भाकृअनुप
ICAR

# Conservation Agriculture

## Mitigating Climate Change Effects & Doubling Farmers' Income


**ICAR Research Complex for Eastern Region**
ICAR Parisar, P.O. : Bihar Veterinary College
Patna - 800 014 (Bihar)

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*Edited by*
J S Mishra • B P Bhatt • Rakesh Kumar • K K Rao

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ICAR Research Complex for Eastern Region, Patna, Bihar

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त्रिलोचन महापात्र, पीएच.डी.
एफ एन ए, एफ एन ए एस सी, एफ एन ए ए एस
सचिव एवं महानिदेशक

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# FOREWORD

India is the second most populous country in the world with a population of 1.35 billion. This population is expected to reach 1.7 billion by 2050, making it as the most populated country in the world. To feed the increasing population food production must increase by 70%. This challenge is critical in view of the declining per capita availability of natural resources, land degradation and soil mining, soil carbon loss, and adverse effect of climate change on agricultural production and environment. The low and highly fluctuating agricultural productivity and farm income are causing a detrimental effect on the interest in farming, and farm investment, and forcing more and more farmers, particularly younger group, to leave farming. It is apparent that income earned by a farmer from agriculture is crucial to address agrarian distress and promote farmers welfare. Realizing the need to pay special attention to the plight of farmers, the Hon'ble Prime Minister of India announced to double the farmers income by 2022 to promote farmers welfare, reduce agrarian distress and bring parity between income of farmers and those working in non-agricultural profession.

Unsustainable use of land in tillage-based conventional agricultural system has a negative effect on the quality of the essential natural resources such as soil, water, biodiversity and associated ecosystem services provided by nature. This degradation in natural resources has resulted in declining factor productivity and crop yields, leading to food insecurity in many regions of the developing world. This is likely to further increase with growing population pressure unless measures are taken to increase the agricultural productivity through more efficient use of natural resources and with minimal impact on the environment. Adoption of conservation agricultural practices based on three principles of minimum soil disturbance, permanent organic cover on the soil surface, and crop diversification is the foundation of a sustainable intensification of crop production since it is economically profitable, environmentally safe, and practically efficient as practiced on over 180 million hectare of cropland worldwide, corresponding to 12.5% of the total global cropland.

I congratulate the ICAR Research Complex for Eastern Region for bringing out this publication 'Conservation Agriculture: Mitigating Climate Change Effects & Doubling Farmers' Income' for sustainable agricultural development in the region. This publication contains the wealth of information on diverse aspects of conservation agriculture and climate change. I am sure that this publication will contribute in pursuit of our quest to find solutions for sustainably enhanced intensified agricultural production.

**( T. MOHAPATRA )**

**Dated the $3^{rd}$ December, 2018**
**New Delhi**

# Preface

Despite its rich endowment of fertile soil, adequate rainfall and sufficient ground water and bright solar radiation, the agricultural productivity in Eastern region is low. Crop production system in the region is still by and large traditional. The conventional agricultural system (excessive tillage, monocropping/cereal-cereal cropping, removal/burning of crop residues, etc) 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. Therefore, a paradigm shift in farming practices through eliminating unsustainable parts of conventional agriculture is desired for sustaining productivity of natural resources. Rice is the principal crop grown during rainy season, succeeded by wheat/ pulses, oilseeds in rice-based cropping systems. But, the system productivity is quite low due to late harvest of long-duration rice varieties and delayed sowing succeeding crops. Conservation Agriculture (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. Serious efforts have been made by the research organizations and the State Governments to develop and promote resource conservation technologies in the region for improving productivity and profitability. However, a coordinated effort involving multi-stakeholders to make the farmers aware and demonstrate the technologies on a large scale is needed. Further, necessary back-up in the form of suitable farm machinery, training, credit and government policies is required to be provided to enable farmers adopt these technologies.

To address the above issues and enhance the knowledge base of the researchers, policy makers and other stakeholders, and further to expose them to the developments in conservation agriculture and climate change for climate resilient agriculture and increasing farmers' income, Ministry of Agriculture, Government of India Sponsored Model Training Course on 'Conservation Agriculture: Mitigating Climate Change Effects & Doubling Farmers' Income' was organized at ICAR Research Complex for Eastern Region, Patna during 11-18 September 2018. This publication is the outcome of compilation of lecture notes/book chapters of above training course. This book contains 34 chapters dealing with the conservation agriculture and climate change for climate resilient agriculture and increasing farmers' income 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 book 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. We firmly believe that this publication will be highly useful to the researchers, policy makers, students and other stakeholders.

Editors

# 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 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 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, 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. 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

**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.

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*). 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 productivity 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 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 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 machine, KVK started front line demonstration 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.

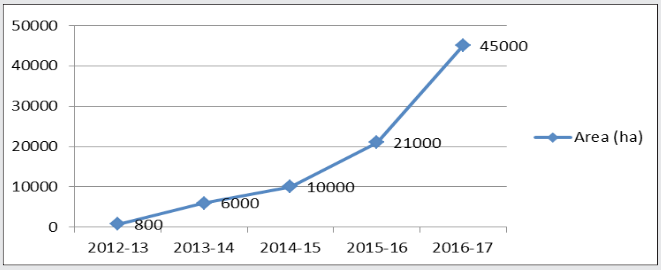


Fig. : Area (ha) expansion of zero tillag e wheat sowing

**Economics of Zero tillage in wheat6**

| Year | Average yield (t/ha) | Cost of cultivation (Rs/ha) | Gross returns (Rs/ha) | Net returns (Rs/ha) | Benefit:cost 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

**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. Previously, Sanjeev kumar was cultivating his land traditionally with minimum application 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 successfully through applying these conservation agriculture technologies, which, according to him, has brought about several benefits like reduction in cost of production, 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 Vaishali 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 farmers 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 witnessing 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 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 need to be ensured.

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# Climate Change Scenario and Technological Options for its Adaptation

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Human interferences such as industrialization, deforestation, faulty agricultural practices heavy use of fertilizers have increased atmospheric concentrations of greenhouse gases (GHG) such as carbon dioxide, methane and nitrous oxides. Climate change has become a common phenomenon now a days as experienced due to increasing $CO_2$ level, temperature, erratic rainfall, frequent drought and other extreme weather events. Carbon dioxide is the major contributor among the greenhouse gases causing global warming. Intergovernmental Panel on Climate change (IPCC 2007) estimates that the current atmospheric $CO_2$ concentration has been increased more than 50% with respect to the preindustrial concentration. There is growing evidence that these changes are impacting the physical processes, species and ecosystems globally. The increasing level of $CO_2$ concentration is accepted to have substantial effects on the world's ecosystems by directly affecting plant growth and development. The enhanced levels of $CO_2$ affects the rate of photosynthesis causing mismatch in the C:N thereby affecting the agricultural productivity. The International Geosphere – Biosphere programme determined the direct (e.g. photosynthesis, growth) and indirect (climatic change responses) effects of elevated $CO_2$ and other trace gasses on agricultural and natural ecosystems.  The atmospheric general circulation model (GCM) predicts an increase in mean surface temperature of several degrees with a doubling of current $CO_2$ concentration (Watson *et al*. 1990).

The most reliable climate change projections for India under A2 and B2 scenarios have so far been made by the Hadley Centre, UK, and IITM, Pune, using a regional climate model, PRECIS. It suggests that by the end of 21st century the mean annual surface temperature of the country may increase by 3.0-5.0 $^{o}$C under A2 scenario and by 2.5-4.0 $^{o}$C under B2 scenario, with warming more pronounced in the northern part (Rupa Kumar *et al.* 2006). Temperature rise over India is expected to be uniform over most of the country while slightly more warming over NW region is expected.  The expected warming by 2070 is likely to be 1.5 to 2.0$^{o}$C over most parts of the country. The simulation results also suggest that the pre-monsoon period (March-May), which is normally dry, may experience 30- 50% higher rainfall across the region while the post-monsoon period (October-November) may witness 10-20% higher rainfall in the central part and a decline by 5-15% elsewhere. Along with these changes the rainy days are expected to be fewer by about 10 days in a year in the northern half of Rajasthan, Punjab and Haryana states, while the south-western part of Rajasthan and adjoining arid Gujarat may have rainy days fewer by ~5 days. Extreme rainfall events are likely to increase along the west coast, west central India and NE region.

The increased atmospheric temperature has impacted distribution of plant species, plant community composition and functioning of ecosystem. Out of the total anthropogenic $CO_2$ emission almost half of it accumulates in the atmosphere and rest is absorbed by sinks in the ocean and the terrestrial ecosystems. Natural $CO_2$ sink strengths are varying with time and space and accordingly are the changes in weather and climate. The assessment of impacts, adaptation, and vulnerability in the Working Group II contribution to the IPCC's Fifth Assessment Report 2014 (IPCC, 2014; WGII AR5) evaluates how patterns of risks and potential benefits are shifting due to climate change. It considers how impacts and risks related to climate change can be reduced and managed through adaptation and mitigation. The report assesses needs, options, opportunities, constraints, resilience, limits, and other aspects associated with adaptation.

In India, as per prediction crop yield will be reduced by 4.5 to 9 per cent, which is roughly up to 1.5 % of GDP per year (Venkateswarlu *et al.* 2013) with medium-term climate change (2010-2039). Climate change impact will be more negative on rainfed agriculture which constitutes nearly 58 % of net cultivated area. As per various reports and prediction models, climatic changes are likely to aggravate the problems of future food security by exerting pressure on agriculture. The yield reduction is likely brought out by many factors including pests, weeds and diseases, loss of biodiversity, rise in sea level, saline water intrusion in coastal belts, poor quality of irrigation water, decline in soil fertility, and irregularities in onset of monsoon, heat wave, cold wave, drought, flood and cyclone. There can be positive as well as negative effect of climate change on yield. Therefore, it is of utmost importance to enhance resilience of agriculture to climate change through technological options and planned adaptation.

The adaptation strategies would initially benefit from the technologies developed so far in this fragile ecosystem to combat drought and desertification, especially the improvements made in the traditional wisdom for water resources conservation and use, agroforestry systems and mixed cropping, etc. Efforts would then be required to enhance crop resilience and adaptation to climate change for sustainable production, food and nutrition security. This may be achieved by developing varieties of arid crops that are tolerant to flowering time high temperature, extra early varieties for shortened moisture availability period and varieties with terminal drought tolerance. Developing varieties with in-built developmental plasticity, i.e., that are early-maturing and capable of yielding grain under short dry periods but should have the ability to make best use of high moisture availability during good rainfall years by prolonging their vegetative phase, resulting in higher grain and fodder yield. Concerted efforts are also required to understand the mechanism involved in controlling heat and terminal drought tolerance to identify genetic stocks for the traits correlated with these stresses, e.g., as in the case of pearl millet. Efforts are needed to enhance soil organic carbon for improving soil health and sustainability. Carbon sequestration potentials of the arid areas need to be assessed for developing strategies on re-vegetation of wastelands.

The farming systems provides the direct benefit of sustainable production and help in carbon sequestration, soil enrichment, biodiversity conservation and improve air and water quality. Conservation of biodiversity and mitigation of GHG are the major environmental challenges in today's perspective and this has become the major political and scientific concerned at the global level. At the same time there is need for integrating food production with environmental services through farming systems.

## Climate Change Scenario in India

In India agriculture contributes to the global warming through emission of carbon dioxide ($CO_2$), methane ($CH_4$) and nitrous oxide ($N_2O$). As per report of The Indian Network for Climate Change Assessment (INCCA, 2010), that the net Greenhouse Gas (GHG) emissions from India in 2007 was 1727.71 million tons of $CO_2$ equivalent (eq) which includes:

- $CO_2$ emissions (1227.76 million tons);
- $CH_4$ emissions (20.56 million tons); and
- $N_2O$ emissions (0.24 million tons)

On per-capita basis, India is one of the lowest Greenhouse Gas (GHG) emitters in the world. Its emission of 1.18 tonnes of $CO_2$ equivalent per capita in 2008 was nearly one-fourth of the corresponding global average of 4.38 tonnes. GHG emissions (net $CO_2$ equivalent emissions) were made in energy (57.8%), industry (21.7%), agriculture (17.6%) and waste sectors (3%). In the agricultural sector major sources are enteric fermentation (63.4%), rice cultivation (20.9%), agricultural soils (13.0%), manure management (2.4%) and on-field burning of crop residues (2.0%) (Pathak and Agarwal 2012). Thus, rice cultivation, soils, and field burning of crop residues contributes 35.9% of the total emissions from agriculture (INCCA 2010).

## Impact of Climate Change on Agriculture

Inter-Governmental Panel on Climate Change has projected have predicted that by the end of this century, global earth temperature is likely to increase by 1.8 to 4.0°C. This will cause frequent drought, heat waves, erratic rainfall and. The incidence of pests and diseases would be significantly increased. This will cause instability in food production and will threaten farmers' food security. Increase in global temperature will have major effect on plant species composition, distribution, production and carbon accumulation and its partitioning in above and below ground parts as well as in the soil. The projected increase in atmospheric $CO_2$ and temperature and their effect on agriculture is given in Table 1.

In India, as per prediction crop yield will be reduced by 4.5 – 9.0 per cent, which is roughly up to 1.5 % of GDP per year (Venkateswarlu *et al.* 2013) with medium-term climate change (2010-2039). Climate change impact will be more negative on rainfed agriculture which constitutes nearly 58 % of net cultivated area. As per various reports and prediction models, climatic changes are likely to aggravate the problems of future food security by exerting pressure on agriculture. The yield reduction is likely to be brought out by many factors including pests, weeds and diseases, loss of biodiver-

**Table 1. Effect of climate change on agriculture (with no climate policy interventions)**

| | 2025 | 2050 | 2100 |
|---|---|---|---|
| $CO_2$ Concentration | 405 – 460 ppm | 445-640 ppm | 540-970 ppm |
| Global mean temperature changes from 1990 | 0.1-1.1 $^{O}C$ | 0.8-2.6 $^{O}C$ | 1.4-5.8 $^{O}C$ |
| Global mean sea level rise from 1990 | 3-14 cm | 5-32 cm | 9-88cm |
| Agricultural effects | | | |
| Average crop yields | Cereals crop yield increase in many mid and high altitude regions. Cereal crops yields decrease in most tropical and subtropical regions | A mixed effect on cereal yield in mid latitude regions. More pronounced cereal yield decreases in tropical and subtropical regions. | General reduction in cereal yields in most mid latitude regions for warming of more than a few $^{0}C$. |
| Extreme low and high temperatures | Reduced frost damage to some crops. Increased heat stress damage to some crops. Increased heat stress in livestock. | Effects of changes in extreme temperatures amplified. | Effects of changes in extreme temperatures amplified. |
| Income and prices | - | Income of poor farmers in developing countries decreases. | Food prices increase relative to projected that exclude climate change |

(*Sources:* Anonymous)

sity, rise in sea level, saline water intrusion in coastal belts, poor quality of irrigation water, decline in soil fertility, and irregularities in onset of monsoon, heat wave, cold wave, drought, flood and cyclone. There can be positive as well as negative effect of climate change on yield. Therefore, it is of utmost importance to enhance resilience of agriculture to climate change through technological options and planned adaptation.

## Impact of Elevated $CO_2$ on Carbon Assimilation and Biomass Production

Majority of plants have $C_3$ and $C_4$ photosynthetic pathways and it is generally agreed that the growth of plant with the $C_3$ pathway is stimulated more by $CO_2$ enrichment than the $C_4$ plants (Imai and Murata 1979). Kimball (1983) reported biomass increase in response to a doubling of ambient $CO_2$, which range from 10 to 43% in $C_3$ crop plants and 24% in $C_4$ plants. Wand *et al*. (1999) reported growth enhancements of both $C_3$ and $C_4$ grasses with elevated $CO_2$, although greater responses were in $C_3$ grasses. While photosynthesis in $C_4$ plants can respond directly to increases in $CO_2$ above present atmospheric concentrations (Le Cain and Morgan 1998), the response is considerably more limited compared to that of $C_3$ species.

In Indian arid and semi arid region, forage species particularly perennial grasses cover large land area and can serve the major sink of increased atmospheric carbon dioxide. Therefore, the dominant grasses (*Cenchrus ciliaris* and *Panicum maximum*) and legumes (*Stylosanthes hamata*) were evaluated for resilience under elevated $CO_2$ (600±50 ppm) in side open top chambers (OTC) for their growth, photosynthesis and dry matter accumulation. (Bhatt *et al*. 2007a, 2008, 2010). The canopy photosynthesis (PN x LAI) increased by 2.5 folds in *C. ciliaris* and 1.55 folds in *S. hamata* under elevated $CO_2$ (600±50 ppm) over the open field grown crops whereas in *P. maximum* canopy photosynthesis increased by 152%. The dry biomass accumulation increased by 2.52 folds and 1.76 folds in *C. ciliaris* and *S. hamata* respectively under elevated $CO_2$ over the open field grown crops. The increase in biomass production may be due to enhanced rate of photosynthesis and higher fixation of carbon and its allocation to the plant components. (Pal *et al.* 2004) also observed increased leaf size, plant height and dry mass of shoot in *Trifolium alexendrinum* under elevated $CO_2$. Increase in canopy photosynthesis and dry matter accumulation under elevated $CO_2$ indicating that these crop species should be promoted for carbon sequestration in the tropical environment. These results revealed that these fodder crop species have the potential to assimilate atmospheric $CO_2$ even under increasing level of $CO_2$ (600±50ppm) and therefore will help in understanding the relationships between productivity and $CO_2$ assimilation in different agro-ecosystems in monoculture and intercropping systems.

## Technological Options for Climate Change Adaptation

### 1. Development of drought and heat tolerant varieties

Research and development efforts are requisite at genetic, physiological, biochemical and molecular level to identify traits associated with heat, drought and salinity tolerance. Physiological manipulations are required to **e**nhance the source - sink potential, light use efficiency, nutrient use efficiency, photosynthetic water use efficiency, low photorespiration and higher carbon economy. Plant architecture and in particular root structure play significant role to enhance the crop productivity. In recent advances, phenomics of physiological traits and identification of QTLs and modelling play significant role in developing the climate resilient genotypes. Large number of QTLs have already been reported for several traits in various crops related to drought tolerance. Carbon isotopes discrimination (CID), canopy temperature (CT), water-soluble carbohydrates and chlorophyll fluorescence analysis have become the most widely used techniques available to plant physiologists. Developing climate resilient varieties having in-built plasticity with early-maturity and potential to produce grain under dry periods but at the same time also having the ability to make best use of high moisture availability during good rainfall years, resulting in higher grain and fodder yield besides being tolerant to high temperature at flowering and grain filling stage is important. Amalgamation of molecular biology, genetics, genomics and plant physiology with breeding is essential to develop the climate resilient genotypes. Such strategies will have combined benefits for climate change mitigation and adaptation.

### 2. Crop diversification and intercropping

In the present scenario of climate change sole cropping is risky in the low rainfall zone resulting in lower yield. In such areas intercropping is a feasible option to minimize the risk of crop production, ensure reasonable returns at least from the intercrop and also improve soil fertility with a legume intercrop. Cotton, soybean, pigeonpea and millets are the major crops in the scarce rainfall zones. Intercropping of these crops is more profitable and is a key drought coping strategy. In the rainfed condition of Rajasthan, cluster bean, moth bean and mung bean traditionally grown as a mixed crop with pearl millet and sesame. These crops can be successfully grown in 2:1 row proportion of pulses and pearl millet as intercrop. This system is quite resilient as compared to sole cropping. Crop rotation of cluster bean/moth bean/ mung bean with pearl millet/ mustard followed by wheat and cumin is also resilient technology for the region.

### 3. Integrated Farming System

Agriculture is the most important economic activity in India. Although contributing only to about 14% in national GDP, its performance strongly influence other sectors of the economy like livestock, industry, trade and commerce due to strong linkages. Besides, it is the income generating activity of more than two third population of the nation. The progress in Indian agriculture is impressive from a net importer to food surplus Nation producing 260 million tonnes of food grains. To keep pace with the increasing population and their expectations we need to maintain at least 4-5% annual growth rate in agriculture sector. However, challenges exist at mega scale mainly the shrinking land and water resources, decreasing factor productivity and threats of climate change. In Indian context, its impact would be high as more than 60% of agricultural land is rainfed and by now about 50% of land holdings are below 1 hectare and about 80% are less than 2 hectares. In the fragile ecosystems like arid zone where average land holding size though large (>4 ha) extreme weather uncertainties and low production levels have made all categories of farmers equally vulnerable. The objective of any strategy for imparting resilience in agriculture would be to spread the risk and better utilization of available resources.

In areas prone to drought and heat, integrated farming systems such as short duration grain crops along with fodder crops with MPTS (agroforestry, silvopastoral and horti-agri/horti-pasture systems) are useful. The region is highly vulnerable and dependence on single farm enterprise by farmers is risky, therefore, different resilient systems are developed to cope with the harsh climate in the region. Some prominent systems are:

## Agroforestry System

Finding low-cost methods to sequester carbon is emerging as a major international policy goal in the context of increasing concerns about global climate change. Agroforestry can play important role in carbon sequestration because of carbon storage potential in its multiple plant species and soil. Proper management of agroforestry systems can make them effective carbon sinks. Agroforestry systems with perennial crops may be important carbon sinks, while intensively managed agroforestry systems with annual crops are more similar to conventional agriculture. In order to exploit this vastly unrealized potential of C sequestration through agroforestry in both subsistence and commercial enterprises in different agro-ecological zones, innovative policies, based on rigorous research results, have to be put in place. It has also been assumed that rangelands may be a substantial global sink for atmospheric carbon. The significant increase in soil organic carbon sequestration, forage production and forage quality demonstrate the potential of this practice to improve rangeland health and assist in the mitigation of elevated atmospheric carbon dioxide levels. Afforestation and reforestation, better land cover management practices such as conservation tillage and rehabilitation of degraded lands and pasture lands, and improved livestock management practices can all contribute significantly to reducing carbon emissions.

