wheat crop immediately after rice harvesting and without any pre-sowing irrigation in some cases. The water saving under zero-tillage has been recorded at the time of first post-sowing irrigation (Hobbs and Gupta, 2003) and Malik et al., 2004). Similarly the bed planting of wheat can be used for a significant improvement in the water productivity but the success of this technology will depend on the type of soil and source of irrigation. Laser land leveling is an important component of resource conservation technology that can improve water productivity at field level Gupta (2003).

Under rain-fed conditions a shift towards high productivity, decentralized micro-irrigation system can help saving water. Narayanmoorthy (2004) sees the potential of drip irrigation to help solve the water scarcity in India. The hope of installing rainwater-harvesting structures can shape vegetables or horticulture based cropping system in the profitable proposition. It may not work in cereal based cropping system. To spur entrepreneurialism farmers should be assisted to change from subsistence to commercial objectives.

Resource conservation technologies

An analysis of productivity changes and future sources of growth for the rice-wheat cropping system was undertaken by Joshi et.al. 2003. According to their analysis, productivity gains have slowed down and there is an urgent need for technologies that can prevent any further reduction in the rate of yield decline in the IGP.

The concept of no-till was not new to the IGP and the technology had been tried previously but set aside as it did not ‘fit’ the local farming systems. However, in the (late 1990s there was a key difference – rampant herbicide – *resistantP. minor* was seriously limiting productivity (Malik and Singh 1993, 1995) is one of the most productive agricultural regions in India, if not the world. Consequently, no reasonable management option could be overlooked, including no-till. Due to the seriousness and the scale of the problem, bodies such as ACIAR, CIMMYT and the Rice-Wheat Consortium (RWC), which had also been attempting to introduce reduced tillage systems in this region, supported scientists engaged in this program. Although new herbicides have been the most important tool in the management of herbicide-resistant *P. minor*, (Malik et.al, 1996, 1997, 2000) their rapid adoption was facilitated by the reduction in the cost of cropping brought about by no-till (Malik *et al.*, 2002, 2004).

The soil conservation may be achieved through reduction in soil detachment and its transport by wind. Some of resource conservation technologies which may improve soil structure in favour of soil conservation include growing cover crops, sowing crops with zero tillage, maintaining required level of soil fertility and converting marginal and degraded lands to restorative land use. Incorporating legumes in the continuous monoculture of cereals can restore the soil health. Zero tillage when practiced in conjunction with crop residue and cover crops will improve soil structure and enhance soil organic carbon (Dick *et al*. 1998).

If a farmer follows zero tillage along with residue cover and cover crops, it is easy to track carbon due to increase in soil organic carbon content (Dick *et al*. 1998), decrease in CO_2 emissions caused by frequent tillage (Reizebo and Loerts 1998) and reduction in fuel consumption (Table 6).

Table 6. Reduced CO_2 emission by conservation tillage for a loamy silt soil at Legrand, NE Italy for a 7-year period. (Borin *et al*. 1997).

Parameter	Conventional tillage	Ridge tillage	No tillage
SOC pool (Mg/ha)	48.3	52.5	50.6
?C (kg/ha/yr)	-	593	770
Stored CO_2 in soil (kg/ha/yr)	-	2174	2823
Fuel consumption (kg/ha/yr)	116	64	43
Saved CO_2 in fuel (kg/ha/yr)	-	162	227
Saved CO_2 total (kg/ha/yr)	-	2336	3050

Some concerns have been raised about the long-term effects of no-till on the biotic and abiotic properties of the soil. The uncertainty of long-term effects is unlikely to disappear until its long-term effects are demonstrated by local research undertaken on farmer fields. Scientists at the Haryana Agricultural University established long-term sites under no-till under the ACIAR-funded project which later managed under the NATP project of the Indian Council of Agricultural Research (ICAR). These trials are still continuing. Studies conducted so far have shown that after 15 years at these permanent sites, wheat yields under no-till are consistently greater than under the conventional tillage system. At all of these sites, the planting time for the two tillage systems were either the same or the conventional was sown no more than 4-7 days later than the no-till. No-till technology appears to have solved several problems without creating any new ones.