Lowering the emission of $CO_2$ and low cost technologies for its mitigation are emerging as major concerns of discussion at international level. It has been estimated that the rates of C sequestration is very high through development of silvopasture in the carbon depleted soils because of their diversity of plant species and growth forms, enhanced productivity and ability to accumulate and retain carbon stocks in the soil and in vegetation. The multi-tier agroforestry systems at its active growing phase sequester maximum amount of carbon as compared to monoculture field crops, pasture and mature forests. Restoring of carbon to carbon depleted soils should be the priority in wastelands development which can be met through promoting silvopasture systems, nurse cropping, rehabilitation the land by planting nitrogen fixing trees, native grasses, legumes and other shrubs/tree species. In one of the study under degraded soils in semi-arid tropics of India, the organic carbon stock of soil increased in the range of 3.39 Mg C/ha to 5.40 Mg C/ha and the carbon sequestration in vegetation has been recorded as 10.23 Mg C/ha to 41.00 Mg C/ha under different tree-crop combinations in the active growth stage. The total carbon sequestration in vegetation+soil under different trees+pasture grasses+legume ranged from 13.49 t $CO_2$e/ha/yr to 42.25 t $CO_2$e/ha/yr after four years of system growth (Bhatt and Roy 2012). Under elevated $CO_2$ (600±50 ppm) in OTC the intercropping systems of *Cenchrus ciliaris+Stylosanthes hamata* and *Panicum maximum + S. hamata* sequestered carbon to 41.67 t $CO_2$e/ha/yr and 46.47 t $CO_2$e/ha/yr which were 141.3% and 85% over the crops grown in open field respectively exhibiting the potentiality of these species combinations for mitigating the elevated $CO_2$ (Bhatt *et al.* 2007b). This has suggested that integration of grasses and legumes with or without trees in intercropping systems are the potential viable land use options for mitigation of elevated atmospheric $CO_2$ and maximization of carbon sequestration. Enhancing $CO_2$ assimilation and its sequestration through agroforestry systems, afforestation, perennial pasture development and eco-restoration can be the potential options for carbon farming and green business in the coming years under climate change programme. There must be effective programme about the impact of climate change and its mitigation through agricultural management systems under clean development mechanism with the incentives to the farmers for their environmental services.

Agroforestry systems can be useful in maintaining production during drier years, a common phenomenon in arid and semi-arid regions of India. During complete drought situations, deep root systems of trees are able to explore a larger volume of water and nutrients from deeper soil layers, which help to maintain depleting soil moisture conditions to some extent. In drought prone environment of arid western Rajasthan, as a risk aversion and coping strategy, the traditional agroforestry systems avoid long-term vulnerability as trees act as an insurance against drought, insect-pest outbreaks and other threats, instead of a yield-maximizing strategy aiming at short-term monetary benefits (Rathore 2004).

Integration of trees, agricultural crops, with or without incorporating animals into an agroforestry system has the potential to enhance soil fertility, biodiversity and carbon sequesteration (Nair *et al.* 2009). As per reports, agroforestry has a mitigation potential of 1.1–2.2 Pg carbon over the next 50 years. FAO recognizes the importance of agriculture to achieve global and regional mitigation targets (Marja-Liisa *et al*. 2011). Integration of trees and shrubs with annual crops is the most adapted, climate resilient production system to provide food-fodder-energy along with conserving the natural resources. The system arrests degradation and maintains soil fertility, diversifies income sources, increases and stabilizes income, enhances use efficiency of soil nutrients, water and radiation, and provides regular employment.

**Agroforestry for ecosystem services and environmental benefits**

Agroforestry systems are believed to provide a number of ecosystem services such as: (i) carbon sequestration, (ii) biodiversity conservation, (iii) soil enrichment and (iv) air and water quality improvement. IFS can be a viable land-use option to mitigate and adapt the effect of climate change in addition to alleviating poverty, and also offers a number of ecosystem services and environmental benefits. This realization should help to promote IFS as low cost option to enhance the farmers income and also incentivising the farmers for practicing this system.

**Adaptation through silvopastoral system**

Looking at the demand of forage for livestock and also firewood and timber requirements of human population; silvopasture system that ensures livestock-tree-pasture integration and simulates the multi-storeyed physiognomy of natural forests, is identified as a potential alternate system of land management and climate change adaptation technology in arid and semiarid regions. Area specific silvopasture systems for degraded grazing/forest lands, eroded lands, ravine areas, alkali/sodic soils, water-logged areas and mine spoils have been developed and demonstrated. An account of such models is presented in context of their better management for improving rural living conditions and also to check environmental degradation. Development of silvopasture systems on degraded lands in semiarid regions is considered important to meet the challenges on account of their potential to optimise production and economic returns per unit area besides restoration of hydrological functions and other environmental gains

## Horticulture and Horti-agri System

Horticulture based production system is considered effective strategy for improving productivity, employment opportunities, economic condition and nutritional security. Several drought hardy fruit crops like *Capparis decidua, Salvadora oleoides, Cordia dichotoma, Zizyphus nummularia var. rotundifolia, Z. mauritiana* are suitable for the area receiving rainfall < 300 mm. Several other fruit such as *Embilica officinialis, Punica granatum, Aegle marmelos, Phoenix dactylifera,* and *Tamarindus indica* can be grown in the area having irrigation facilities.

## Conservation Agriculture

Conservation agriculture (CA) 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. CA is in operation by soil tillage, permanent organic soil cover and diversified crop rotations in the case of annual crops or plant associations in case of perennial crops. CA is associated with increased fertility, mineralization of nutrients and to maintain soil moisture over long duration for the use of crop. Conservation Agriculture is climate sustainable technology as it provides sustainable production system, conserving and enhancing the natural resources and increasing the variety of soil biota, fauna and flora. It also act as a sink for $CO_2$ on regional and global level. Farmers should be incentivized for practicing this technology as ecosystem service. CA can be attractive as it allows the reduction of production costs over the years and maintain crop productivity. Three principles of conservation agriculture include; direct planting of crop seeds (Zero tillage), soil cover by crop residues and cover crops and crop rotation. Apart from agronomic and economic benefits CA play significant role in environmental amelioration. It reduces soil erosion, improve water and air quality, increases the biodiversity and carbon sequestration.

## Management of Wastelands/degraded Lands, Grazing lLands and Watersheds

In India large area is under wastelands, watersheds and grazing lands which need restoration and rehabilitation to conserve the natural resources. The grassland and grazing lands serve as major forage to the livestock besides conserving soil and water and also maintaining the soil fertility. Due to degradation the loss of keystone species, the species critical to ecosystem and functioning is a final indicator that irreversible land degradation has occurred. Strategies for sustainable dry land management should therefore, primarily address the maintenance or restoration of soils, rather than species conservation *per se*. Large areas of wasteland available in India may be brought under restoration. Increased forage production from these areas would reduce the pressure from arable lands as well as from available grazing lands. Reduced grazing pressure would lead to diversity richness of range grasses. Controlled grazing as per the carrying capacity has been the proper way to utilize native rangelands. Overgrazing invites annuals and guide biodiversity loss of palatable perennial pasture species.

Re-vegetation is an attempt to provide potential vegetation cover to the degraded lands. This requires long term, medium term and short term strategies for rehabilitation of such grasslands (Pathak and Bhatt 2001). In fact this requires natural resource management to help in conservation, assure biodiversity increase and improve opportunities for higher productivity through effective policies and people's participation. Assisted natural regeneration (ANR) approach for short term restoration of grasslands, watershed approach for speeding the process of re-vegetation and use of nurse crops (eg. leguminous crops) for augmenting the process. Cultivation of leguminous herbs, shrubs and trees works as bio-tillage to improve the soil health through biological nitrogen fixation, use of nutrients from various depths, carbon sequestration, soil enrichment and nutrient recycling, reduction in soil erosion and improvement in soil physical condition.

The existing natural diversity of grasses is depleting fast due to indiscriminate use and several other factors. Under the climate change mitigation and adaptation strategies, it is urgently required to manage these arid grasslands and rangelands through restoration, rehabilitation and convergence. Proper utilization is another way to control the degradation of existing grasslands through people's participation. Now there is need to develop climate smart grassland systems for production and ecosystem services over the years and livelihood sustainability in the hot arid region. Management of grasslands and re-seeding are the utmost adaptation strategies to mitigate climate change.

## Water Harvesting and Management

In the absence of groundwater access, harvesting runoff by constructing farm ponds provides opportunity for supplemental irrigation for small holder farmers in rainfed areas. Rainwater harvesting needs to be promoted at every farm in the rainfed areas as a drought proofing strategy. After saturating the soil profile, rainwater needs to be harvested in a technically planned farm pond of suitable size and type, thus ensuring seepage and evaporation proof storage. Instead of providing irrigation to the entire fields, a selected area with proper protection and/or using polyhouse/ shade nets for high value crops through supplemental irrigation could be a better option to earn remunerative income.

Watershed management and groundwater recharge can be the adaptation approaches to mitigate the climate change. Due to scarcity of surface water, Rajasthan is dependent on ground water resources to a great extent. The mean annual rainfall in Rajasthan is 590 mm. It, however, varies from region to region and from year to year. It ranges from about 350 mm to less than 100 mm in the hot arid region of western Rajasthan. About 80 per cent of the annual precipitation is lost in evaporation and seepage into the soil, less than 7 per cent contributes to the recharge of groundwater. Out of total available surface and groundwater, major portion of water resource is being used for agriculture (>85%). Heavy withdrawal of groundwater for irrigation is resulting in depletion of groundwater table by 0.5 - 0.7 m every year. Constructions of artificial recharge structures in many projects showed that it would be possible to recharge groundwater under different hydrogeological conditions through structures like check dams, sub-surface dykes, gabion, percolation tanks and injection wells. Groundwater aquifer offers feasible alternative to store additional quantity of water available as surplus monsoon runoff. Subsurface storage has some other advantages like little evaporation, widely distributed, operational efficiency and available on demand compared to surface storage of water in reservoirs. Percolation tanks, pondage in stock tanks with infiltration galleries, sand filled dam, anicuts across the stream, sub-surface barriers etc. are used for groundwater recharge.

Adoption of conservation measures like anicuts, loose stone check dams, brush wood check dam etc. in watershed area (Jhanwar watershed, Jodhpur) has resulted in recharge/increase of ground water level @ 0.33 - 0.75 m year$^{-1}$. In another watershed at Osian-Bigmi (1991-96), conservation measures like loose stone check dams; vegetative barriers and anicuts resulted in rise in water table by 1.1 m indicating the effectiveness of conservation measures for the recharge of ground water. Sub-surface barriers constructed across ephemeral streams traps sub-surface flow to recharge groundwater aquifer.

In integrated watershed management, *in-situ* moisture conservation should be given top priority by adopting appropriate techniques such as formation of contour, bunding, stone/sand walls, cultivating on contour and bunds, nurse crop cultivation, soil organic matter amendments and cultivation of perennial crops as per the slopes and soil types. Such measures are useful, as water stored in soil is used productively for crop production rather than being lost through unproductive evaporation from storage in tanks. After saturating the soil profile, the excess water should be harvested in a guided manner in farm ponds or other storage structures in the farmers' fields for using it to supplement the crop water demand during dry spells or to grow second crop during the post-rainy season.

To increase the water productivity and reduce the evaporative loss of water, the micro-irrigation systems such as sprinklers and drip have been promoted at farmers level under different cropping systems. The micro-irrigation systems can minimise the water loss and save water more than 50% as compared to the conventional irrigation system.

## Future Thrusts

- Adoption of farming systems approach that involves the combinations of crops, livestock, trees, fruit crops, vegetables, etc. depending upon the farm resources.
- Development of early maturing, high temperature and drought tolerant varieties of cereals, pulses, oilseeds and fodder crops.
- Development and introduction of water use efficient crops and cropping systems.
- Development of dual purpose varieties/ hybrids that give high grain yield and good quality fodder.
- Availability of good quality seed and planting materials at affordable prices and effective measures to check the flow of spurious seeds to farmers.
- Development of effective insect and disease management strategies in view of changing climate scenario.

- Popularization of efficient irrigation methods like drip and sprinkler; farmers' involvement for enhancing ground water recharge, water harvesting and water productivity; and cultivation of crops that use water more efficiently.
- Conservation of plant and animal genetic resources.
- Introduction of grasses, appropriate shrubs and trees in community grazing lands and development of common grazing lands for higher carrying capacity with respect to biomass and fodder.
- Creation of fodder banks, popularisation of fodder varieties and their cultivation need high priority.
- Exploitation of under-utilized plants as additional source of income for livelihood security.

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# Concept of Conservation Agriculture and its Role in Management of Rice-Fallows in the Eastern Indo-Gangetic Plains

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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 |

## Conservation Agriculture in Rice Fallows

Sustainable, profitable and resilient smallholder agriculture is the key to food and nutritional security for the growing populations of India. There is a need to increase and diversify food production to meet the increasing food and nutritional demands of growing population, and to provide additional income to smallholder farmers. However, increasing production by expanding the area is limited due to increasing pressure on croplands for alternative uses. Hence, intensification of cropland is an imperative and variable solution.

Rice-fallows are those rainy season rice grown areas which remain fallow during winter season due to lack of irrigation facilities, late harvesting of long-duration high yielding rice varieties, soil moisture stress at planting time of winter crops due to early withdrawal of monsoon, water-logging and excessive moisture during November/December, open grazing practice of domestic animals and problems of stray cattle and blue bulls. As per the recent estimates, approximately 22.3 m ha of suitable rice-fallow areas exist in South Asia, with 88.3% in India, 0.5% in Pakistan, 1.1% in Sri Lanka, 8.7% in Bangladesh, 1.4% in Nepal, and 0.02% in Bhutan (Gumma *et al*. 2016). These areas are suitable for intensification with a short duration (≤3 months), low water-consuming grain legumes such as chickpea, lentils, blackgram, greengram, and oilseeds viz. linseed and safflower, to improve smallholder farmer's incomes and soil health. Eastern region comprising of Chhattisgarh, Jharkhand, Assam, Bihar, Eastern Uttar Pradesh, Odisha and West Bengal accounts for nearly 80% of the total rice fallow area of the country (NAAS 2013).

## Production Constraints in Rice Fallows

**Moisture stress:** Lower soil moisture storage and lack of irrigation facilities are the major crop production constraints in rice fallows. Although rice fallow areas receive normal to high rainfall during rice (*Kharif*) season, most of the rain water is lost due to high runoff and low moisture storage capacity of the soils. Soil compaction after puddle rice restricts water infiltration in to the soil, and development of deep and wide cracks in soils after rice harvest helps in faster depletion of stored soil moisture through evaporation. Soil moisture stress at the time of sowing of fallow season crops results in poor plant stand. Even if the crop is established well with residual soil moisture, lack of winter rains towards reproductive stage often leads to complete crop failure (Ghosh *et al*. 2016). The available soil moisture gets exhausted by the time crop reaches to reproductive stage resulting in terminal drought and heat stress. The other production constraints in rice fallows are listed below:

- Cultivation of long-duration rice varieties.
- Lack of improved short duration varieties and quality seeds.
- Narrow sowing window due to faster depletion of residual soil moisture after rice harvest.
- Lower soil organic matter content due to mono cropping and open grazing, problem of soil acidity and alkalinity.
- Poor soil physical properties after puddled transplanted rice.
- Excessive weed infestation (*Cuscuta* spp. in pulses and oilseeds) and lack of selective post-emergence herbicides to control these weeds in pulses and oilseeds.
- Incidence of rust in lentil, powdery mildew in greengram and blackgram, and wilt complex in chickpea.
- Poor mechanization due to resource poor farmers, small and fragmented land holdings.
- Excessive moisture in coastal region, parts of Bihar and eastern Uttar Pradesh.
- Open animal grazing and problem of blue bulls.

## Management Strategies

**Water harvesting and storage:** For obtaining optimum productivity in rice fallows, it is necessary to have proper soil moisture at sowing and facility of water for at least one life-saving/supplemental irrigation at the most critical stage. Since, plenty of water in these areas is lost during rainy season through runoff; there is a need to harvest this excess rainwater and store in small farm ponds/reservoirs to provide life-saving irrigation to succeeding fallow crop.

**Use of resource conservation technologies:** Resource conservation technologies such as zero/reduced tillage, retention of rice crop residue/mulching at 5t/ha or 30-40 cm stubble have been found effective in soil moisture conservation and increasing the crop yields and monitory returns 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 zero-till sowing of pulses significantly enhanced the productivity of pulses in rice fallows (Ghosh *et al*., 2016). Retaining 30% rice residues on soil surface and ZT sowing with Happy Seeder increased the 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* system of cropping performed better than ZT (with or without mulch), and produced maximum seed yield due to advantage of early sowing and better utilization of residual soil moisture. Among different crops, lathyrus followed by linseed and lentil recorded the maximum yields and profits (Mishra *et al*. 2016). Zero tillage after rice harvest also facilities timely planting of winter season pulses in rice fallows, and helps to escape negative effects of terminal water stress and rising temperature in spring- summer. Results of farmers participatory trials on ZT lentil and chickpea in Eastern-IGP during 2009-10 showed that using ZT with reduced seed rate (30 kg/ha for lentils and 80-100 kg for chickpea), deeper seed placement (5-6 cm for lentils) improved the crop stand establishment, crop productivity and reduced the 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 suitable improved agronomic packages resulted in higher yield (13%) and a reduced cultivation cost by ~ Rs.3,800/ha and thereby increasing farm profitability of ~ Rs.10,000/ha (Singh *et al*. 2012).

**System mode of crop production:** In order to efficient utilization of soil moisture and maximize the system productivity of rice fallows, long-duration rice varieties need to be replaced with short- to medium duration varieties for early harvesting and timely sowing of succeeding crops. Even for *para/utera* (relay) cropping, where seeds are broadcasted in standing rice crop 10-12 days before harvest, rice fields need to be properly levelled for maintaining uniform soil moisture to facilitate uniform seed germination. Mechanical transplanting or line transplanting of rice gives higher yield of fallow *para* crops.

**Suitable crops and varieties**: Growing early-to medium- duration rice varieties enable farmers to advance the sowing of succeeding crops for efficient utilization of stored soil moisture. The residual moisture left in soil at rice harvest is often sufficient to support short duration crops. In Eastern region, short-season pulses like lentil, grass pea (lathyrus), chickpea, field peas, mungbean, urdbean, and oilseeds such as mustard, groundnut, linseed, and safflower could be cultivated profitably

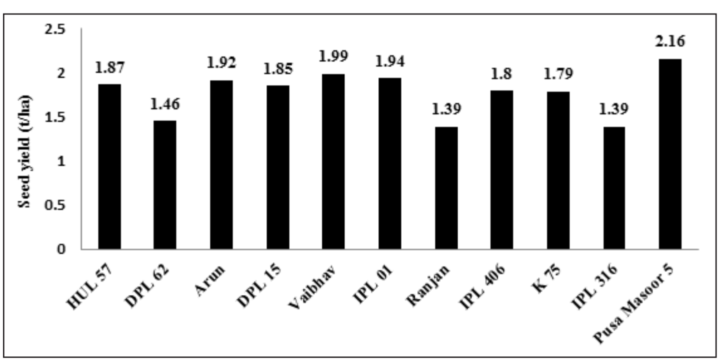


**Fig 1.** Productivity of lentil cultivars under ZT in rice fallows

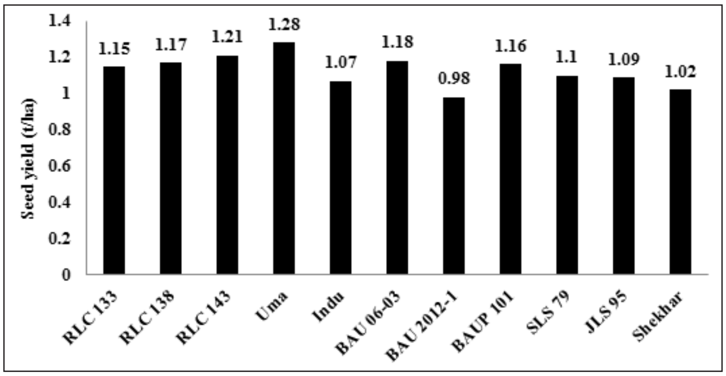


**Fig 2.** Productivity of linseed cultivars under ZT in rice fallows

in rice fallows under zero tillage or *Utera* cropping. In low land areas with excessive soil moisture, lentil and lathyrus can be grown successfully as *Utera* cropping. Small-seeded varieties of pulses have been found better than the large-seeded. In Jharkhand and Chhattisgarh, cultivation of bottle gourd was also found promising with limited irrigation facility. **Lentil** cultivars 'Pusa Masoor 5' , 'Vaibhav', 'HUL 57', 'KLS 218' and 'Arun'; **chickpea** 'C 235', 'Pusa 256', 'JG 14' and 'Vardan; ' **linseed** 'Uma' (1.21 t/ha), 'RLC 143', 'BAU 06-03 and 'RLC 138'; **grass pea** 'Ratan' and 'Prateek' have been found promising in rice fallows.

**Seed priming and optimum seed rate:** Seed priming, i.e. overnight soaking of seeds with simple water or nutrient solution before sowing, is an important low-cost technology to improve the germination and seedling emergence. It is always recommended to increase the seed rate by 20-25% in rice fallows to have a desired plant population.

**Seed treatment and foliar plant nutrition**: Pulses seed should be treated with fungicides followed by *Rhizobium*, phosphate solublizing bacteria (PSB) and Vesicular-arbuscular mycorrhizae (VAM) fungi and *Trichoderma* inoculation before sowing for disease free plant and better nodulation. Foliar spraying of $KNO_3$ and $Ca(NO_3)_2$ at 0.5% significantly improved the yield of grass pea in rice fallows (Sarkar and Malik 2001). Foliar spraying of nutrient solution like urea and DAP at 2% at vegetative stage or before flowering stages enhanced the productivity of pulses (Layek *et al*. 2014).

**Pest management**: Diseases namely root rot, powdery mildew and yellow mosaic, and insects like pod borer cause heavy damage to rice fallow pulse crops. For management of insect-pest and diseases, integrated pest management strategy involving seed treatment with fungicides and bio-control agent *Trichoderma*, selection of disease tolerant varieties and spraying of need-based fungicides/insecticides will be useful. Similarly integrated weed management strategies including crop residue mulching, zero till sowing, application of post-emergence herbicides like quizalofop for grassy weed control and need based manual weeding should be adopted.

## Conclusion

There is a great scope of horizontal increase of area under pulses and oilseeds utilizing rice fallows in eastern India. With appropriate planning and policy interventions combined with efficient crop production technologies, these fallow lands could be converted in to productive lands in a phased manner. Even if 50% (~ 5.0 m ha) of the rice fallows in eastern India with minimum of 0.5t/ha pulse productivity could be brought under pulses, an additional production of 2.5 m tones could be added in national pulse basket, besides improving the soil health. This additional pulse production will not only cut foreign exchange incurred on the import, but also provide nutritional security to weaker sections of the society.

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# Changing Climate Scenario: Possible Mitigation Option to Improve the Crop Productivity in Eastern IGP

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The Eastern Indo Gangetic Plains (E-IGP) comprises of Eastern Uttar Pradesh, Bihar, West Bengal, and plain parts of Assam. Major socioe-conomic constraints of the region are like; small and fragmented farm holdings, lowest per capita availability of land, inequitable agrarian structure, resource poor farmers, and poor infrastructure facilities like roads, communication power supply, storage and marketing (Singh *et al.* 2011). These characteristic features of the region make it difficult to achieve the potential yields of the cultivated crops in the region in spite of the availability of fertile soils, favourable climate and an abundant supply of water. Even though the region receives a fairly good amount of rain (1025 mm to 2823 mm), surface and ground water resources they are grossly underutilized, and therefore a large proportion of the cultivated area does not receive any irrigation water. Owing to poor utilization of water resources, the cropping intensity in the region is low. About 70% of land is prone to natural calamity viz., water logging, flood or drought. Agriculture production systems in the E-IGP are still largely traditional, and often located in less favourable ecosystems as compared to the North-western and Central IGP, resulting in low yield and low farm income (Singh and Kumar 2009). Generally farmers in these areas delay their paddy transplanting as it is dependent on monsoon which later results in low rice yields and consequently they attain low wheat yields also due to delayed sowing. Furthermore, vagaries of rainfall during monsoon season (floods and droughts) aggravate the problem of assured water supply for the crops.

## Climate Change: A Matter of Concern

The impact of climate change on agriculture and food security has become a major issue of concern for researchers and policymakers round the world. Extreme weather events in the form of heat, droughts, floods, and variable rainfall patterns will have a significant negative impact on agriculture production. According to one assessment, by the 2080s world agricultural productivity will decline by 3-16 percent (FAO 2010). There is very good chances of decrease in rice yield up to 5 % for every 1°C rise in temperature above 32 °C (IPCC, 2007). Climate change is expected to significantly modify weather patterns like variations in temperature, rainfall intensity, number of rainy days, and extreme weather events. The E-IGP will also be facing a problem of feeding ever-increasing population under the climate change scenario. The temperature rise may exceed 4°C in parts of northwest India and Bihar. The number of rainy days could decrease by about 15 days in W-IGP and between 5-10 days in E-IGP. An increase in rainfall intensity by 1-4 mm/day in E-IGP and increased frequency of storms would result in flood-drought situation (IWMI 2009). Wheat, a major crop of the IGP, is expected to face a significant risk of reduced productivity due to a rise in winter-season temperatures.

## Observed climatic changes Report by Intergovernmental Panel on Climate Change:

Warming of the climate system is unequivocal, and since the 1950s, many of the observed changes are unprecedented over decades to millennia. The atmosphere and ocean have warmed, the amounts of snow and ice have diminished, sea level has risen, and the concentrations of greenhouse gases have increased (IPCC 2013).

- In the Northern Hemisphere, 1983-2012 was likely the warmest 30-year period of the last 1400 years.
- The globally averaged combined land and ocean surface temperature showed a warming of 0.85 (0.65-1.06) °C, over the period 1880 to 2012. The total increase in average temperature between 1850-1900 period and the 2003-2012 period is 0.78 (0.72- 0.85) °C.
- Averaged over the mid-latitude land areas of the Northern Hemisphere, precipitation has increased since 1901.
- Changes in many extreme weather and climate events have been observed since about 1950. It is very likely that the number of cold days and nights has decreased and the number of warm days and nights has increased on the global scale.
- It is likely that the frequency of heat waves has increased in large parts of Europe, Asia and Australia. There are likely more land regions where the number of heavy precipitation events has increased than where it has decreased.
- On a global scale, the ocean warming is largest near the surface, and the upper 75 m warmed by 0.11 (0.09-0.13)°C per decade over the period 1971 to 2010.
- It is very likely that regions of high salinity where evaporation dominates have become more saline, while regions of low salinity where precipitation dominates have become fresher since the 1950s.
- Over the last two decades, the Greenland and Antarctic ice sheets have been losing mass, glaciers have continued to shrink almost worldwide, and Arctic sea ice and Northern Hemisphere spring snow cover have continued to decrease in extent.
- Over the period 1901 to 2010, global mean sea level rose by 0.19 (0.17- 0.21) m.
- In 2011 the concentrations of greenhouse gases carbon dioxide ($CO_2$), methane ($CH_4$), and nitrous oxide ($N_2O$) were 391 ppm, 1803 ppb, and 324 ppb, and exceeded the pre-industrial levels by about 40%, 150%, and 20%, respectively.

- The ocean has absorbed about 30% of the emitted anthropogenic carbon dioxide, causing ocean acidification.
- Total radiative forcing is positive, and has led to an uptake of energy by the climate system. The largest contribution to total radiative forcing is caused by the increase in the atmospheric concentration of $CO_2$ since 1750.

## Climate Change Scenarios and the Way Foreword

In the Fifth Assessment Report of IPCC, it has defined a set of four new scenarios, denoted as Representative Concentration Pathways (RCPs). They are identified by their approximate total radiative forcing in year 2100 relative to 1750: 2.6 $Wm^{-2}$ for RCP2.6, 4.5 $Wm^{-2}$ for RCP4.5, 6.0 $Wm^{-2}$ for RCP6.0, and 8.5 $Wm^{-2}$ for RCP8.5. These four RCPs include one mitigation scenario leading to a very low forcing level (RCP2.6), two stabilization scenarios (RCP4.5 and RCP6), and one scenario with very high greenhouse gas emissions (RCP8.5). For RCP6.0 and RCP8.5, radiative forcing does not peak by year 2100; for RCP2.6 it peaks and declines; and for RCP4.5 it stabilizes by 2100. In all RCPs, atmospheric $CO_2$ concentrations are higher in 2100 relative to present day as a result of a further increase of cumulative emissions of $CO_2$ to the atmosphere during the 21$^{st}$ century. These projections are relative to 1986-2005 (IPCC, 2013).

- Global surface temperature change for the end of the 21st century is likely to exceed 1.5°C relative to 1850 to 1900 for all RCP scenarios except RCP2.6. It is likely to exceed 2°C for RCP 6.0 and RCP 8.5, and more likely than not to exceed 2°C for RCP 4.5 (Table 1).
- It is virtually certain that there will be more frequent hot and fewer cold temperature extremes over most land areas on daily and seasonal timescales as global mean temperatures increase. It is very likely that heat waves will occur with a higher frequency and duration. Occasional cold winter extremes will continue to occur.
- Extreme precipitation events over most of the mid-latitude land masses and over wet tropical regions will very likely become more intense and more frequent by the end of this century.
- Due to the increase in moisture availability, ENSO-related precipitation variability on regional scales will likely intensify.
- Best estimates of ocean warming in the top one hundred meters are about 0.6°C (RCP 2.6) to 2.0°C (RCP 8.5), and about 0.3°C (RCP 2.6) to 0.6°C (RCP 8.5) at a depth of about 1000 m by the end of the 21st century.
- Reductions in Arctic sea ice extent range from 43% for RCP 2.6 to 94% for RCP 8.5 in September and from 8% for RCP 2.6 to 34% for RCP 8.5 in February.

**Table 1. Projected change in global mean surface air temperature and global mean sea level rise for the mid- and late 21st century relative to the reference period of 1986-2005.**

| | | 2046-2065 | | 2081-2100 | |
|---|---|---|---|---|---|
| | Scenario | Mean | Likely range | Mean | Likely range |
| Global mean surface temperature change (°C) | RCP2.6 | 1.0 | 0.4 to 1.6 | 1.0 | 0.3 to 1.7 |
| | RCP 4.5 | 1.4 | 0.9 to 2.0 | 1.8 | 1.1 to 2.6 |
| | RCP6.0 | 13 | 0.8 to 18 | 2.2 | 1.4 to 3.1 |
| | RCP8.5 | 2.0 | 1.4 to 2.6 | 3.7 | 2.6 to 4.8 |
| | Scenario | Mean | Likely Range | Mean | Likely range |
| Global mean sea level rise (m) | RCP2.6 | 2.4 | 0.17 to 0.32 | .40 | 0.26 to 0.55 |
| | RCP 4.5 | 0.26 | 0.19 to 0.33 | 0.47 | 0.32 to 0.63 |
| | RCP6.0 | 0.25 | 0.18 to 0.32 | 0.48 | 0.33 to 0.63 |
| | RCP8.5 | 0.30 | 0.2 to 0.38 | 0.63 | 0.45 to 0.82 |

## Possible Mitigation Options to Improve Crop Productivity

In order to achieve climate mitigation targets, both $CO_2$ and non-$CO_2$ GHG emissions need to be reduced substantially. Non $CO_2$ emissions contribute about 30% to total global GHG emissions and to radiative forcing. The most important non- $CO_2$ greenhouse gases are methane ($CH_4$) and nitrous oxide ($N_2O$), and agriculture is the largest contributor to these global anthropogenic non-$CO_2$ emissions. Agriculture's non- $CO_2$ emissions account for about 10-12% of total global GHG emissions. The most relevant sources of $CH_4$ emissions are enteric fermentation (32-40% of total agriculture emissions) and paddy rice cultivation (9-11%). The most relevant sources for $N_2O$ emissions are related to livestock (37-77%, mostly from manure) and synthetic fertilizer application (12%) (IPCC 2014). This suggests that the agricultural sector may play a crucial role in climate change mitigation via methane and nitrous oxide abatement.

### Conservation agriculture

Conservation agriculture (CA), mainly promoted for resource conservation and agricultural sustainability, has potential to improve crop productivity, enhance resource use efficiency and also helps cope with some weather extremes. CA-based system substantially reduces the production cost (upto 23 %) but produces almost equal or even higher than conventional system; thereby increasing the economic profitability of production system. CA-based production systems also moderated the effect of high temperature (reduced canopy temperature by 1-4°C) and increased irrigation water productivity (by 66-100%) compared to traditional production systems thus well adapting to heat and water stress situations in IGP. Moreover CA based rice wheat systems emit 10-15 % less GHG than conventional systems (Sapkota *et al.* 2015). Some of the CA-based technologies such as :

- **Laser-aided land leveling** has been found more efficient than traditional leveling, reducing water applications by as much as 40 percent, improving the efficiency of fertilizer, and boosting rice and wheat yields by from 5 to 10 %.
- **Laser-aided land leveling, zero or reduced tillage** (ZT or RT), **crop residue retention** on the soil surface, and crop diversification have been evaluated individually as alternatives to conventional practices, and positive benefits in terms of enhanced productivity and reduced cost have been reported in a range of agro-ecological regions (Laik *et al*. 2014).
- **Alternate wetting and drying** of rice fields where the paddy is flooded and the water is allowed to dry out before re-flooding helps cut water consumption by up to 50 percent.
- Another is **aerobic rice**, where seeds are sown directly into the dry soil, then irrigated. Both approaches result in water savings of 30 to 50 percent.
- Farmers can save fertilizer with **'needs-based' nitrogen management** with the use of leaf color chart indicating the best times for fertilization and legumes in the cropping system. Using the charts, farmers have reduced fertilizer applications by up to 25 percent with no reduction in yield.
- **Raised-bed planting** also produces significantly higher rice yields.
- **System of rice intensification (SRI)** has reported 20%-100% or more increased yields, up to a 90% reduction in required seed, and up to 50% water savings.
- **Integrated Farming System is** known for **i**ntegration of various agricultural enterprises *viz*., cropping, animal husbandry, fishery, forestry etc. and have great potentialities in the agricultural economy. These enterprises not only supplement the income of the farmers but also help in increasing the family labor employment.

### Climate-smart agriculture (CSA)

It includes a number of technological, policy, and institutional interventions (Aggarwal *et al*. 2004) revolving around seed, water, energy, and nutrients and some risk-averting and risk-insuring instruments that increase the resilience and stability of agriculture and thus help farmers adapt to and reduce the risk of climate change. The selection of climate-smart technologies can be done as depicted in Table 2.

## Conclusion

For achieving sustainability of the agriculture production system in E-IGP region and to feed ever-increasing population under prevailing climate change and variability, it becomes necessary to use best practices and technologies to mitigate the negative impacts of climate change. In E-IGP, where the drought and floods are major climatic constraints and delayed sowing of crops leads to economic losses to farming society CA- practices like zero/ reduced tillage as well as CSA- technologies will be an option with strong base to mitigate the ill effects of changing climate as ultimately these technologies results in reduction of greenhouse gas emission, sequestration of carbon dioxide in the soil and increased crop resilience to heat, droughts, and floods.

**Table 2: Selected technology options under CSA**

| CSA technologies | Definition |
|---|---|
| 1.Water-smart technologies | Interventions that reduce water requirements to produce the same or a higher level of yield. |
| Rainwater management | In situ rainwater storage in rice paddies with 20-25 cm bunds. This technique is for rice only. |
| Laser land levelling | Levelling of land with a laser leveller. |
| System of rice intensification | 7- to 10-day-old seedlings are transplanted at 20 cm spacing with 1-2 seedlings per hill. |
| Furrow-irrigated raised bed | Growing crops on ridges or beds. Irrigation is applied through furrows separating the beds. |
| 2. Energy-smart technologies | Technologies that help reduce energy consumption during land preparation without affecting yield levels. These also help reduce water requirements for crops. |
| Direct-seeded rice | Dry seeds are sown either by broadcasting or drilling in line. |
| ZT / minimum tillage | The crop is seeded through a seeder in an untilled field, and the crop residue is incorporated into the soil. At present, this technique is limited to wheat only. |
| 3. Nutrient-smart technologies | Technologies that save/supplement/avoid chemical fertilizer use for crops and enrich carbon in the soil. |
| Green manure | Cultivation of legumes in a cropping system. This practice improves nitrogen economy and soil health/quality. |
| Integrated nutrient management | Integrated use of organic and chemical fertilizers to partially (25 % to 50 %) reduce NPK (nitrogen, phosphorus, and potassium) requirements without affecting productivity and improve soil health. |
| Leaf colour chart | Standardized colour charts are used to identify nutrient deficiency to estimate fertilizer doses in different field locations. |
| 4. Weather-smart instruments | Interventions that provide services related to financial security and weather advisories to farmers. |
| Crop insurance | Crop-specific insurance to compensate income loss due vagaries of weather. |
| Weather advisories | Information and communication technology-based forecasting about the weather. |
| 5.Introduction of stress tolerant crops and diversification | Tolerant crops withstand biotic and abiotic stresses and crop diversification reduces water demands and helps in harnessing nutrients from different soil layers. |
| Drought-tolerant variety | Seed variety that is tolerant to drought or relatively dry weather conditions. |
| Crop diversification (maize-wheat cropping) | Rice is replaced by maize on part of the land to economize on water use. |

*Source:* Taneja *et al.* (2017)

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# Sustainable Intensification through Conservation Agriculture-based Agronomic Management in Indian Agriculture

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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:

- 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.
- 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<br>Deformation | 132.5<br>16.4 | 40.3<br>5 |
| Wind erosion loss of topsoil terrain Deformation/overblowing | 6.2<br>4.6 | 4.1<br>1.9 |
| Chemical deterioration loss of nutrients<br>Stalinization | 3.7<br>10.1 | 1.1<br>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<br>Ludhiana | 0.06<br>Jabalpur | 0.01<br>Ranchi | 0.12<br>Bhub | 0.23<br>Palampur | 0.08<br>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).

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.

**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.

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 (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-resistant *P. 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. 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 *Bipolaris-sorokiniana* 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. 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. 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.

## 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**

| Experiment and farming system | Organic | | | Conventional | | |
|---|---|---|---|---|---|---|
| | Input | Offtake | Leaching | Input | Offtake | Leaching |
| | (Kg N/ha/yr) | | | (Kg N/ha/yr) | | |
| 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 |

{*Torstensson (2003a), **Hessel Tjell ***et al.*** (1999), ***Torstensson (2003b)}

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# Prospects of Organic Farming in Eastern India

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The Green Revolution began in mid-1960s through the introduction of new high yielding varieties of wheat and rice, turned India from 'Begging bowl' to 'Grain bowl'. The food grain production had increased from 82 million tonnes (mt) in 1960-61 to 284.83 mt by 2017-18, with record production of rice (112.91 mt), wheat (99.7 mt), course cereals (46.99 mt) and pulses (25.23 mt). However, the benefits were mainly confined to north-western states of Haryana, Punjab and western Uttar Pradesh. It helped farmers of the region, having good irrigation network and increased the farm productivity substantially over the years. However, the benefits of the Green Revolution could not reach to the Eastern states and other rainfed areas of the country, which contribute about 60% of the country's total food grain production. Though the country could achieve food security through Green Revolution, it laid to over exploitation of natural resources coupled with indiscriminate use of inorganic fertilizers, insecticides and pesticides and thereby declining factor productivity, increasing soil salinity, loss of biodiversity, lowering of ground water table, environmental pollution, pest resurgence, land degradation are some of its consequences. Therefore, the advantages of the Green Revolution have now been masked by the problems posed by it.

The Eastern region of the country comprising of Assam, Bihar, Chhattisgarh, Eastern Uttar Pradesh, Jharkhand, Odisha and West Bengal, holds promise for a Second Green Revolution, which can be accomplished through holistic management of land, water, crops, biomass, horticultural, livestock, fishery and human resources. This region is unique for its suitability to the production of many agricultural commodities. The region has fertile soils and ample water resources, the two most important natural resources required for higher productivity. The majority of the areas in these states have a length of growing period of 240 days or more, which is adequate to support double cropping. Annual rainfall in the region varies from 1000 mm to 2500 mm. Average rainfall during last 14 years was more than 2000 mm in the Lower Gangetic Plains and 1000 mm to 1250 mm in the Middle Gangetic Plains, and Plateau and Coastal regions. Though the region is rich in natural resources, its potential could not be harnessed in terms of improving agricultural productivity, poverty alleviation and livelihood improvement. It is rightfully thought that the second Green Revolution would be started in the Eastern region to ensure food security of the nation. To achieve this, the large untapped production reservoir should be exploited through an appropriate blend of technologies, services, input and output rising policies and above all farmer's participation. However, in second Green Revolution, it is the need of the hour to shift from fertilizer and pesticides based conventional agriculture practices to natural and renewable resource based sustainable agriculture, which is cheap, environment friendly and emphasizes on the conservation of natural resources.

Organic agriculture is a unique production management system which promotes and enhances agro-ecosystem health, including biodiversity, biological cycles and soil biological activity, and this is accomplished by using on-farm agronomic, biological and mechanical methods in exclusion of all synthetic off-farm inputs. It emphasizes the use of natural inputs (i.e. mineral and products derived from plants) and the renunciation of synthetic fertilizers and pesticides. The US Department of Agriculture in 1980 defined the concept of Organic agriculture as "a production system which avoids or largely excludes the use of synthetically compounded fertilizers, pesticides, growth regulators, and livestock feed additives. To the maximum extent feasible, organic agriculture systems rely upon crop rotations, crop residues, animal manure, legumes, green manure, off-farm organic wastes, mechanical cultivation, mineral bearing rocks, and aspects of biological pest control to maintain soil productivity and tilth, to supply plant nutrients, and to control insects, weeds and other pests". The concept of the soil as a living system which must be 'fed' in a way that does not restrict the activities of beneficial organisms necessary for recycling nutrients and producing humus (http://www.fao.org/docrep/003/ac116e/ac116e02.htm accessed on 4th December, 2018).