Savings in irrigation water use are also an important feature of no-till systems. The RW Consortium in collaboration with HAU undertook a detailed investigation of the savings in irrigation water use under no-till (Gupta, 2003). Fields under no-till and conventional tillage systems were selected along an irrigation channel in Haryana to determine irrigation water use. Studies showed that irrigation water used was 13-33% lower in the fields under no-till, which was attributed to lower water infiltration rate under no-till. The overall assessment of irrigation water use by 4 villages in this irrigation scheme showed about 10% saving in water due to the adoption of no-till. Average water use efficiency (kg grain produced/mm water used) was estimated to be 18.3 kg/ha/mm in no-till fields as compared to 12 kg/ha/mm in the conventional tillage fields, an increase of 35%. This improvement in water use efficiency is likely to be related to avoidance of transient waterlogging after the first irrigation, which is a common feature of wheat crops grown with conventional tillage in rice-wheat rotation. Savings in irrigation water can also arise in some seasons when soil moisture content after rice harvest is adequate to sow wheat without any pre-sowing irrigation. To ensure that the no-till technology serves the long-term interest of farmers and the environment, it is important to establish long-term studies by maintaining permanent sites on farmer fields. So far these studies in Haryana have shown no association between no-till and changes in nematode, insect and fungal populations.

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 17 years and should support the cropping system intensification (Ashok Yadav and R.K.Malik, 2016, Per. Comm). From long-term on-farm trials maintained since ACIAR project, it was found that soil health of ZT plots was superior to CT as studied by Ajeet*et al.* (2015). Data show that the carbon stock in surface 0.4 m soil depth increased by 19.0, 34.7 and 38.8% over CT in 15 years in sandy loam, loam and clay loam soil, respectively.

In addition, it was also found that quality of wheat grain was improved under ZT compared to CT. For example, wheat grain grown under ZT had higher protein, grain hardness and chapatti (Indian bread) score from all 4 of rotations (rice-wheat, sugarcane-wheat, pearl millet-wheat and cluster bean wheat) than CT (Coventry *et al.*, 2011). Compared to CT, the grain quality of wheat under long-term ZT (15 years) in sequence with rice, pearl millet and sorghum was superior (Ashok Yadav, Per. comm).

In Haryana, Jaipal et al. (2002) studied the effects of tillage practices of sowing wheat on the spectrum of insect species present over 3 years. On-farm sites (n = 24) were sampled every two weeks during the regular growing season of rice and showed the presence of 61 species of insects and spiders. The number of species present was considerably less in the wheat crop. The spectrum of insect fauna present in and around the no-till wheat fields was substantially richer in beneficial fauna than that found in the vicinity of the conventional tillage fields. The rice stubble may have provided shelter to a variety of spiders, ants, earwigs, lady beetles and bugs. These beneficial fauna were also noticed to take refuge in grasses and other weeds growing on the bunds of wheat fields or nearby wastelands. The no-till sites with rice stubble shaved off or burnt *in situ* harbored lower numbers of natural enemies of pests than those with stubble retained. Such fauna in wheat fields sown with conventional tillage or raised-bed methods was, however, almost absent.

Singh *et al.* (2002) indicated that the population of soil fungi was greater in conventional than no-till fields in Haryana at the Crown Root Initiation (CRI) and dough stage of wheat, while no consistent trend was observed in paddy. *Fusarium* species, *Drechslerarostrata* and *Penicillium* species were predominant fungi in the rhizosphere of wheat and rice. The population of *F. moniliforme* was greater in conventionally sown wheat fields than under no-till. *F. moniliforme*, *F. pallidoroseum*, *D. oryzae* and *D. rostrata* were found to be pathogenic in paddy and *Alternariatriticina* and *Bipolarissorokiniana* on wheat. There was no significant difference between the tillage systems in the incidence and severity of major diseases of rice-wheat sequence in Haryana.

Tillage practices in the extensive rice-wheat cropping systems of Asia are also changing (Hobbs and Gupta, 2003). Surface seeding, in which the wheat seed is broadcast directly on to the saturated soil left by the rice crop, or zero tillage techniques, enable timelier establishment of the wheat crop. The use of raised beds, stimulated by work at CIMMYT, can greatly improve water productivity (Wang *et al*. 2004). With these changes have come the need to avoid the traditional puddling of rice soils, which while it may reduce drainage losses, is not necessarily needed to attain high yields (Hobbs and Gupta 2003).