Organic farming is an approach for sustainable agricultural production without deteriorating soil quality, farm diversity and avoiding hazards to the environment on a long-term basis. The awareness on environmental and health issues associated with modern intensive agriculture has led to an increasing demand for organic products among consumers across the globe. They are rediscovering the benefits of traditional and holistic farming that maintain soil health and biodiversity. In India, about 5.71 million ha area is under organic cultivation (Singh 2017). During 2015-16, India produced 1.35 million MT of certified organic products such as fruits, vegetables, spices, dry fruits, coffee, cereals & millets, oil seeds, pulses, sugarcane, medicinal plants, tea, cotton, etc. Due to the increased demand of organic food and non-food products, the organic farming is becoming a profitable venture. Considering the growing interest towards the organic products government of India during 2014-15, formulated *Paramparagat Krishi Vikas Yojana* (PKVY) under the National Mission on Sustainable Agriculture (NMSA)'. The programme envisages development of 10,000 organic clusters and providing chemical-free farm inputs and increasing the certified area by 5 lakh hectare within a period of 3 years.

## Concept of Organic Farming

Organic farming is very much native to this land. This system was practised in India since thousands of years. The entire agricultural system in traditional India was practised using organic techniques, where animal and plant products were used as fertilizers and pesticides (Mahapatra *et al*. 2009). The concept of organic farming is based on following principles:

- Nature is the best role model for farming, since it does not use any inputs nor demand unreasonable quantities of water.
- The entire system is based on intimate understanding of nature's ways. The system does not believe in mining of the soil of its nutrients and do not degrade it in any way for today's needs.
- The soil in this system is a living entity.
- The soil's living population of microbes and other organisms are significant contributors to its fertility on a sustained basis and must be protected and nurtured at all cost.
- The total environment of the soil, from soil structure to soil cover is more important.

The **goal** of organic agriculture is to contribute to the enhancement of sustainability. The 'sustainability' refers to the successful management of agricultural resources to satisfy human needs while at the same time maintaining or enhancing the quality of the environment and conserving natural resources for future generations. Sustainability in organic farming must therefore, be seen in a holistic sense, which includes:

1. *Ecological sustainability*: Recycling the nutrients instead of applying external inputs, no chemical pollution of soil and water, promote biological diversity and improve soil fertility, prevent soil erosion and animal friendly husbandry, using renewable energies.
2. *Economic sustainability*: Satisfactory and reliable yields and low cost on external inputs, crop diversification to improve income, value addition through quality improvement and on-farm processing.
3. *Social sustainability:* Sufficient production for subsistence and income, a safe and healthy food, good working conditions for women and men, building on local knowledge and tradition.

## Principles of Organic Agriculture

Organic agriculture is based on the following 4 major principles:

### Principle of health

- Organic agriculture should sustain and enhance the health of soil, plant, animal, human and planet as one and indivisible.
- Healthy soils produce healthy crops that foster the health of animals and people.
- Health is the wholeness and integrity of living systems.
- The role of organic agriculture, whether in farming, processing, distribution, or consumption, is to sustain and enhance the health of ecosystems and organisms from the smallest in the soil to human beings.

**Principle of ecology**

- Organic agriculture should be based on living ecological systems and cycles, work with them, emulate them and help sustain them.
- This principle roots organic agriculture within living ecological systems.
- It states that production is to be based on ecological processes, and recycling
- Nourishment and well-being are achieved through the ecology of the specific production environment.
- Organic management must be adapted to local conditions, ecology, culture and scale.
- Inputs should be reduced by reuse, recycling and efficient management of materials and energy in order to maintain and improve environmental quality and conserve resources.

**Principle of fairness**

- Organic agriculture should build on relationships that ensure fairness with regard to the common environment and life opportunities.
- This principle emphasizes that those involved in organic agriculture should conduct human relationships in a manner that ensures fairness at all levels and to all parties - farmers, workers, processors, distributors, traders and consumers.
- It aims to produce a sufficient supply of good quality food and other products.
- Natural and environmental resources that are used for production and consumption should be managed in a socially and ecologically fair way and should be held in trust for future generations.

**Principle of care**

- Organic agriculture should be managed in a precautionary and responsible manner to protect the health and well-being of current and future generations and the environment.
- Organic agriculture is a living and dynamic system that responds to internal and external demands and conditions.

These principles state that precaution and responsibility are the key concerns in management, development and technology choices in organic agriculture.

## Global Scenario of Organic Agriculture

In 1924, the Austrian philosopher Dr. Rudolf Steiner conceptualized and advocated a system of biodynamic agriculture, which was probably the first organic agriculture movement, and in 1927 a trademark 'Demeter' was introduced for organically produced food. In 1939, Lady Eve Balfour of England published a book 'Living Soil', that was the first scientific approach to compare conventional and organic farming systems. The concept of 'Biological Agriculture' was developed by Peter Rush and Hon's Muller in Switzerland. Masanobu Fukuoka, a Japanese microbiologist developed an approach of 'no-till organic system' also known as 'Fukuoka farming'. Later he released a book '*One Straw Revolution*' on natural farming in 1975 The term 'organic' in relation to farming was first used by Lord Northbourne (1940) in his book '*Look to the Land*'. The formation of International Federation of Organic Agriculture Movement (IFOAM) in 1972 in France gave framework for the discussion and codification of internationally recognized principles of organic farming.

According to the latest survey (*The World of Organic Agriculture - Statistics and Emerging Trends 2018*) on certified organic agriculture world-wide show, 1.2% of the world's agricultural land is organic. Nearly 57.8 m ha of agricultural land are managed organically by 2.7 million producers in 178 countries in 2016 (Fig 1). The regions with the largest areas of organically managed agricultural land are Oceania (27.3 m ha or almost 50% of the global organic farmland), Europe (13.5 m ha or 23%), Latin America (7.1 m ha or 12%) and Asia (4.9 m ha or 9%). The countries with the most organic agricultural land are Australia (27.3 m ha), Argentina (3.0 m ha) and the China (2.3 m ha). The countries with the highest numbers of producers are India (8,35,000), Uganda (2, 10, 352), and Mexico (2,10,000).

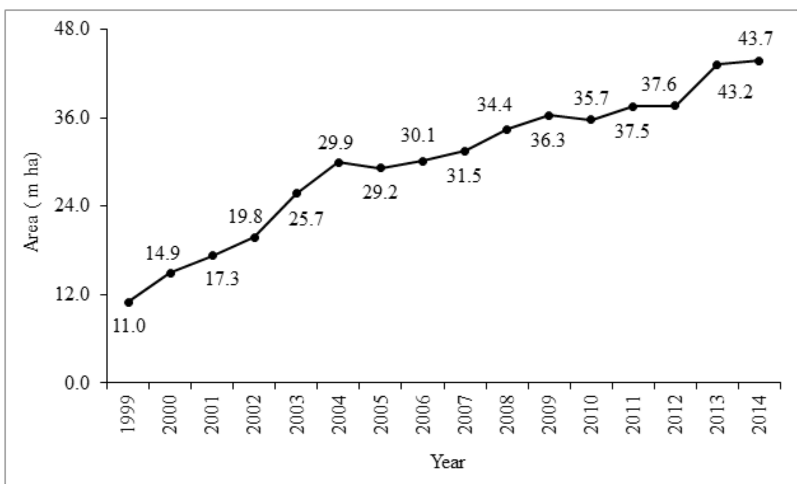


**Fig 1.** Growth of the organic agricultural land 1999 to 2014 in the world

## Organic Farming in Indian Context

Modern agriculture using high yielding varieties responsive to irrigation and fertilizers, played a vital role in achieving food security through Green Revolution. The over exploitation of natural resources coupled with indiscriminate use of inorganic fertilizers and pesticides for the past six decades has led to several ill effects. The awareness on environmental and health issues associated with modern intensive agriculture has led to an increasing demand for organic products across the country. The traditional agricultural practices evolved in villages and farming communities over the millennium were the true forms of Organic agriculture. According to the report of World of Organic Agriculture 2018, India is home to 30 per cent of the total organic producers in the world, but accounts for just 2.59 per cent (1.5 million hectares) of the total organic cultivation area of 57.8 million hectares. India ranked 1st in terms of producer (650,000 nos.) and 2nd in largest organic area (0.13 m ha) under oilseeds production, and 4th in the largest area (0.72 m ha) of organic agricultural land in 2014. Our country has the 3rd in largest organic wild collection and beekeeping area (3.99 m ha) in 2014. Overall India ranks 11th in organic agricultural land in the world and 2nd in Asia. The total area under organic certification is 5.71 m ha (2015-16). This includes 26% cultivable area (1.49 m ha) and rest 74% (4.22 m ha) forest and wild area for collection of minor forest produces. Several states in India had already initiated steps to encourage the organic farming among the farming communities. Uttarakhand and Sikkim has already been declared as organic states. Among all the states, Madhya Pradesh has covered largest area under organic certification followed by Himachal Pradesh and Rajasthan (Table 1). India produced around 1.35 million MT (2015-16) of certified organic products. The organic food export realization was around 298 million USD. The development of organic agricultural land in India during 2005-2014 has been depicted in Fig. 2. Many States *viz.*, Uttaranchal, Karnataka, Madhya Pradesh, Maharashtra, Gujarat, Rajasthan, Tamil Nadu, Kerala, Nagaland, Mizoram, Sikkim have been promoting organic farming. The State-wise major crops grown under organic farming in India has been given in Table 2.

**Table 1. Area under organic farming 2013-14**

| Major States | Area (ha) | Land holding size (ha) |
|---|---|---|
| Madhya Pradesh | 2,32,887 | 1.78 |
| Maharashtra | 85,536 | 1.44 |
| Rajasthan | 66,020 | 3.07 |
| Sikkim | 60,844 | 1.42 |
| Odisha | 49,814 | 1.04 |
| Gujarat | 46,864 | 2.03 |
| Uttar Pradesh | 44,670 | 0.76 |
| Uttarakhand | 24,739 | 0.89 |
| Karnataka | 30,716 | 1.55 |
| Kerala | 15,020 | 0.22 |
| Goa | 12,854 | 1.14 |
| Andhra Pradesh | 12,325 | 1.08 |
| India | 7,23,039 | 1.15 |

*Source:* 9th Report of Committee on Estimates 2015-16, National Project on Organic Farming, Ministry of Agriculture, GoI.; Agricultural Census 2010-11

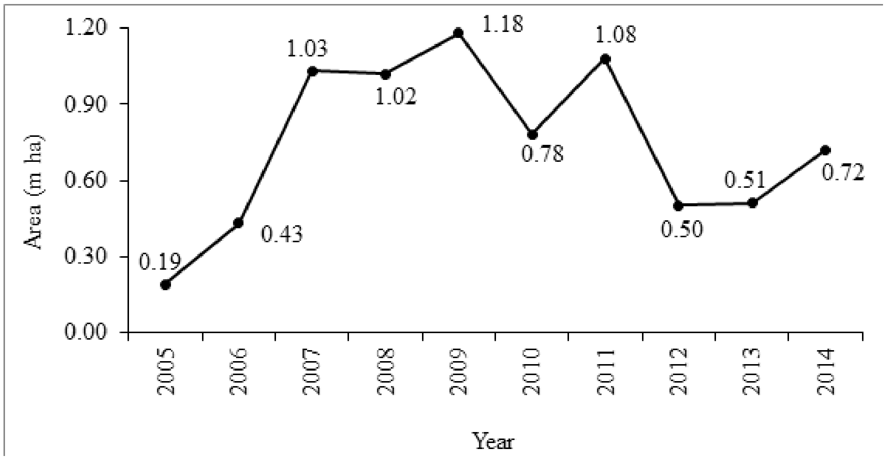


**Fig 2.** Development of organic agricultural land in India during 2005-2014

(***Source:*** FiBL-IFOAM Survey (The World of Organic Agriculture - Statistics and Emerging Trends 2016)

Organic produces are increasingly preferred by major urban centres in India. There is a high demand for Indian organic products especially tea, coffee, cotton etc. in the international market. Even in domestic market, consumers search for organic food products. The global trade during 2013-14 was USD 60 billion (Rs. 3,60,000 crores) and may touch USD 100 billion (Rs. 6,00,000 crores) within the next five years. Trade in India may reach Rs. 5000-6000 crore, which is about 1% of the global trade. The International Competence Centre for Organic Agriculture (ICCOA) estimated that the domestic market for organic products in the year 2011-12 was Rs. 300 crore and grew to Rs. 600 crore in 2012-13 i.e. a growth rate of 100%. The organic products are exported to European Union, US, Canada, Switzerland, Korea, Australia, New Zealand, South East Asian countries, Middle East, South Africa etc. Oil seeds (50%) lead among the products exported followed by processed food products (25%), cereals & millets (17%), tea (2%), pulses (2%), spices (1%), dry fruits (1%), and others.

## Regulatory Mechanisms in India

Recognition of Participatory Guarantee Systems (PGS) has been one of the significant developments in the Indian Organic sector during the past year by the government and implementation levels. The Food Safety and Standards Authority of India (FSSAI) has launched an 'Indian Organic Integrity Database' to help consumers to verify authenticity of organic food. It has also introduced a common logo for organic foods with the tagline 'Javik Bharat'. The Government of India has implemented the National Programme for Organic Production (NPOP) in the year 2001. This programme involves the accreditation programme for certification agencies, norms for organic production, promotion of organic farming etc. The Standards for *Organic Production* are notified in *NPOP* by the Director General of Foreign Trade under the Foreign Trade (Development and Regulation) Act, 1992. NPOP defines the regulatory

**Table 2. State-wise major crops grown under organic farming in India (both certified & In-conversion)**

| States | Crops grown |
|---|---|
| Arunachal Pradesh | Maize/sorghum, Pulses, oilseeds, tea/coffee, herbal/medicinal plants |
| Andhra Pradesh | Cotton, maize, pulses, oilseeds, fruits and vegetables |
| Assam* | Tea/coffee, fruits and vegetables |
| Bihar* | Vegetables and fruits |
| Chhattisgarh* | Rice, wheat, vegetables |
| Delhi | Wheat, vegetables |
| Goa | Fruits, vegetables |
| Gujarat | Cotton, pulses, oilseeds, vegetables |
| Haryana | Basmati rice, wheat, maize, vegetables |
| Himachal Pradesh | Wheat, fruits, vegetables |
| Jammu and Kashmir | Spices, fruits and vegetables |
| Jharkhand* | Vegetables and fruits |
| Karnataka | Cotton, rainfed wheat, maize, sorghum, pulses, oilseeds, vegetables |
| Kerala | Spices, vegetables, herbals |
| Manipur | Spices, vegetables, herbals |
| Maharashtra | Cotton, rice, wheat, pulses, oilseeds, spices, vegetables |
| Madhya Pradesh | Soybean, wheat, vegetables |
| Meghalaya | Spices, vegetables |
| Odisha* | Spices, cotton, vegetables and fruits |
| Punjab | Basmati rice, wheat, vegetables |
| Sikkim | Maize, sorghum, vegetables, spices, herbs |
| Rajasthan | Cotton, wheat, seed spices, vegetables |
| Tamil Nadu | Tea, herbs, spices |
| Uttar Pradesh* | Rice, wheat, maize, vegetables |
| Uttarakhand | Basmati rice, vegetables, maize, sorghum, herbs, spices |
| West Bengal* | Tea and vegetables |

*States of Eastern Region

mechanism and is regulated under two different acts for export and domestic markets. NPOP notified under Foreign Trade Development and Regulation Act (FTDR) looks after the export requirement. The NPOP notified under this act has already been granted equivalence by European Union and Sweden. USDA has also accepted the conformity assessment system of NPOP. Due to this, the product certified by any Indian accredited certification agency under NPOP can be exported to Europe, Sweden and USA without the requirement of re-certification. To lookafter the requirement of import and domestic market the same NPOP has been notified under Agriculture Produce Grading, Marking and Certification Act (APGMC). Regulatory body of NPOP under FTDR act is Agricultural and Processed Foods Export Development Authority (APEDA) under Ministry of Commerce and of NPOP under APGMC act is Agricultural Marketing Advisor (AMA) under Ministry of Agriculture. Accreditation of Certification and Inspection Agencies is being granted by a common National Accreditation Body (NAB). Eighteen accredited certification agencies are looking after the requirement of certification process. Out of these 4 agencies are under public sector while remaining 14 are under private management.

## Requirements for Organic Farming

There are certain minimum requirements that need to be fulfilled to certify the farm as organic. These are:

**Conversion:** The time between the start of organic management and certification is called conversion period. The farmers should have a conversion plan prepared if the entire field is not converted into organic at a time. In that case, it is necessary to maintain organic and nonorganic fields separately. In the long run the entire farm including livestock should be converted into organic. The conversion period is decided based on the past use of the land and ecological situation. Generally, the conversion period is two years for annual crops and three years for perennial crops.

**Mixed farming:** Animal husbandry, poultry, fisheries, etc. should be practiced in addition to agricultural farming.

**Cropping Pattern:** Crop rotation should be followed if annual crops are grown. Intercropping should be practiced when perennial crops are grown. Crop rotation should cover green manure as well as fodder crops. In case of perennial crops, cover crops like *Tephrosia purpurea* should be grown to protect the soil.

**Planting:** Species and varieties cultivated should be adapted to soil and climatic condition and resistant to pests and diseases. Seeds/planting materials should be procured from organic source. If not available, chemically untreated seeds/planting materials can be used one time. Use of genetically engineered seeds or planting materials such as tissue culture, pollen culture, transgenic plants is not allowed.

**Manurial policy:** Soil fertility should be maintained/enhanced through raising green manure crops, leguminous crops etc. The residues of plants after harvest should be incorporated into the soil as far as possible. Bio-degradable materials of microbial, plant or animal origin shall be applied as manures. (eg. compost, vermicompost, farm yard manure, sheep penning etc.) Use of synthetic/chemical fertilizers is not permitted. The mineral based materials like rock phosphate, gypsum, lime, etc. can be applied in limited quantities when there is absolute necessity.

The following products are permitted for use in manuring/soil conditioning in organic fields:

Farm yard manure, slurry, green manures, crop residues, straw and other mulches from own farm saw dust, wood shaving from untreated wood, calcium chloride, lime stone, gypsum and chalk magnesium rock sodium chloride, bacterial preparations (bio-fertilisers), eg. azospirillum, rhizobium, bio-dynamic preparations, plant preparation and extracts, eg. neem cake vermicompost.

**Insect-pest, disease and weed management:** Use of synthetic/chemical pesticides, fungicides and herbicides is not permitted. Natural enemies shall be encouraged and protected. (e.g. raising trees in the farm attracts birds which kills pests of the crops, nest construction etc.), products collected from the local farm, animals, plants and micro-organisms and prepared at the farm are allowed for control of pests and diseases. (e.g. neem seed kernel extract, cow urine spray). Use of genetically engineered organisms and products are prohibited for controlling pests and diseases. Similarly, use of synthetic growth regulators is not permitted.

## Programmes on Organic Farming by Government of India

The National Project on Organic Farming (NPOF) was started in 2004 to facilitate, encourage and promote development of organic agriculture in the country. NPOF is being implemented by National Centre of Organic Farming at Ghaziabad and its eight Regional Centres at Bangalore, Bhubaneshwar, Panchkula, Ghaziabad, Imphal, Jabalpur, Nagpur and Patna. Besides, various programmes have also been initiated by the Government of India in recent years to facilitate, encourage and promote development of organic agriculture in the country, such as: National Mission for Sustainable Agriculture (NMSA), Paramapragat Krishi Vikas Yojana (PKVY), Rashtriya Krishi Vikas Yojana (RKVY), Mission for Integrated Development of Horticulture (MIDH), National Mission on Oilseeds & Oil Palm (NMOOP), National Food Security Mission, National Project on Management of Soil Health and Fertility (NPMSH&F), **Mission Organic Value Chain Development for North Eastern Region,** Network Project on Organic Farming of ICAR.

### Strength of Organic agriculture in Eastern region

- Varied agro-ecological zones in eastern region offer production of various agri-horti crops, animals and fishes.
- Small land holding pattern, where large-scale commercial agriculture is not feasible.
- Dependence of mid altitude and plateau farmers on within farm renewable resources.
- Low rate of ground water utilization and irrigation facilities.
- Nearly 91% population of indigenous livestock, particularly of cattle and goat besides birds.

### Weaknesses

- Lack of awareness about organic food market although some of the upland farmers are producing food organically.
- Non-existence of proper marketing channel.
- Lack of processing, post-harvest and value addition facilities.

- Unawareness about organic food production standards, almost negligible linkages with agencies dealing with different aspects of organic agriculture.
- Lack of incentives from Govt. machineries.
- Non-identification of accreditation and certifying agency on regional basis.

**Opportunities**

- Development of agro-ecological zone specific farming system.
- Opportunities to increase the production by 3-4 folds under valley ecosystem and extensive organic farming under upland ecosystem.
- Mechanization of agriculture for increasing agricultural production.
- Rain water conservation and management.
- Agro-forestry interventions, particularly in classified wastelands and water congested ecologies.
- Opportunities for horticultural development including apiculture.
- Conservation and utilization of bio-resources through conventional and bio-technological interventions.
- Value addition and export market tapping.
- Eastern region has nearly 19.42 m ha rainfed Hill & Plateau region. Hence, at least 25% of 19.42 m ha area, i.e., 4.85 m ha could be targeted to bring under organic category.
- Likewise 0.82 m ha rainfed area of NEH region could be targeted to bring under organic farming.

**Threats**

- Soils of the region are low in fertility, excluding alluvial soils.
- Organic carbon depletion and less organic nutrient sources.
- Small, scattered and fragmented land holdings.
- Danger of extinction of valuable bio-resources due to introduction of hybrids and HYVs.
- Lowest per capita income.
- High population density.

## Organic Agriculture and Climate Change

Organic agricultural systems have an inherent potential to both reduce GHG emissions and to enhance carbon sequestration in the soil. Careful management of nutrients in organically managed systems is an important potential contribution in reducing $N_2O$ emissions from soils, which are the most relevant single source of direct GHG emissions from agriculture (El-Hage Scialabba and Mu¨ller-Lindenlauf 2010). Inclusion of the indigenous knowledge in organic farming is an important characteristic of organic agriculture in adaptation and crop development concerning climate change (Niggli *et al*. 2008, Muller and Davis 2009). Details of mitigation potential of organic agriculture is given in Table 3.

**Table 3. Mitigation potential of organic agriculture**

| Source of Greenhouse gases (GHG) | Share of total anthropogenic GHG emissions | Impacts of optimized organic management | Remarks |
|---|---|---|---|
| Direct emissions from agriculture | 10–12% | | |
| $N_2O$ from soils | 4.2% | Reduction | Higher nitrogen use efficiency |
| CH4 from enteric fermentation | Opposed effects | Opposed effect | Increased by lower performance and lower energy concentration in the diet but reduced by lower replacement rate and multi-use breeds |
| Biomass burning | 1.3% | Reduction | Burning avoided according to organic standards |
| Paddy rice | 1.2% | Opposed effect | Increased by organic amendments but lowered by drainage and aquatic weeds |
| Manure handling | 0.8% | Equal | Reduced methane emissions but no effect on $N_2O$ emissions |
| Direct emissions from forest clearing for agriculture | 12% | Reduction | Clearing of primary ecosystems restricted |
| Indirect emissions | | | |
| Mineral fertilizers | 1% | Completely avoided | Prohibited use of mineral fertilizers |
| Food chain | ? | (Reduction) | Inherent energy saving but still inefficient distribution systems |
| Carbon sequestration | | | |
| Arable lands | | Enhanced | Increased soil organic matter |
| Grasslands | | Enhanced | Increased soil organic matter |

*Source:* El-Hage Scialabba and Mu¨ller-Lindenlauf (2010)

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# Best Management Practices for Impending Climate Change through Conservation Agriculture

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Climate change is a most important threat to today's agriculture and recognized as a worldwide phenomenon that impacts people's livelihoods in many ways. This is especially important in rural areas where households are heavily dependent on rain-fed agriculture and natural resources in general for their livelihoods. India is a land of agriculture where about 70% land comes under rainfed situation. Farmers' perception and the household level data were analysed to understand the determinants of adaptation to climate change and the impacts of sustainable land management practices on agricultural productivity and climate change vulnerability. Rainfall has been showing a decreasing trend and increased variability.

Sustaining the productivity at higher level is the key issue in Indian agriculture to meet the growing demands of food and fibre for the increasing population. In order to overcome such problems, a new technology came into existence called 'Sustainable Agriculture'. Sustainable farming system goals at meeting the needs of growing population without endangering the resource base for future generations. Therefore improvement of soil quality and health is indispensable for sustaining the agricultural productivity. Attaining food security for a growing population and alleviating poverty while sustaining agricultural systems under the current scenario of climate change are the major challenges before most of the Asian countries. Therefore, a paradigm shift in farming practices through eliminating unsustainable parts of conventional agriculture (ploughing/tilling the soil, removing all organic material, monoculture) is crucial for future productivity gains while sustaining the natural resources. Conservation agriculture (CA), a concept evolved as a response to concerns of sustainability of agriculture. CA is a resource-saving agricultural production system that aims to achieve production intensification and high yields while enhancing the natural resource base through compliance with three interrelated principles, along with other good production practices of plant nutrition and pest management (Abrol and Sangar, 2006).

FAO of the United Nations defines CA as a 'concept for resource-saving agricultural crop production that strives to attain acceptable profits together with high and sustained production levels while concurrently conserving the environment. CA is a resource-efficient and resource-effective form of agriculture. CA as a method of managing agro ecosystems for improved and sustained productivity, increased profits and food security while preserving and enhancing the resource base and the environment. The goal of CA is to conserve, improve and make more efficient use of natural resources through integrated management of available soil, water and biological resources combined with external inputs. Thus the role of best management practices and particularly conservation agriculture in immense to maintain soil health which will help to build up a resilient agriculture production system under changing climatic conditions.

## Sustainable Land Management

Sustainable land management (SLM) has been defined as "a knowledge- based procedure that helps to integrate land, water, biodiversity and environmental management to meet rising food and fiber demands while sustaining ecosystem serices and livelihoods" (World Bank, 2006). It interrelates other approaches like soil and water conservation, conservation agriculture, natural resource management etc. to promote integration of biological, physical, socioeconomic needs to achieve a productive and healthy ecosystem.

Land degradation is a global problem and can be brought about by numerous factors such as monocropping, excessive tillage, overgrazing, deforestation and poor management of agrochemicals and fertilizers. Thus developments of sustainable land use practices are urgently required because of wide spread resource degradation from poor land use practices. Extensive researches have been conducted to identify and develop SLM practices and systems for a wide range of environments and socioeconomic conditions that exist across the world. The common components of SLM are (1) understanding the ecology of land use management, (2) maintain or enhance productivity, (3) maintenance of soil quality, (4) increased diversity for higher stability and resilience, (5) provision of economic and ecosystem service benefits for communities, and (6) social acceptability.

Sustainable production system has five major objectives:

(i) Achievement of increased agricultural productivity and enhanced ecosystem services;
(ii) Enhanced use efficiency of inputs like water, nutrients, energy, pesticides, land and labour;
(iii) Judicious use of external inputs derived from fossil fuels and preference for alternatives (such as recycled organic matter, biological nitrogen fixation);
(iv) Conservation of soil, water and biodiversity through use of 'minimum soil disturbance' and maintaining organic matter cover on the soil surface to protect the soil;
(v) Use of natural and managed biodiversity of species to build systems' resilience to abiotic and biotic and economic stresses, with an emphasis on improving soil organic matter content as a substrate essential for soil microbial activity.

## Conservation Agriculture

Conservation agriculture (CA) is based on three principles: no or minimum soil disturbance through no or minimum tillage, permanent soil-surface cover through organic residues, and suitable crop rotations through diversification in the annual crops, by using the shallow and deep-rooted crops or including pulse in crop rotation, and suitable plant species in perennial cropping system.

### (a) Minimizing soil disturbance by mechanical tillage

Minimum soil disturbance provides optimum aeration in the root-zone, moderate organic matter oxidation, improved porosity for water movement, retention and release and limits the re-exposure of weed seeds and their germination (Kassam and Friedrich 2009). Soil biological activity produces very stable soil aggregates as well as various sizes of pores, allowing air and water infiltration. This process can be called "biological tillage" and the biological soil structuring processes will disappear with mechanical soil disturbance.

### (b) Enhancing and maintaining organic matter cover on the soil surface

Using cover crops or crop residues on soil surface can protect the soil surface from detrimental beating action of rain drops, conserves water and nutrients, promotes soil biological activity, maintains soil temperature and alter the microclimate in the soil for optimal growth and development of soil organisms, including plant roots. In turn it improves soil aggregation, soil biological activity and soil biodiversity and carbon sequestration (Ghosh *et al*. 2010).

### (c) Diversification of species

Diversification of both annuals and perennials in associations, sequences and rotations which contributing to enhanced crop nutrition and improved system resilience. Cropping sequence and rotations involving legumes helps in minimal rates of build-up of population of pest species, through life cycle disruption, biological nitrogen fixation, control of off-site pollution and enhancing biodiversity.

The conservation technology information centre (CTIC, 1993) has defined conservation tillage as "tillage and planting system in which at least 30% of the soil is covered with plant residues after planting to reduce soil erosion." The CTIC has subdivided the conservation tillage into 4 systems: zero tillage, reduced tillage, stubble mulch tillage and ridge tillage.

Conservation agriculture are being extensively researched around the world and show as a promising SLM practices (Hobbs *et al.* 2010).Several regions of world showed interest to this system because of increasing resource degradation and declining crop yield in conventional land use practices. Conservation agriculture improves soil quality and maintains soil health by improving the physical, chemical and biological properties of soil.

## Conservation Agriculture and Soil Physical Quality

Studies reveal that adoption of CA practices leads to significant improvement in soil physical environment and thereby soil quality over time (Verhulst *et al*. 2010). However, effects of CA on soil physical properties can vary from location to location depend on the tillage system and their intensity, agro-climatic condition and type of soil. The beneficial effect of CA in term of better soil quality is reflected through improvement in physical soil properties like lower bulk density (BD), higher aggregate stability, enhanced water holding capacity and better soil structure.

### Soil structure and aggregation

Among the physical factors, soil structure is one of the most important parameter that has strong correlation with soil quality and tillage intensity. Soil Aggregation and their stability have great influences on nutrient dynamics water holding capacity. Therefore, aggregated soil structure is most desirable characteristics for higher crop productivity. Parihar *et al*. 2016 reported that continuous adoption of CA practices i.e. zero tillage and Permanent bed along with retention of crop residue over seven year resulted into 23 to 32.5 % higher water stable aggregates as compared to conventional system in 0-15 cm soil depth.

### Hydraulic conductivity

Hydraulic conductivity of the soil was found to be significantly and positively correlated with the total soil macro-pores and tillage practices. Parihar *et al*. 2016 reported, that after seven year of adoption the saturated conductivity of the a sandy loam soil increased by 11.1 and 12.0 % in ZT in 0-15 and 15-30 cm soil layers, respectively, compared to conventional tillage in north western IGP of India. The increase in saturated conductivity under ZT was mainly attributed to decrease in BD and increase in effective pore volume due to better soil aggregation.

### Bulk density

Continuous adoption of conventional tillage leads to formation of hard pan below the plough layer which results in high bulk density which is not suitable for crop growth. It has been reported that long term adaption of CA practices associated with lower soil bulk density (BD) because residue retention and minimum soil disturbance of soil leading to lower compaction which accounted for lower soil BD under CA(Jat *et al.* 2013). Further, inclusion of legumes in intensive maize based rotations resulted into significantly lower soil BD compared to monoculture of maize. The higher SOC and differential chemical composition of crop residues and root biomass brings out differential addition of SOC that leads to difference in soil BD.

## Conservation Agriculture and Soil Chemical Quality

The important chemical properties affected by tillage practices are soil organic carbon status, pH, cation exchange capacity, nutrient dynamics etc.

## Soil organic carbon status

Decrease in fertility status of cultivated land due to declining organic matter is a great matter of concern in most of the Asian countries. Soil organic carbon (SOC) is the backbone of soil quality and reported to be an important indicator of agricultural sustainability. Machado *et al*. 2001 found that adoption of zero tillage resulted in significant increase in total carbon (30%), active carbon pool (10%), and passive carbon pool (18%) compared to conventional tillage system. The higher SOC under zero tillage might be due to increased soil aggregation that can store more carbon over conventional tillage. Thus, zero tillage is recognized as promising strategy to maintain or even improve SOC stocks in soil.

## Soil pH

The lower pH in zero tillage was attributed to accumulation of organic matter in the upper few centimetre under zero tillage soil causing increases in the concentration of electrolytes and reduction in pH. Thus tillage may not directly affect soil pH but its effects on pH will depend on the prevailing climatic condition, soil type and management factors.

## Nutrient dynamics

Tillage also affects the nutrient availability of soil system. Exchangeable Ca, Mg and K were significantly higher in the surface soil under NT compared to the ploughed soil. The lowest values of soil OM, N, P, K, Ca and Mg were recorded in conventional till plots and it could be due to the inversion of top soil during ploughing which shifts less fertile subsoil to the surface in addition to possible leaching.

## Conservation agriculture and soil biological quality

The major soil biological properties affected by tillage are microbial population, microbial biomass carbon, enzymatic activity, active carbon, soil respiration, etc.

The soil organic matter content influences the activity of soil microbes to a great extent there by affects soil organic carbon dynamics. Earthworms are major component of soil macro-fauna and important in maintaining soil fertility status. Their burrowing activities improves soil aeration and water infiltration. Due to disruption of fungi mycelia by tillage technique, a decreased fungal biomass and increased bacterial biomass with increasing tillage disturbance.

## Microbial biomass carbon

Microbial biomass carbon (MBC) is a breathing part of the soil organic matter which plays a critical role in nutrient transformation. Continuous use of CA based management practices leads to reduction in soil disturbance which can stimulate soil microbial biomass and improve its metabolic rate, resulting in better soil quality, which in turn, can increase crop productivity (Hungria *et al.* 2009).

### Soil enzymatic activity

Tillage disturbs the soil natural state there by lowers the enzymatic activities. Soil fluorescein di-acetate (FDA) hydrolysis is a measurement of the contribution of several enzymes, mainly involved in the decomposition of organic matter in soil. Higher FDA value is the sign of positive soil health. Vargas *et al.* (2009) had been noticed higher levels of fluorescein di-acetate (FDA) hydrolysis under ZT than CT systems.

## Sustainable Water Management

Water is a vital component of agricultural production. Assessing how water flows around the farm and measuring how much water should be needed for a crop will help farmers to manage water efficiently and reduce pollution risks. Pradhan Mantri Krishi Sinchayee Yojana (PMKSY) is one of the most important step towards sustainable water management. The main objective of this mission is 'Per Drop More Crop'. Improvement of water use efficiency is the main challenge for water management in agriculture. This can be achieved through

(1) An increase in crop water productivity through irrigation,
(2) A decrease in water losses through soil evaporation,
(3) An increase in soil water storage through better management practices.

Conservation agriculture plays a vital role in sustainable water management. Because in conservation agriculture the surface runoff is reduced due to presence of soil cover and infiltration rate increases as compared to conventional tillage system. Due to high organic matter content, bulk density decreases with increase in porosity and there by improves the water holding capacity of soil.

Minimal tillage reduces volume and velocity of surface runoff, leading to reduction in soil erosion and nutrient loss; incorporation of crop residues enhances soil water availability, reduces evaporation losses, improves infiltration by restricting surface runoff and reduces surface sealing from raindrop impacts ( Araya *et al.* 2011). Recent studies have reported that CA improved crop water productivity by 10–40% (Ngwira *et al*. 2012). Patil and co-workers (2016) found surface runoff observed in conservation practices was 28% less compared to the conventional system, which may be attributed to residues retention than minimum tillage. Dahiya, S. conducted an experiment at CCSHAU, Hisar to study sustainable management of water in direct seeded rice for optimizing the production. He reported that water saving of 9-57% was recorded by adopting direct seeding rice culture.

## Climate Change and Conservation Agriculture

Adaptation of improved management practices on agricultural land not only enhance the food security but also offset fossil fuel emissions at the rate of 0.5 $PgCyr^{-1}$ (Lal, 2005) . Climate change is likely to strongly affect rice-wheat, rice-rice and maize-based cropping systems that, today, account for more than 80% of the total cereals grown on more than 100Mha of agricultural lands in South Asia. Global warming may be beneficial in some regions, but harmful in those regions where optimal temperatures already exist; an example would be the rice-wheat mega-environments in the

IGP that account for 15% of global wheat production. Agronomic and crop management practices have to aim at reducing $CO_2$ and other greenhouse gas emissions by reducing tillage and residue burning and improving nitrogen use efficiency. In the IGP, resource-conserving technologies continue to expand in the rice–wheat cropping systems and significantly reduce release of $CO_2$ to the environment. This GHG emission can be mitigated by shifting to an aerobic, direct seeded or NT rice system. (Grace *et al*. 2003). Nitrous oxide has 310 times the warming potential of carbon dioxide, and its emissions are affected by poor nitrogen management. Sensor-based technologies for measuring normalized differential vegetative index and moisture index have been used in Mexico and South Asia to help improve the efficiency of applied nitrogen and reduce nitrous oxide emissions.

## Conclusion

Conservation agriculture offers a new paradigm for agricultural research and development different from the conventional one, which mainly aimed at achieving specific food grains production targets in sustainable manner. A shift in paradigm is necessary due to widespread problems of resource degradation. Integrating concerns of productivity, resource conservation and soil quality and the environment is now fundamental to sustained productivity growth. Developing and promoting CA systems will be highly demanding in terms of the knowledge base. Scientists should identify the problems in the systems and should promote conservation agriculture through various demonstration among the farmers. Conservation agriculture is found to be more efficient in sustainable land management by affecting its physical, chemical and biological properties. It improves infiltration rate and reduce surface runoff there by also useful in sustainable water management. Conservation agriculture offers an opportunity for arresting and reversing the downward spiral of resource degradation, decreasing cultivation costs and making agriculture more resource – use-efficient, competitive and sustainable. "Conserving resources – enhancing productivity" has to be the new mission.

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# Diversifying Crop Rotations with Nitrogen Fixing Legumes

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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

**Table 1. Agriculturally important legume species**

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

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.

## 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-malnutrition 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 discussed 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 intercropping 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 submergence 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 progressive 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-adoption 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 pattern 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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# Diversification of Rice-Wheat System through Climate Resilient Cropping in Eastern India

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Cropping intensity of the eastern region is low (140%) and needs to be increased to meet the growing food demands for ever-increasing population. Crop diversification has been recognized as an effective strategy for achieving objectives of food and nutrition security, income growth, poverty alleviation, employment generation, judicious use of land and water resources, sustainable agricultural development and environmental improvement (FAO 2001). It basically means moving away from growing single crop to a number of crop and such move towards crop diversification helps in (1) full and better use of available land, labour and water resources, (2) reducing risks arising out of crop failures, yield losses, market failures, and (3) realizing quicker or regular returns for the farmers. Thus, both the number and types of crops included in cropping sequence are important. For this, heavy reliance on cereal crop needs to be shifted towards millets and pulses. Gangwar and Ram (2005) reported that inclusion of legumes and other crop using intensification and interruptive approaches, as per resource availability, led to the considerable improvement in productivity. Alternative cropping system, so developed may be practised for better returns than that from existing cropping system. In a particular agro-climatic and resource condition, identification of most suitable crop sequence based on its productivity, stability, land use efficiency (LUE) as well as production efficiency is a paramount task. Performance of a crop sequence is chiefly judged in terms of productivity and net returns. Nevertheless, understanding of yield stability, energetics and LUE provides an additional base for identification of better and efficient crop sequence for a particular area. Therefore, for diversification of cropping system, options left are replacement of rice and wheat by inclusion of millets/fodder/legumes. Hence, it is necessary to work out the location-specific cropping system for agro-ecosystem of Eastern India, which utilize resources judiciously to maximizing the returns, protect environment and meets the daily requirement.

## Need of Crop Diversification

In changing scenario of globalization, agriculture in India has to face new challenges to compete at global level in agricultural commodities. Indian agriculture is now facing second generation problems, i.e., lowering water table, nutrient imbalance, soil degradation, salinity, resurgence of the pests, environmental pollution and decline in profits. Crop diversification shows a lot of promise in alleviating these problems through fulfils the basic needs, regulating farm incomes, withstanding weather aberrations, controlling price fluctuation, ensuring balanced food supply, conserving natural resources, reducing the fertilizer/pesticide load, environmental safety and creating employment opportunity. Ability of diversify the cropping pattern for attaining the various goals depends on opportunities, need of diversification and responsiveness of the farmers. During last four decades of 20$^{th}$ century, global population doubled from 3 to 6 billion and by 2020, it will reach 8 billion. Food and nutritional security, is therefore, a serious global concern. The projection reports suggest that five populous countries, i.e., China, India, Indonesia, Brazil and Nigeria would have half of the world population by 2020 and will face serious food deficits. Despite an increase in its population from 548 million in 1971 to 1027 million in 2010, per capita availability of cereals has not decreased due to Green Revolution (GR) that set in late 1960s; it was 417.6 g/day in 1971 and 422 g/day in 2010-11 (Fertilizer Statistics, 2010-11). GR in India started with introduction of Sonora 64 and Lerma Rojo in 1966; wheat production increased from 10.4 mt in 1965–66 to 16.5 mt (~ 50%) in a period of one year only. It was soon discovered that dwarf wheat needed lower temperature for good germination and tillering and therefore, wheat sowings in North India had to be delayed from mid-October to mid-November. This provided one additional month for preceding *kharif* in North India.