Organic farming

Contrary to popular belief of sustainable agriculture through organic farming, it is now being reported that if organic farming is widely adopted, lower yields will require 25-82 % more land to sustain food production. This will be contrary to what we gained from green revolution technologies. While examining the implications of organic farming in Europe and Australia, Kirchmann and Ryan, 2004 have concluded that mean yields are generally 25-45% lower on organic farms than on conventional farms primarily due to reduced level of plant available nutrients. In Europe, organic farming increases nitrate leaching, both per unit area and per unit of food produced due to lower N use efficiency (Table 7). Further it has been argued that focus on organic resources and the refusal to include synthetic fertilizers can be best described as recycling poverty in situations like Africa where farming systems have an extremely poor resource base. The soil organic matter content in long term experiments in Norway declined in both conventional and organic farming but it was more in the organically treated soils (Korsaeth and Eltun, 2000) In order to maintain environmental resources locally, it will be better to extract easily soluble inorganic fertilizers from organic wastes through new nutrient recovery technologies. The approach towards organic farming is based on ideology but not on the scientific judgment. Farmers always seek simplicity of information on the far side of such complexities such as this. The prospects of small farmers to benefit from organic farming seem to be less in the light of risk associated with this technology.

Table 7. Nitrogen input, off take and leaching in organic and conventional long-term trials in Sweden {*Torstensson (2003a), **Hessel Tjell et al (1999), ***Torstensson (2003b)}

Experiment and farming system	Organic			Conventional		
	Input	Offtake	Leaching	Input	Offtake	Leaching
	(Kg N ha^{-1} yr^{-1})			(Kg N ha^{-1} yr^{-1})		
Halland-site						
Crops only*	66	30	43	99	79	29
Crops + animals**	120	105	35	113	71	26
Vastergotland-site						
Crops only***	105	42	20	113	85	3
Mean	97	59	33	108	78	19

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Contributors

Dr. B. P. Bhatt
Director, ICAR Research Complex for Eastern Region, Patna- 800014, Bihar

Dr. J.S. Mishra
Head, DCR, ICAR Research Complex for Eastern Region, Patna- 800014, Bihar

Dr. R.K. Malik
Senior Agronomist & Leader, All India CSISA-CIMMYT, Patna, Bihar

Dr S.P. Poonia
Research Platform Co-ordinator CSISA-CIMMYT, Patna

Dr S.K. Singh
Principal Scientist & Head In charge, DLWM, ICAR Research Complex for Eastern Region, Patna- 800014, Bihar

Dr. Rakesh Kumar
Scientist, DCR, ICAR Research Complex for Eastern Region, Patna- 800014, Bihar

Dr. Sanjeev Kumar
Principal Scientist, DCR, ICAR Research Complex for Eastern Region, Patna- 800014, Bihar

Dr. S.K. Naik
Principal Scientist, ICAR-RCER, Farming System Research for Hill & Plateau Region, Ranchi-834010, Jharkhand

Dr. Abhay Kumar
Principal Scientist, DSEE, ICAR Research Complex for Eastern Region, Patna- 800014, Bihar

Dr. Ujjwal Kumar
Principal Scientist & Head, DSEE, ICAR Research Complex for Eastern Region, Patna- 800014, Bihar

Shri K. Koteshwar Rao
Scientist, DCR, ICAR Research Complex for Eastern Region, Patna- 800014, Bihar

Dr. Kirti Saurabh
Scientist, DCR, ICAR Research Complex for Eastern Region, Patna- 800014, Bihar

Dr A. Rahman
Principal Scientist, DLWM, ICAR Research Complex for Eastern Region, Patna- 800014, Bihar

Dr Shivani
Principal Scientist, DCR, ICAR Research Complex for Eastern Region, Patna- 800014, Bihar

Dr S.S. Mali, Scientist
Scientist, ICAR-RCER, Farming System Research for Hill & Plateau Region Ranchi-834010, Jharkhand

Miss Manisha Tamta
Scientist, DCR, ICAR Research Complex for Eastern Region, Patna- 800014, Bihar

Dr S. Mondal
Scientist, DLWM, ICAR Research Complex for Eastern Region, Patna- 800014, Bihar

Dr N Chandra
Principal Scientist, DSEE, ICAR Research Complex for Eastern Region, Patna- 800014, Bihar

Dr S Maurya
Senior Scientist, ICAR-RCER, Farming System Research for Hill & Plateau Region, Ranchi-834010, Jharkhand

Dr B K Jha
Principal Scientist, ICAR-RCER, Farming System Research for Hill & Plateau Region, Ranchi-834010, Jharkhand

Dr I S Singh
Principal Scientist, Research Center Makhana, Darbhanga
Dr N Bhakta
Principal Scientist, DCR, ICAR Research Complex for Eastern Region, Patna- 800014, Bihar

Dr Pawan Jeet
Scientist, DLWM, ICAR Research Complex for Eastern Region, Patna- 800014, Bihar

ICAR Research Complex for Eastern Region

ICAR Parisar, P.O. : B.V. College, Patna - 800 014