About 1/3$^{rd}$ of India's cereals is produced in R-W belt, contributes to food grain procurement by Government of India for its public distribution system (Kumar *et al*. 1998). Besides declining fertility, low wheat yields in RWCS might be due to a short turnover period between rice harvest and delayed wheat sowing because high soil moisture after rice harvest and delay in removal of rice straw. Manufacture of ZT machines in country and their availability at an affordable price is call of time. Although RWCS has boon from food security view, being an intensive cropping system is heavily taxing two most important natural resources of soil and water, which are essential for survival of human life. Global availability of water was ~3500 $m^3$/person/yr in 1950, 1250 $m^3$/person/yr in 2003 and estimated to be 760 $m^3$/person/yr in 2050. Rice is a heavy-water consuming crop; ~ 5000 l are needed to produce ~1.0 kg rice. Cultivation of rice in Punjab, Haryana and western UP, where monsoon rains are not as heavy as in traditional rice belt, farmers to heavily rely on GW through tube wells. This has lowered the water table in the region, but can be prevented by adopting rice–chickpea, pigeonpea-wheat and rice-mustard at least once in a 3-4 year cycle. These cropping systems reduce the demand for GW at least in one season and produce much-needed pulses and oilseeds (Prasad and Nagarajan, 2004). With increase in area under pulses, production of pulses in India has remained static at 12±2 mt in last 30 yrs and per capita availability of pulses has, however, declined from 60.7 g/day in 1951 to 47.2 g/day in 2010. Situation in respect of oilseeds is different, where due to TMO, production of vegetable oils increased from 2.75 mt in 1980–81 to 4.96 mt in 2000-2015. Recent studies by MSSRF showed protein-energy deficiency in rural population is widespread in India. Due to shortage of oils and pulses in country, these are being imported; ~4.32 mt of edible oil at a value of Rs.6475 crores and ~2.18 mt of pulses at a value of Rs.3160 crores. This import of oil and pulses has to be checked. Further, growing of summer mungbean even on half of the area in RWS belt (5 m ha) can produce ~2.5 mt of pulses, amount being currently imported in country and addition ~30–60 kg N/ha to RWS by incorporation of its residue. But, the information on diversified millets/pulses/oilseed/fodder system with cropping intensity of >300% coupled with RCT is meager.

## Present Status of the Technology at National and International Levels

Eastern region of India comprising states of Bihar, Jharkhand, Odisha, Chhattisgarh, Upper Assam, West Bengal and eastern UP, is one of most backward regions of the country, characterised by high population pressure, high incidence of poverty, small size of land holdings and poor rural infrastructure. Nevertheless, regions have strength such as (i) higher proportion of cultivated area under high-value crop (7.9%) as compared to all-India average (5%) (ii) Conducive agro-climatic condition for cultivation of a variety of crops. Therefore, sound and empirical understanding of nature of crop diversification and constraints to accelerating its spread is necessary in Eastern India. It is assumed that present and future demand of food can be met through intensive crop production with increase in productivity per unit area and time particularly in rainfed ecosystem. Therefore, there is need to diversify existing cropping system with inclusion of oilseeds/pulses/millets/fodder. In recent past, diversification in agriculture has occurred largely through crop substitution and concern have been expressed, whether this process would sustain in long-run, given fact that land frontiers are closing with little scope to bring additional land under cultivation and land holdings are getting smaller under population pressure (Rai *et al.*2010).Contribution of diversification to agricultural growth in India has been quite substantial, ~30% during 1990s (Joshi *et al.* 2007).Continuous cereal-cereal production systems have led to numerous production vulnerabilities in Indian agriculture. Thus, in order to sustain crop productivity, minimum soil disturbance, cover and crop diversification assume vast importance (Gangwar *et al*. 2006).

Diversification through intervention of pulses/oilseeds/millets, soil and nutrient and pest management is viable option to cope up with emerging challenges. These crops emerged as alternative options for replacing rice and wheat in cereal based systems in water dearth areas. RWCS is most dominant system in alluvial plains and wider adoption of this system is mainly owing to its high productivity and less risk (Kumar *et al.* 2001). But continuous adoption of this system led to problem of specific weeds, reduced soil fertility and pests, which resulted in declining productivity. Since, rice and wheat is staple food of the states; it is difficult to replace it, and only option left to replace rice and wheat to some extent is trough resilient cropping system. Growing of crops like pulses/ oilseeds/millets/fodder is an alternative approach for realizing higher profitability. Sharma *et al.* (2007) reported that diversification through inclusion of fodder crops help to improve the economic situation. In view of these facts, present study is planned to conduct and find out an alternative resilient cropping to rice and wheat system for sustaining the livelihood of farming community of the Eastern India.

**Table 1. System rice equivalent yield (SREY) as influenced by diverse cropping system *REY: Rice equivalent yield, SREY: System rice equivalent yield**

| Cropping system | REY (t/ha) | | SREY (t/ha) |
|---|---|---|---|
| | *Kharif* | *Rabi* | |
| TPR-Wheat-Mungbean (FP) | 4.75 | 5.49 | 10.53 |
| DSR-Wheat (ZT)-Mungbean (ZT) (CA) | 5.35 | 5.89 | 11.48 |
| Soybean-Maize (ZT) | 3.65 | 9.18 | 13.31 |
| DSR-Mustard (ZT)-Urdbean (ZT) | 5.15 | 6.57 | 12.45 |
| Foxtailmillet-Lentil(ZT)-Fallow | 1.91 | 5.37 | 7.56 |
| Pearlmillet-Chickpea (ZT)-Fallow | 4.03 | 6.94 | 10.90 |
| Fingermillet-Toria (ZT)-Fallow | 2.01 | 3.61 | 5.81 |
| Jowar (Grain)-Chickpea (ZT)-Fallow | 4.35 | 7.54 | 11.54 |
| Maize (Green cob)-Pigeon pea (ZT) | 12.53 | 9.39 | 22.41 |
| Sorghum (Fodder)-Mustard (ZT)-Urdbean (ZT) | 9.72 | 6.26 | 15.97 |
| LSD (P=0.05) | 0.39 | 0.57 | 0.91 |

## Research Initiated at ICAR Research Complex for Eastern Region, Patna

A long term study was initiated at the ICAR RCER Patna, with keeping 10 different cropping system *viz*. transplanted rice (TPR)-wheat-mungbean (Farmers practices, FP), direct seeded rice (DSR)-wheat(ZT)-mungbean (ZT) (CA), soybean-maize (ZT), DSR-mustard-urdbean, foxtail millet-lentil-fallow, pearlmillet-chickpea-fallow, fingermillet-*toria* (ZT)-fallow, sorghum (grain)-chickpea(ZT)-fallow, maize (green cob)-pigeonpea and sorghum (fodder)-mustard (ZT)-urdbean (ZT) during *kharif* season of 2016 on clay loamy soil. Results revealed that significantly highest system annual 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). The lowest system productivity was associated with finger millet-*toria*- fallow system (5.81 t/ha) during the experimentation.


Fig. 1. View of the crop diversification experiment during *kharif* season

Based on the two years findings, it may be concluded that to achieve the maximum productivity, profitability, cropping system, i.e., maize cob-pigeonpea followed by sorghum fodder-mustard-urdbean can be adopted for lowland and irrigated ecosystem. Similarly, Jowar-chickpea followed by Bajra-chickpea cropping system may be an alternative resilient cropping system for upland rainfed condition to achieve the sustainability of the regions.

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# Carbon Sequestration Opportunities in Conservation Agriculture

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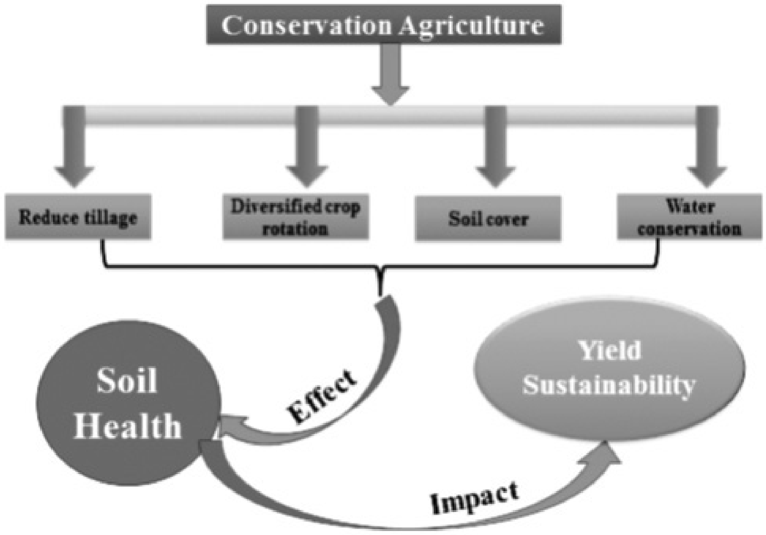
Global warming has already increased temperatures and by the end of twenty-first century is likely to exceed 1.5°C due to anthropogenic emissions of greenhouse gases (GHGs), such as carbon dioxide ($CO_2$), methane ($CH_4$), and nitrous oxide ($N_2O$) (IPCC, 2013). Continuous monoculture, ecological constraints, lack of good quality seed and crop rotations, and use of extensive farming have led to degradation of soil and other natural resources. Degradation of natural resources threatens food security and livelihood opportunities of farmers, especially those who are poor and under-privileged. Soil erosion, nutrient mining, and C loss are among the major causes of soil degradation. Agricultural soils are comparatively more susceptible to erosion because of the removal of vegetation before planting the following crop, coupled with frequent cultivation of the soils. The loss of C due to soil degradation in the past 1000 years represents 16-20% of the present-day global soil C stock of 1200-1500 Pg (1 Pg = $10^{15}$ g) to 1 m depth (Haider 1999). Decomposition of biomass and soil C stock has been a principal source of atmospheric $CO_2$ over the past century (Lal 1997). The loss of soil organic carbon (SOC) by mineralization may range from about 20 % in 20 years in temperate climates to about 50 % in 10 years in the tropics (Woomer *et al*. 1994).

Sequestration of C is the removal of $CO_2$ from the atmosphere into various long lived chemically bound forms, either on land or in the ocean (Franzluebbers, 2008). Soil is an important sink to capture and store atmospheric $CO_2$ in the form of organic (through photosynthesis by plants and humification of the biomass) and inorganic C (through formation of pedogenic carbonates (Bhattacharyya *et al*. 2008). Restoring and maintaining soil fertility in a sustainable manner is also essential to increase productivity, and SOC is a key determinant of soil quality, through its strong influence on physical, chemical, and biological properties and processes. Therefore, it is necessary to restore soil C stock by using judicious land use and adopting best management practices (BMPs) because agriculture is integral to any solution to adapt and mitigate climate change (Lal 2008).

Conservation agriculture (CA) is gaining acceptance in many parts of the world as an alternative to conventional agriculture. Conversion to CA improves water infiltration and reduces erosion, moderates soil temperature, suppresses weeds, improves soil aggregation, reduces soil compaction, increases surface soil organic matter (SOM) content, reduces emissions of GHGs, decreases costs of production, saves time, and




Carbon sequestration through conservation agriculture

maintains some fallow through direct seeding. Conversion to CA enhances soil C sequestration by maximizing C inputs and minimizing C outputs (Franzluebbers, 2008).

## Principal Components of CA and its Effect and Impact

The conservation agriculture system follows three key principles, i.e.

a. *Minimal disturbance* of soil through NT systems — along with sufficient residue biomass enhances soil and water conservation, controls soil erosion, improves soil aggregation, increases soil biological activity, improves soil biodiversity, enhances water quality, and increases soil C sequestration.
b. *Permanent soil covers*, maintained during crop growth phases and fallow periods, prevent the physical impact on soil from wind and rain, and moderate soil temperature.
c. *Crop rotations and associations* reduce the need for pesticides and herbicides, control weeds, minimize off-site pollution and enhance biodiversity.

## Influence of Crops and Cropping Systems

The main sources of C input into soil through plants are roots–shoots, root exudates, and root-borne organic substances released into the rhizosphere during plant growth as well as root hairs and fine roots sloughed by root elongation. Changes in soil conditions alter the rate of plant biomass decomposition and SOM mineralization; therefore, appropriate soil and crop management is important to C sink in soils. Sequestering soil organic carbon (SOC) is the key strategy to improve soil health and mitigating climate change. Furthermore, increased allocation of SOC into passive pools of longer residence time helps to achieve higher carbon sequestration in soils.

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).

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 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 and resulted in significant depletion of 17.56% in C stock with respect to S3 in 0–30 cm soil depth.

Naik *et al*. (2017) observed that in a 6 year old mango, guava and litchi orchards of Eastern Plateau and Hill region of India caused an enrichment of total SOC by 17.2, 12.6 and 11 %, respectively, over the no-orchard. The mango orchard registered highest significant increase of 20.7, 13.5 and 17.4 % in very labile, labile and non-labile carbon, respectively, over no-orchard. The mango orchard registered the highest total soil organic carbon of 62.5 Mg/ha and carbon build rate of 1.53 Mg C/ha/year and resulted in 17.3% carbon build-up over no-orchard. Mina *et al*. (2008) reported that lentil (*Lens esculenta,* variety VL-4; October-April) and finger millet ( *Eleusine coracana,* variety VL-149; June-September), in rotation per year, increased C, N, and enhanced enzymatic activity under zero-zero tillage systems.

Cover crops improve soil by increasing infiltration of the excess surface water, alleviating compaction and improving structure of tilled soil, and adding SOM that encourages beneficial soil microbial life and enhances nutrient cycling. Short-duration drought-hardy legumes like horse gram (*Macrotyloma uniflorum* L.) can be grown with off-season rainfall for fodder/green manuring to improve SOC concentration and partially meet the nutrient requirements of the following rainy season crops.

## Tillage

Tillage plays an important role in the management of nutrient storage and release from SOM with CT inducing rapid C and N mineralization from the soil. Tillage led to the loss of particulate organic carbon (POC) which accounted for 80 % of the total C loss (Chan *et al.* 2002). Tillage disturbs soil aggregates and accelerates the decomposition of aggregate-associated SOM. Adoption of no-tillage (NT) or reduced tillage systems with little disturbance enhances stabilization of SOC. Presence of residue cover in NT system reduces rainfall impact, and minimizes soil and plant nutrient loss in comparison with those under CT. West and Post (2002) observed that the land converted from a CT system to NT system (both with residue retention) can sequester on average 48 ± 13 g C/m$^2$ /year.

Chaudhury *et al*. (2014) studied the influence of different combinations of tillage and residue management on C stabilization in different-sized soil aggregates and also on crop yield after 5 years in a continuous rice–wheat cropping system and observed increases in SOC concentration by 33.6 %, wheat yield by 8.3 %, water stable macro-aggregates by 53.8 %, and macro aggregate-associated C by 20.8 % when compared to those under CT. As these aggregates form, small particles of carbon, such as partially decayed plant residues, are captured in the center of the aggregates. At the center of these aggregates, these carbon rich materials are physically protected from microbial attack. Microbes cannot penetrate the center of these stable aggregates, and conditions at the center, where oxygen and water are low, discourage microbial metabolism.

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 (Lal 2004). In general, C emission is more in CT than NT due to a higher use of diesel.

## Balanced Fertilization

Fertilization can stimulate C assimilation by plants and increase C allocation to underground biomass. Kundu *et al*. (2013) assessed the CA effect with balanced fertilization of a maize-horse gram crop sequence and reported that SOC varied from 3.1 to 4.5 g/kg which was slightly higher than that under a conventional system (2.9–4.2 g/kg). Kukal *et al*. (2009) reported that balanced use of fertilizers had more soil C sink capacity probably because of greater C input in rice–wheat system. Long-term adoption of NT with enough N fertilizer use proved to be effective tools to improve SOC stock by 3.4 and 4.5 Mg C/ha over unfertilized plots (Soler 2012).

## Integrated Nutrient Management

Jiao *et al*. (2006) observed that application of 30 Mg/ha/yr of composted cattle manure to maize production systems increased the water-stable macro-aggregate within 4 years, and aggregation was related to the soil C concentration, suggesting that soils with more water-stable aggregate indicates higher soil C concentration under NT system. Aulakh *et al*. (2013) reported that best management practice of 100 % in NP + FYM + CR registered macroaggregates of > 50 % of total soil mass and also enhanced total organic carbon (TOC) 5.8 g/kg in surface layer and from 2.7 to 3.6 g/kg in subsurface layer after 2 years over control (3.8 g/kg) in CA. Nayak *et al*. (2012) reported that application of the RDF to a rice–wheat system in IGP (through either chemical fertilizers or INM strategy) increased the concentrations of SOC, POC, and MBC along with total SOC stocks and the rate of C sequestration.

## Crop residues

Carbon stock in soil not only depend upon amount of crop residues (CR) returned to soil but also depend on quality of crop residue, which varies according to crop selected in a particular cropping system. The predominant crop production systems in rainfed regions of India are, sorghum, finger millet, pearl millet, maize, upland rice, groundnut, soybean, cotton (*Gossypium* spp.), food legumes, etc. Several studies have revealed that C input through various crop components (viz., leaf fall, stubbles, roots, rhizodeposition, etc.) returned back to soil can enhance C sequestration (Srinivasarao *et al*. 2013b). Data from the long term manurial experiments on major rainfed production systems in India showed the highest C input through CR in a soybean–safflower (*Carthamus tinctorius*) system (3.4 Mg/ha/year) in Vertisols followed by an upland rice–lentil system (1.7 Mg/ha/year) in Inceptisols, a groundnut-based system (1.2 Mg/ha/year) in Alfisols, a finger millet and winter-sorghum-based system (0.8 Mg/ha/year) with the lowest in a pearl-millet-based system (0.3 Mg/ha/year) in Aridisols (Fig. 1). Efficient management of CR can also play a vital role in refurbishing soil productivity as well as increasing the use efficiency of inorganic fertilizers. Thus, CR management is receiving attention because of its diverse and positive effects on physical, chemical, and biological properties of soil. CR has the potential to increase total SOC content by 33.6 %, equivalent wheat yield by 8.3 %, water-stable macro-aggregates by 53.8 % and macro-aggregate-associated C by 20.8 % over CT with transplanted rice after 5 years of continuous rice–wheat cropping (Chaudhury *et al*. 2014).

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 read-

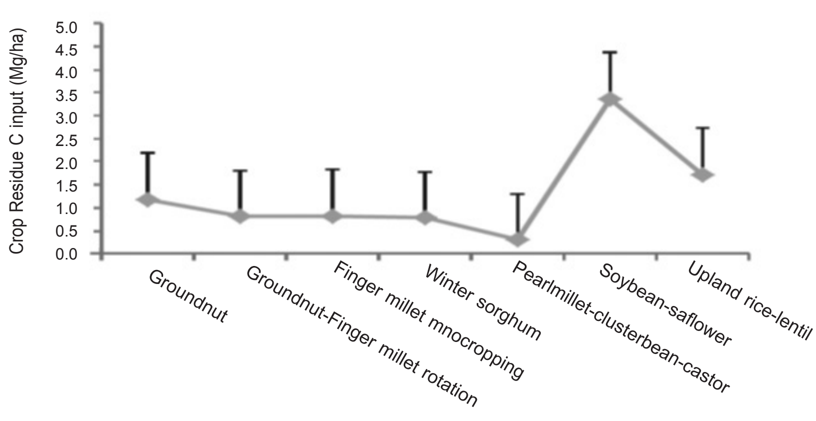



**Fig. 1.** Annual crop residue C input (Mg/ha) in different rainfed crop production systems.

ily 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).

## Conclusion

Soil carbon sequestration involves transferring atmospheric carbon into the soil via plant photosynthesis and keeping those soil-based carbon pools protected as effectively as possible from microbial activity. Conservation agriculture is to avoid mechanical disturbances of the soil, which saves time, energy and labor while conserving water and nutrients in the soil that support crop production. Further, sequestering of atmospheric C and enhances soil quality and partially reduce green hot gases as well as promoting ecologically and economically sustainable system. CA has the capacity for short-term maximization of crop production as well as the potential for long-term sustainability (i.e., C storage) at farm level. CA is an important technology to restore soil processes, control soil erosion, and reduce tillage-related production costs. These are sufficient reasons to promote the systematic conversion of the traditional system to CA. Recycling organic resources containing polyphenols and lignin may affect the long-term decomposition dynamics and contribute to the buildup of SOC. 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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# Carbon and Nitrogen Mineralization Dynamics: A Perspective in Rice-Wheat Cropping System in Eastern Indo-Gangetic Plains

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Rice-wheat cropping system (RWCS) is one of the world's largest agricultural production systems, covering an area of ~26 M ha spread over the Indo Gangetic Plains (IGPs) in South Asia and China. Rice and wheat are harnessing enormous soil fertility therefore, to maintain the productivity of this system, replenishment of soil nutrients is necessary. It has not only resulted in mining of major nutrients (NPKS) from soil, created a nutrient imbalance, leading to deterioration in soil quality. Deficiencies of NPK are most extensive. One ton of wheat grains are estimated to remove 24.5, 3.8, and 27.3 kg N, P, and K, respectively, whereas similar production of rice grains removes 20.1 kg N, 4.9 kg P, and 25.0 kg K (Tandon and Sekhon 1988). Because of agricultural strength of the country, crop residues (CRs) production is also huge. In India, over 500 Mt of agricultural residues are produced every year. Punjab alone produces ~20.8 Mt of rice residue and 23.3 Mt of wheat residue annually (Dhar *et al*. 2014). Although during last three decades fertilization practices have started playing a dominant role in the RWCS, crop residues still play an essential role in cycling of nutrient. With availability of 37.87 Tg of rice and wheat residues for recycling, associated nutrient (N + P + K) potential was 0.634 Tg (Samra *et al*. 2003). According to Sarkar *et al*. (1999), RWCS accounts for nearly one-fourth of the total crop residue production in India. One ton of rice residues contain ~ 6.1 kg N, 0.8 kg P, and 11.4 kg K, while one ton of wheat residues contain ~4.8 kg N, 0.7 kg P, and 9.8 kg K.  Integrated uses of plant nutrients with mineral fertilizers have either maintain or enhance soil quality and improve performance of crop along with cropping system. Therefore, proper crop residue management (CRM) can play an important role in increasing soil organic matter and nutrient supplying capacity, reducing ill effects of residue burning, as this leads to destruction of SOM as well as plant nutrients i.e. NPKS. Incorporation of crop residues alters soil environment, which in turn influences microbial population/activity in soil and subsequent nutrient transformations. Through this chain of events, management of crop residues regulates efficiency with which fertilizer, water, and other reserves are used in a cropping system. No single residue management practice is superior under all condition. Therefore, it is important to determine benefit and adverse effect of residue management options before these are recommended to the farmers for adoption. Research carried out in last few decades relating residue management to soil chemical, physical, and biological properties and consequent fertilizer management practices in RWCS provides valuable directions for efficient management of crop residues in rice-wheat cropping.

## Importance of Residue Retention in Field in Relation to C and N Mineralization

Crop residues are considered a vital natural resource for conserving and sustaining soil productivity. Addition of CRs to soil is a useful tool in maintaining and increasing amounts of soil organic matter. Therefore, soils have significant capacity for C storage and to mitigate atmospheric $CO_2$. Upon mineralization, CRs also supply essential plant nutrients. So, recycling of CRs is suggested as a potential means of sustaining soil fertility and productivity over long-term For recycling crop residues, in situ incorporation and mulching with reduced or no tillage are the major residue management options. Management of CRs in conservation tillage has crucial effect on soil C and N dynamics, a better knowledge about CRs decomposition and N mineralization dynamics of residue C and N is essential to quantify potential benefits of changes in tillage practices and residue management on soil quality and crop production. CRM as practiced in RWCS is of three types (1) wheat straw management in rice and its residual effect in following wheat, (2) rice straw management in wheat and its residual effect in following rice (3) wheat straw management in rice and rice straw management in wheat (cumulative effect). Incorporation of CRs provides readily available C and N to soils depending upon the decomposition rates and synchrony of nutrient mineralization. Yadvinder-Singh *et al*. (2004) reported that rice residues incorporation increased organic carbon content of sandy loam soil more significantly than straw burning or removal after 7 years (Table 1).

**Table 1. Effect of crop residue management on SOC (%) and Total N (%)**

| Type of crop residue and soil | Duration of study (years) | Residue management | Organic C (%) | Total N (%) |
|---|---|---|---|---|
| Rice straw in wheat and wheat straw in rice; sandy loam | 10 | Removed | 0.38 | 0.051 |
| | | Burned | 0.43 | 0.055 |
| | | Incorporated | 0.47 | 0.056 |
| Rice straw in wheat in rice– wheat rotation; sandy loam | 7 | Removed | 0.38 | - |
| | | Burned | 0.39 | - |
| | | Incorporated | 0.50 | - |

(Beri *et al*. 1995; Yadvinder-Singh *et al*. 2004)

Naklang *et al*. (1999) used the two indices to calculate a carbon management index (CMI). They measured two fractions of organic carbon in soil. The more labile fraction (CL) was measured by oxidation with 333 mM $KMnO_4$, and the nonlabile C (CNL) plus the C not oxidized by 333 mM $KMnO_4$, (i.e., CT-CL). The total C (CT) was measured by combustion. On the basis of changes in CT between a reference site and the cropped site, a carbon pool index (CPI) was calculated:

$CPI = CT_{cropped}/CT_{reference}$

On the basis of changes in the proportion of CL in the soil (labiality = LI = CL/CNL), a labile index was determined.

CMI = CPI X LI X 100

Incorporation of leaf litters increased the CMI from 9 in 1992 (initial) to about 20 after 3 years in 1996 and CMI in no-litter treatment increased to 13. Straw incorporation did not significantly affect the CT (4.44 versus 4.11 mg $g^{-1}$) and CL (0.78 versus 0.79) compared to straw removal treatments. The measurement of CL is a more sensitive indicator of SOM dynamics. Total C measurement is still required to estimate bulk soil C change; however, CL more accurately and quickly detects the impact of management on soil C. Calculation of the CMI takes into account the change in CT pool size and its lability and gives a more definitive picture of soil C dynamics than when only a single parameter is used.

The quantity of SOM is not the sole factor that should be considered when devising management practices to optimize the agronomic benefits of SOM. A higher quantity of SOM does not automatically lead to a higher quality of SOM. It remains a difficult task to identify and quantify the intrinsic quality of an SOM pool in terms of nutrient supply power, microbial activity, or physical or chemical indices. Labile SOM pools are key suppliers of nutrients to the crop, whereas other SOM pools are more recalcitrant in nature and will provide fewer nutrients, but their chemical and physical properties provide stability to the soil. The studies on soil organic matter dynamics suggest that soil texture, C inputs, and climatic conditions are the primary factors controlling stabilization of soil C. The reduced soil C sequestration in the rice-upland rotation resulted primarily from an increased amount of microbially mediated C mineralization compared to the C mineralization rate in the rice–rice system (Witt *et al*. 2000).

A simplified model of the regulation of nutrient flux in the agoecosystem is presented in Figure 1. This conceptual model depicts the flow of carbon and nutrients among organic residues, organic and inorganic pools in soil, and the plant. Pathways

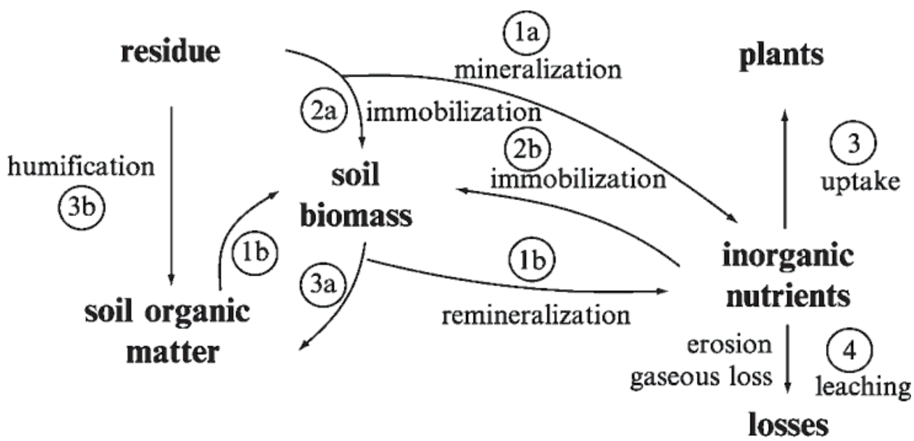


**Fig 1.** Conceptual model of nutrient pathways in crop residue amended soils (Myers *et al*. 1994).

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 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. By manipulating the quality of crop residues, it should be possible to manage nutrient release to coincide with the time course of the nutrient requirements of the crop (Swift 1987). When low-quality crop residues (low N and P, high lignin or polyphenol contents) are incorporated into the moist soil, nutrients become available to the plants. With high-quality residues, nutrients are

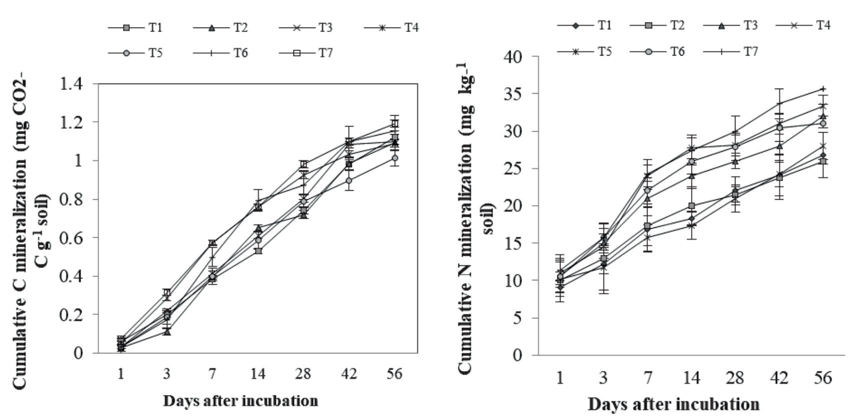


**Fig 2**. Cumulative C and N mineralization under different treatments

$T_1$: Random puddled transplanted rice- Conventional till broadcasted wheat-Zero till green gram (RPTR-CTW-ZT GG); $T_2$: Puddled line transplanted rice (LPTR-CTW-ZT GG); $T_3$: Machine transplanted non-puddled rice (MTNPR- ZTW-ZT GG); $T_4$: Machine transplanted zero-till rice (MTZTR-ZTW-ZT GG); $T_5$: System of rice intensification (SRI-SWI -ZT GG); $T_6$: Conventional till direct seeded rice (CTDSR-ZTW-ZT GG); $T_7$: Zero-till direct seeded rice (ZTDSR- ZTW-ZT GG).

initially released rapidly in excess of plant demand with a risk of nutrients such as N being lost via leaching or denitrification or a nutrient such as P becoming chemically unavailable (Anderson and Swift 1983).

About 70% of the rice lands in south and south-east Asia contain<0.2% N and are considered N deficient (Ponnamperuma 1984). Incorporation of crop residues enhances the N content of several wetland rice fields. Within 3 years of incorporating the rice straw at 6–7 t/ha, total N content in soil increased by 0.021% over the straw removal treatment. A laboratory study was conducted taking soils from Cereal System Initiative for South Asia (CSISA) experiment at main campus farm, ICAR-RCER, Patna from seven different treatments to predict C and N mineralization of rice residue placed on the surface and incorporated into the soil (Unpublished).

$CO_2$ emissions were higher for residues placed on the soil surface ($T_3$, $T_4$, $T_6$ and $T_7$) than for residue incorporated ($T_1$, $T_2$ and $T_5$) into the soils. This result indicates that the incorporation of residues into the soils in our study inhibited residue decomposition, most likely by modifying the availability of oxygen to decomposer microorganisms. Soil Cumulative mineral N for residue placed on the soil surface was higher than for residues incorporated into the soils. These suggests that rice residue addition resulted in greater N immobilization when the residues were incorporated into the soil than when they were applied to the soil surface. Therefore, residues with less N and more C:N ratio incorporated into cropland rather than placed on soil surface to decrease not only the risk of N loss but also $CO_2$ emission.

## Summary and Conclusion

The intelligent management and utilization of crop residues is essential for the improvement of soil quality and crop productivity under rice-wheat cropping systems of the tropics. Crop residues, usually considered a problem, when managed correctly can improve soil organic matter dynamics and nutrient cycling, thereby creating a rather favorable environment for plant growth. Due to intensive cropping of rice-wheat system prevailed in South Asia region it is necessary to manage the huge quantity of its residues, which are the good source of carbon, nitrogen and potassium. Greater knowledge in this area should improve our ability to manage soil nutrients efficiently.

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# Impact of Conservation Agriculture on Soil Physical Properties

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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 undergoes 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 freezingthawing 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 are 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 substances (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 macroaggregates 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 traditional 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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# Soil and Residue Management in Conservation Agriculture

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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 markedlyenhanced. 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 profitability 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 organicmatter.

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 availability 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 residue 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, currently 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 consisting 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 immediately 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 incorporation 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 an-djudicious crop rotations, are gaining more attention in recent years with the rising concern overdegradation of natural resources, mainly soil and water, and to offset the production costs. Further more, 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 willhave 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 highwith 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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# Mechanization and Energy Management in Conservation Agriculture for Sustainable Intensification in Eastern-IGP

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Agriculture, the backbone of Indian economy, employs almost half of the country's work force. Indo-Gangetic Plains (IGP) is the food bowl of India. Continuous practice of tillage-based conventional rice-wheat cropping system (RWCS) in IGP has resulted in stagnating productivity along with adverse impact on the natural resources of the region. Coupled with this, increasing cost of farm inputs like water, fertilizer, non-renewable energy & labor has made agriculture less profitable. Government of India has given a call to double farmers' income by 2022. Out of several strategies, increasing system productivity with concomitant reduction in the cost of cultivation is an important one and attainable by out scaling adoption the new technology for sustainable intensification. Conventional production practices in the IGP allow farmers to harvest only two crops.  Rice and wheat generally occupies the field from the beginning of July to mid-April and most of the farmers keep the same piece of land fallow from April 15 to 1st week of July. During this window of 70-80 days there is abundant sunshine and low pressure of pests; therefore, a crop of short duration of 60-65 days can successfully be raised. This will increase system productivity. Keeping this in mind, sustainable intensification (SI) of RWCS in conjunction with conservation agriculture-based minimum tillage practices, selection of suitable genotypes and adjusting the planting/harvesting schedule can increase cropping intensity for in enhanced productivity, profitability, and employment generation coupled with soil and environmental benefits.

## Sustainable intensification of RWCS for food and nutritional security of small, marginal and landless farmers

Sustainable intensification (SI) of cereal-based cropping systems with the inclusion of legumes in Indo-Gangetic plains is an important strategy to increase the system productivity, profitability, nutritional security and sustainability. In eastern IGP, owing to adoption of short duration rice varieties, wheat is sown in residual moisture of rice fields in last week of October followed by its harvest in early April. This gives adequate interval for taking a crop of green gram (*mung bean*) before onset of rain. Since wheat is sown early, yield improves by one tonne per hectare and farmer get additional tonne of mung bean (approximately equivalent to 4 tonnes of wheat).The general tradition of harvesting mungbean crop in eastern IGP is by pod picking; a job generally performed by woman folks in the community (Fig. 1).They share the crop produce (grains) on 25:75 basis (Fig. 2). Women labourers shared nearly 312 kg of whole grain mung bean pulse, which is used for their household consumption. Thus, introduction of the pulse crop in rice-wheat system not only breaks the monotony of the cereal-cereal production system but also improves house hold nutrition as pulses are one of the major source of protein to the vegetarian farmers.

The field study revealed that pod plucking of greengram crop in one hectare generated 625 hrs of labour employment, which is equivalent to 78 man-days (Fig. 2). With rising temperature in May-June, greengram requires additional 1-2 irrigations, matures in 58-62 days, can be machine harvested to give a yield of 0.8-1.0 t/ha yield besides enriching the soil through nitrogen fixation. The additional income to the farmer justifies for the custom hiring of machines to carry out various farm operations.

**Fig. 1.** Women labourers picking mung bean in Eastern Indo-Gangetic Plains

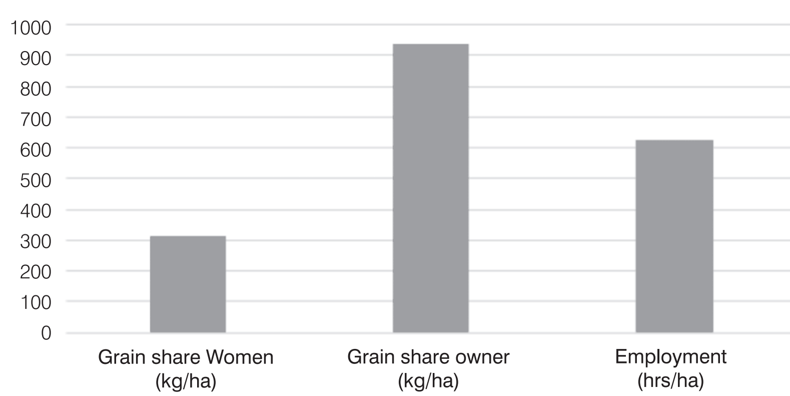


**Fig 2.** Effect of introduction of green gram in rice-wheat system on house hold food security and employment generation

## Sustainable intensification of maize-potato system for small and marginal farmers

Productivity of *Rabi* (winter) maize is generally higher than *Kharif* season crop in the eastern IGP. Many farmers practice intercropping of potato in maize crop. The maize + potato intercropping system is generally very popular among the smallholder farmers in tilled situations. The conventional maize+potato is generally planted after repeated tillage operations followed by making manual raised beds. The potato is planted in raised portion and maize is planted in furrow section of beds. After harvesting of potato, raised bed soil is moved to earthen up maize crop planted in furrow. This practice of making raised beds for potato and then shift soil to earth up maize manually is a very labor and energy intensive rocess. Planting of maize under permanent raised beds is popular around the world and gaining popularity in South Asia.The technology involves planting of potato in the furrow of permanent raise bed; covering it with rice residue (6 t/ha) and planting maize on the top of the raised bed. No irrigation is required as the dew water mulched residue maintained sufficientsoil moisture for the growth of potato and maize. The potato crop (25t/ha)can be harvested from the furrow surface of the permanent bed (Fig. 3) with out disturbing the soil and subsequently irrigation and fertilizer can be applied to the maize crop. Potato does not affect the productivity of maize and compares well with the sole maize crop with similar management practices.

## Precision nutrient management for improving productivity and profitability of wheat

Most farmers' broadcast nitrogenous fertilizers in wheat fields at the time of sowing and subsequently. Usually N is applied in top dressed by broadcast. In general, the broadcasting of fertilizer nutrients results in plant roots to become surface feeder, whereas drilling facilitate roots to grow deeper. Deeper roots efficiently utilizes nutrients available in the deeper layer and reduces the leaching losses of the nutrients, and crop lodging.

BISA has developed the machinery (Fig. 4) that can be used for drilling fertilizer N in NT and surface residue retained conditions either during planting or post-emer-

**Fig. 3.** Maize on permanent beds and potato in furrows for higher system productivity


**Fig. 4.** Drilling of fertilizers improved nutrient use efficiency, productivity and profitability of wheat by 6.7 quintal /ha or net returns of Rs. 7,700/ha.

gence application in the standing crops. With these developments, proper placement of N fertilizer has become possible. Band placement allows for efficient use of N application compared to broadcasting. Further, sub-surface drilling reduces ammonia gas volatilization. Farmers generally apply over or under dose of fertilizers nutrients which reduces farm profits and leads to imbalanced soil health.

## Conservation agriculture practices in rice-wheat cropping system

Conventionally, rice is transplanted in puddle soils and wheat is sown after fields are tilled to a fine tilth. The rice-wheat system is practiced in more than 13 million ha in South Asia. It is widely practiced in Indo-Gangetic Plains, but is now showing signs of natural resource fatigue, and is no more sustainable. Uncertain weather events further add to the challenge and make it difficult to keep pushing the productivity of rice-wheat systems. To address the issues related with natural resource fatigue and make agriculture climate resilient, conservation agriculture based crop management practices were developed for the irrigated systems, which are being adapted and promoted in the region. In initial stages, rice productivity in conventional system was a little less than no-till system but the loss in rice productivity was compensated by the enhanced wheat productivity in zero-till CA systems. After CA has been practised for 2-3 seasons continuously in the presence of residues, it begins to reflect on improved soil health, and enhanced and more yield gains and net benefits which could be as high as about Rs.13,000/ha from the rice-wheat system.

## New cropping systems for higher productivity/profitability for small and marginal farmers of Eastern IGP

### Rice-wheat-mung bean

In this system, rice is grown as direct seeded under zero tillage (ZT) followed by ZT wheat and then summer mung bean crop. Direct seeded rice matures one week earlier than transplanted rice, which allows one week early seeding of the succeeding wheat crop. Zero tillage technology in wheat again save one week time, which required for tillage operations in conventional sown wheat.  Zero tillage and direct seeding facilitate almost 2 week early planting of wheat, which help in avoiding the terminal heat, which is a major issue in late planted wheat. Early harvesting of early planted wheat also helps in timely planting of succeeding summer mung bean crop. The average productivity of rice-wheat cropping system in Bihar is 5.3 t/ha (2.6 t/ha rice and 2.7 t/ha wheat), which can be doubled by adopting this cropping systems based sustainable intensification module. This module is suitable for low-land and mid-land ecologies of Bihar, eastern UP and West Bengal.


**Fig. 5.** Technology transfer model used by BISA-CIMMYT

### Maize-wheat-mung bean

The average productivity of *Kharif* maize in Bihar is 1.5 t/ha due excessive soil moisture and weeds. In this system, permanent raised beds were used to plant the maize, wheat and mung bean crop in a year.  Permanent raised bed help in avoiding the temporary water logging and fewer weeds helped in increasing productivity of *Kharif* maize. Permanent raised beds requires 25-30% less irrigation water and produced equal or higher wheat yield as compared to ZT flat sowing. The average yield potential (total of maize, wheat and mung bean) of this system is more than 12 t/ha per year. This module is suitable for upland ecologies of eastern IGP as well as western IGP.

### Maize- mustard- mung bean

In this system maize, mustard and mung bean crops were planted under permanent raised bed system. The rainy season maize planted in June and harvested in October followed by planting of mustard in mid-October and harvesting it in early march followed by planting of mung bean crop is most economic and sustainable module for upland ecologies of eastern IGP. This system also requires, less irrigation water as compared to other systems.

### Maize-lentil-mung bean

Maize, lentil and mungbean grown in a sequence in a year on permanent raised bed which produced more than 12 t/ha/year rice-wheat equivalent yields. Permanent raised bed help in better aeration to roots of maize, lentil and mung bean crop due to more earth worm activity and less water stagnation. This system requires least irrigation water as Kharif maize and lentil requires no irrigation water only mung bean crop need to be irrigated. This system can be disseminated in water scarcity areas of the eastern IGP.

## Soybean-wheat-mung bean

As soybean is an emerging crop in the region where Kharif maize is suffer with excess soil moisture and rice crop suffer due less rains. In this system, soybean, wheat and mung bean planted on permanent raised beds and produced more than 12t/ha/year system yields. PB avoids excess rain water in rainy season soybean crop and also requires 30% less irrigation water in wheat and mung bean crops.

### Soybean-winter maize

Winter maize is very popular in eastern IGP due to its higher yield potential (9-10 t/ha) but it requires more irrigation water and nutrient. Inclusion of soybean in rotation and permanent raised bed system of planting reduce total water and nutrient requirement of winter crop. Soybean-winter maize yield potential is more than 15 t/ha rice-wheat equivalent yield. This system is suitable in the areas, where sufficient irrigation water is available.

Thus, widespread adoption of newly developed technologies will help not only in raising system productivity per unit area and time but will also help in bringing down the cost of cultivation. This will ultimately help in food, nutrition and livelihood security of the farming community of the regions.

# Role of Farm Mechanization in Mitigating Climate Change Effects

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Climate change refers to any change in climate over time, due to natural variability or as a result of human activity (IPCC, 2007). Climate change is mainly caused by greenhouse gases (GHGs) accumulation in the atmosphere, which results in increased greenhouse effect. Agriculture, especially intensive agriculture which is characterized by monocultures and feeding farm animals – is one of the sectors that generate the highest amount of emissions of $CO_2$ (the main greenhouse gas). In developing countries, GHG emission from agriculture sector is much more because of large number of cattle and inadequate manure management, improper use of agro-chemicals, burning of straw and mismanagement of the land.

Climate change and agriculture are interrelated processes, both of which take place on a global scale and their relationship is of particular importance as the imbalance between world population and world food production increases. Changes in temperature, rainfall and severe weather events are expected to reduce crop yield in many regions of the developing world (Gornall 2010). Agriculture production is strongly influenced by changes in rainfall and temperature patterns as well as other climatic conditions.

## Effect of Climate Change on Agriculture

Change in temperature, rainfall pattern and increase in $CO_2$ concentration will significantly affect crop development. It is estimated that 32-39% of yield variability may take place due to climatic variability (Ray *et al*. 2015). The effect of climate change on a crop can be positive or negative (Table 1) depending upon the variability in climatic factors and current crop or cropping system.

### Conservation Agriculture

Conservation Agriculture is a farming system that promotes maintenance of a permanent soil cover, minimum soil disturbance (i.e. no tillage), and diversification of plant species (FAO, 2018).

**Table 1. Possible positive and negative effects of climate change**

| Change factor | Potential positive effects | Potential negative effects |
|---|---|---|
| Temperature rise | Longer growth periods<br>Faster growth times<br>New crops in cold areas | Increased thermal stress<br>Increase in pest, weed and diseases<br>Problems in flowering and curdling due to vernalization damage |
| Rainfall variations | Increased productivity<br>Decreased demand for water<br>Increased guarantee of water supply | Increased flooding<br>Increased frequency of draughts<br>Increase in weeds, pests and diseases<br>Increased erosion |
| Increased Greenhouses gases emission | Increase in fertilization due to the higher concentration of $CO_2$ | Negative effects of other gases |

*Source:* Iglesias *et al*. (2007)

### Principals of Conservation Agriculture

There are three important principals of Conservation agriculture:

- Minimum or no soil disturbance while growing the crop.
- There should be permanent soil cover of crop residues and stubbles during crop growth (30% of the soil surface covered by residues)
- Diversification of cropping system through crop rotation.

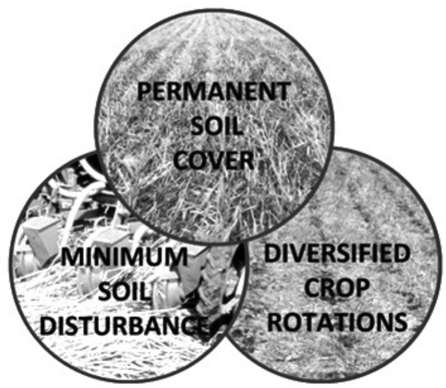



**Fig. 1.** Three principals of conservation agriculture

However, Lal (2014) added that improving soil fertility by integrated nutrient management (INM) for healthy crop growth and biochemical transformation of biomass C into SOM or humus should also be considered as one of the principals of conservation agriculture.

## Advantages of Conservation Agriculture

The implementation of CA leads to significant improvement in soil physical and chemical properties. This results in better soil structure, increase in soil organic matter, improved water infiltration, improved water holding capacity, reduced runoff and less evaporation from soil (Table 2). Also, reduction of tillage operations leads to reduction of $CO_2$ emission originating from less fuel consumption. Some of the advantages of CA is listed below:

- Reduced erosion and environmental degradation
- Improved soil structure and biology

- Improved soil moisture retention
- Higher soil Carbon levels
- Increased yields
- Reduced input costs (low external input)
- Reduced $CO_2$ emissions (reduced use of fossil fuels)
- Long term sustainability both environmental and economic

**Table 2. Main benefits of Conservation Agriculture**

| | |
|---|---|
| For the soil | Reduced erosion |
| | Improvement of structure and porosity |
| | Increase in soil organic matter |
| | Increased soil fertility |
| For air | Carbon sequestrated in the soil |
| | Reduced $CO_2$ emission into the atmosphere |
| For water | Reduced runoff |
| | Increased water holding capacity |

The acreage under CA is slowly increasing. The top countries adopting CA are the United States of America, Brazil, Argentina, Canada and Australia. India with acreage of 1.5 M ha is way behind many countries (Fig. 2).

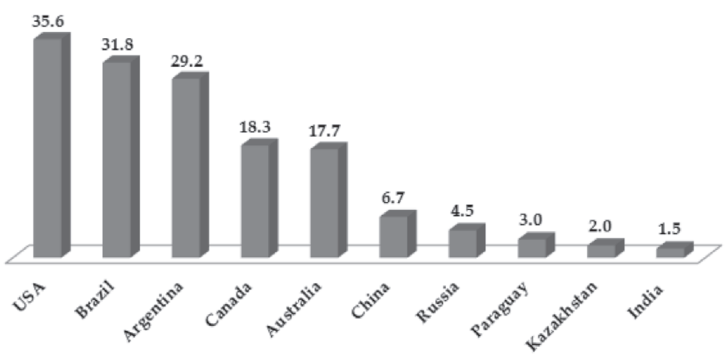
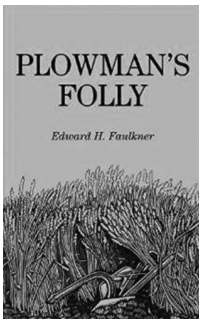



**Fig. 2.** Acreage under Conservation Agriculture in different countries (M ha) (FAO, 2014)

## Evolution of ploughing and Conservation Agriculture




*"There is nothing wrong with our soils except our interference. It can be said with considerable truth the use of tillage has actually destroyed the productivity of our soils"* (Faulkner 1942).

In the 1940s, discussions on pros and cons of plow-less agriculture or no-till farming started with the publication of two books, "Plowman's Folly" and the "The Furrow and Us" (Lal 2015). Faulkner blamed the moldboard plow for disastrous pillage of the soil.

**Table 3. Historical development of Conservation Agriculture**

| Tillage system | Year | Processes |
|---|---|---|
| No-till/direct seeding | 1950s to 1960s | Soil is completely undisturbed prior to planting, except for a narrow slot for seeding, and weed control is achieved by herbicides. |
| Reduced tillage/mulch tillage/ minimum tillage | 1970s | Any tillage system (other than NT), which does not use all primary, secondary, and tertiary tillage operations, but meets 30% residue requirements of SCS/NRCS. Tillage tools used are chisels, field cultivators, discs, sweeps, or blades. Weed control is by herbicides and cultivation. |
| Strip/zonal tillage | 1970s | Soil is kept undisturbed prior to planting; the seed row is tilled/subsoiled prior to planting, but row tillage is performed by chisel, rototiller, or row cleaner at the time of planting. Weed control is by herbicides and cultivation. |
| Ridge tillage | 1980s | The soil is kept undisturbed, 10 to 15 cm high ridges are made either during the previous season with cultivation or at planting. Crop residues are removed from ridge top and put into adjacent furrow. Cultivation and herbicides are used to control weeds. Ridges are reformed annually. |
| Conservation agriculture | 2000s | A holistic approach comprising of (1) residue mulch, (2) no-till system, (3) cover cropping and rotations, and (4) integrated nutrient management. Weed control is by herbicides, cover cropping and mulching. |

## Role of farm machines in facilitating conservation agriculture

The use of farm machinery is indispensable for crop production. It can also be the source of some detrimental effects on sustainable production such as accelerated soil erosion on soil loosened by tillage, formation of plough pans, soil compaction caused by traffic of tractors and other farm machines. Selection of appropriate machinery is important to minimize detrimental effects or to correct existing anomalies.

Tools and equipments used in conservation agriculture are:

(i) Minimum tillage equipment
(ii) Direct seeding equipment
(iii) Cover crop and weed management equipment

**(i) Minimum tillage equipment***:* Its application is confined to area where the crop is going to be planted leaving the rest of the area undisturbed. Usually equipment are tine based to avoid soil inversion and excessive soil disturbance.

**Example**: Rippers, subsoiler, chisel plough

**(ii) Direct seeding equipment**: Direct seeding is a cropping system which aims to improve soil and soil moisture conservation. Direct seeding allows some tillage to solve immediate weed problems and to deal with high moisture and heavy clay soil conditions.

**Example**: Dibblers, air seeder, Zero seed cum fertilizer drill, happy seeder, animal drawn direct seeding planter

*(iii)* **Cover crop and weed management equipment:** The guiding rule for residue management is to ensure that crop residues are evenly distributed in the field after harvest in order to retain soil moisture, regulate soil temperatures for living organisms, suppress weeds and facilitate subsequent seeding operations.

**Example:** Hand operated weeders, Knife roller, Straw chopper, manual sprayers

## Mitigating Climate Change through Conservation Agriculture

Soil management system is based on mechanized tillage. Mechanized tillage was introduced more than half century ago, but now it has become unsustainable, because it emits greenhouse gases (GHG) and does not contribute to the conservation and improvement of natural resources. Due to manipulation of soil the soil organic carbon present in organic matter (OM) of soil decreases due to following reason:

(i) Lower input of OM in the form of crop stubble.
(ii) Mineralization of humus caused by tillage. Tillage facilitates the penetration of air into the soil and hence, mineralization of humus takes place, generating $CO_2$ as main by product.
(iii) The higher rate of erosion, which causes significant losses of OM and minerals.

For all these reasons many authors agree that soil disturbance by tillage is one of the main causes of organic carbon reduction in the soil (Balesdent *et al.* 1990; Six *et al.* 2004; Olson *et al.* 2005). However, adopting conservation agriculture will mitigate these ill effects.

Conservation agriculture will achieve following purposes:

(a) Use of soil management practices which will increase the OM content in soil.
(b) Reduce soil disturbance in order to reduce GHG emission from soil: Due to drastic reduction of tillage operations, the volume of $CO_2$ emission due to fossil fuels as well as due to breakdown of soil aggregates will be greatly reduced (Fig. 3).

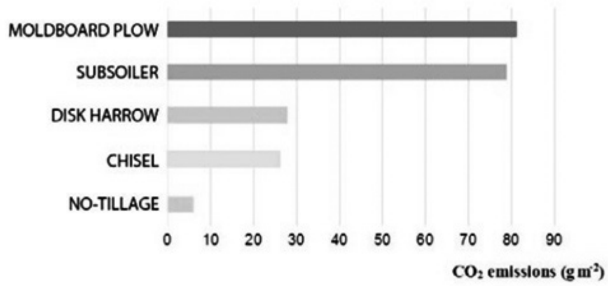



**Fig. 3.** Accumulated $CO_2$ emission (g/m$^2$) 5 hours after the tillage (Reicosky, 1997)

(c) Reduce fuel consumption and use more efficient processes to reduce the GHG emissions associated with them.

The maintenance of permanent cover over soil plays an important role in reduction of wind erosion. Fryear (1985) concluded that in a soil whose surface was covered by 20 % of crop residues, the soil loss was reduced by 57 %. In soils whose surface was covered by 50 %, erosion was reduced by 95 % (Fig. 4)

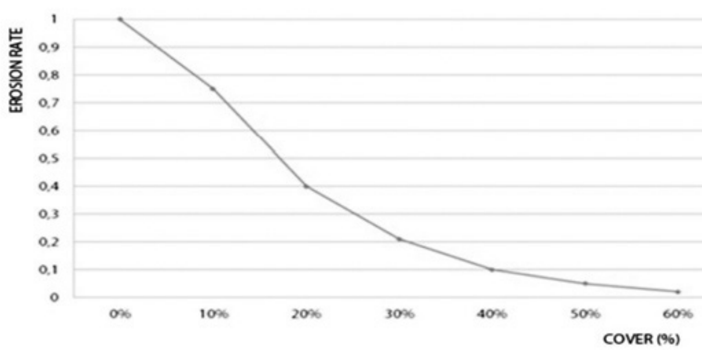



Fig. 4. Reduction of the rate of wind erosion according to percentage of crop residues

## Conclusion

Climate change is a global threat, whose impacts will adversely affect agriculture production. The lower amount of rainfall, prolonged spell of rain or drought, together with increase in temperature, will negatively affect agriculture. Through conservation agriculture, these effects can be mitigated. Conservation agriculture can contribute to reduce GHG emission by storing $CO_2$ as organic carbon in soil and helps adapt through water saving as a consequence of less evaporation from soil.

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# Integrated Farming Systems: An Approach to Improve the Income of Small and Marginal Farmers

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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 socio-economic 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 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 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% of 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 management 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 and 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 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 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 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 MS 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

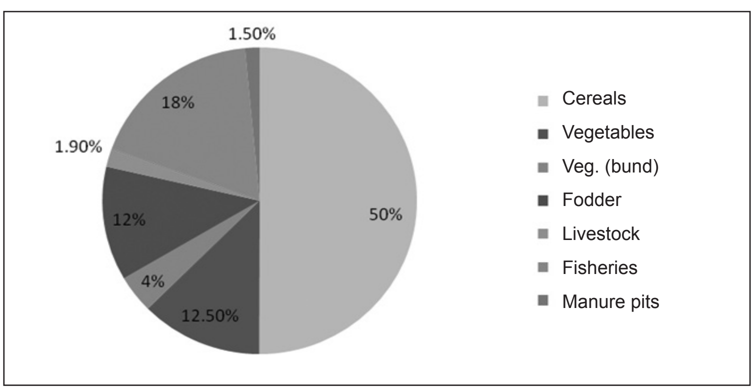
1. **Cereal crops** (50 % area)

   *Kharif:* Rice
   *Rabi:* Wheat/MaizeGram/Mustard

2. **Horticultural crops** (Fruits + vegetables): 12.5 % are**a**

   **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 2 m$^3$ 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*.

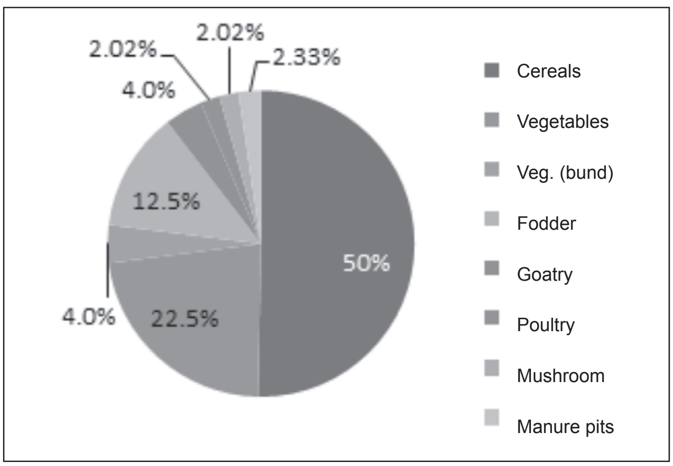
## Land Allocation to Different Components Under One-acre IFS Model

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 600 $m^2$ 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.

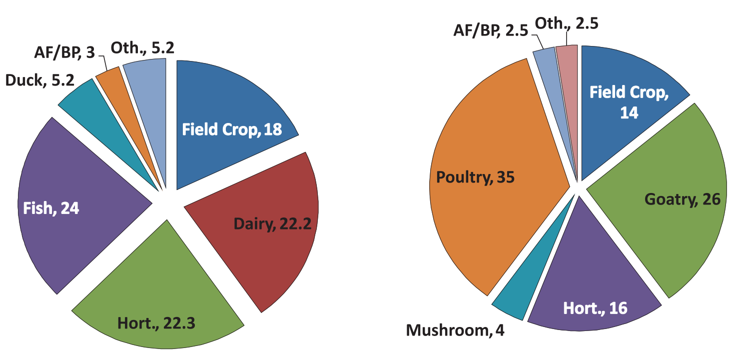
### Income and expenditure from IFS model

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.

**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 |

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).




Two acre IFS model

One acre IFS model

**Fig.1 . Percent contribution to income from different components under one and two acre IFS models**

## 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 (Kumar *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 (Table 2 & 3). In addition to these nutrients an ample quantity of micronutrients was also added to the soil upon nutrient recycling.

**Table 2. Recycling of farm waste and gain/saving of nutrients through 2 acre IFS model at ICAR-RCER, Patna**

| SI. No | Farm waste | Quantity produced (t) | Production/use pattern (t) | Nutrient gain (kg) | Total Nutrient Gain from recycling | Saving (Rs.) | Fert. equivalent (kg) |
|---|---|---|---|---|---|---|---|
| 1. | Cow dung (2 +2) | 13.8 | 8.2 (FYM- 3.6)<br>2.5 (VC: 1.3)<br>4.0- Pond treat. | N-21.5<br>P- 12.2<br>K-13.3 | N=56.5<br>P=39.6<br>K=42.7 | Total: Rs. 4826/- | 118 kg urea<br>247kg SSP<br>71.2 kg MOP |
| 2. | Veg. waste | 11.3 | 6.2 (VC-1.6)<br>6.5 As fodder | N- 28.6<br>P- 22.2<br>K- 24.7 | | | |
| 3. | Duck drop. (35) | 1.21 | As fish feed/silt | N- 6.4<br>P- 5.2<br>K- 4.7 | | | |

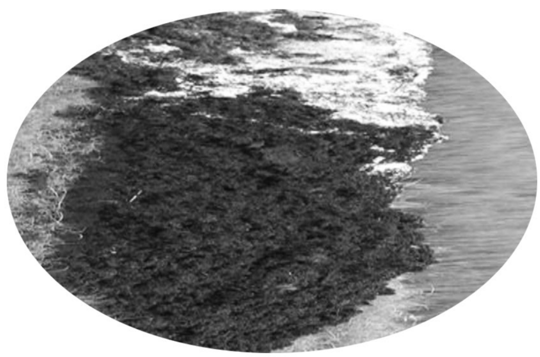
  

## Employment generation

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

**Table 3. Recycling of farm waste and gain/saving of nutrients through 1 acre IFS model at ICAR-RCER, Patna**

| Sl.no. | Farm waste | Quantity produced (q) | Production/use pattern (q) | Nutrient gain (kg) | Total Nutrient Gain Upon Recycling | Saving due to resource recycling (Rs.) |
|---|---|---|---|---|---|---|
| 1. | Goat (20+ 1) droppings | 24.9 | 18.5 (GM- 7.2) 6.4 (VC- 1.7) | N- 10.0<br>P- 5.8<br>K-11.6 | N-44.0<br>P-29.5<br>K-31.2 | 3125 |
| 2. | Veg. waste | 66.2 | 18.4 (VC- 6.8) 50.0 q - As fodder | N- 14.1<br>P- 10.2<br>K- 14.8 | | |
| 3. | Poultry manure (600) | 17.8 | Used in crops (35.2) | N-20.7<br>P- 17.5<br>K- 9.6 | | |
| 3. | RWMML Straw | 46.4 | 4.4 – mush. shed 1.6- Hut 42.8 q- sold | | | |



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 one and two-acre farming system models developed by ICAR RC for ER, Patna andpromoting 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, 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 (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.

For any farming system to sustain in the region, it is necessary is that the situations/conditions are 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 (REM)" 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.

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# Enhancing Water Productivity in Conservation Agriculture

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Water deficits are threatening sustainability of agriculture in many parts of the world and the societies have to ensure efficient use of the limited water resources to avoid further expansion in water deficit areas. In the context of intense competition for water resources, the economic value of water in agriculture is much lower than in other sectors (Barker *et al.* 2003). In recent times, conservation agriculture (CA) featuring reduced or zero tillage, mulching, crop rotations and cover crops is also viewed as a better option to improve the WP of irrigated as well as rainfed agriculture. Main aims of the conservation agriculture include producing more food, income, livelihoods, and ecological benefits at less social and environmental cost per unit of the agro-input (or water) which are very similar to the goals of improving agricultural water productivity. Increased water demand for agriculture will further stress the terrestrial and aquatic ecosystems and intensify competition for water resources. Improving 'water productivity' (WP) in combination with CA can reduce the need for additional water and land in irrigated and rainfed systems. Water saving achieved from improved 'water productivity' in agriculture will serve the need to sustain ecosystems.

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:

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

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.

CA is an agronomic integrated practice of no-tillage, application of mulch and intercropping, which is increasingly propagated amongst farming communities. Zero tillage, along with other soil conservation practices, is the cornerstone of CA (Dumanski *et al*. 2006). Positive changes in soil quality, in terms of physical structure, infiltration rates and carbon content as a result of CA, have been reported (Nyamadzawo *et al*. 2012). CA also leads to optimization of crop yields, profits and labour requirement while the capacity of smallholder farmers to attain improved livelihood security increases. The CA practices have been widely adopted in tropical, subtropical, and temperate regions of the world for both rainfed and irrigated systems. Previous studies (Pretty *et al*. 2006; Hengxin *et al*. 2008; Rockstrom *et al*. 2009; Jat *et al*. 2011) have shown improvements in the crop yields, resource use efficiency (water, nutrients and energy) and soil health under CA compared to conventional tillage systems. Many promising pathways for increasing water productivity are available for rainfed and irrigated farming systems. These include supplemental irrigation to supplement rainfall, deficit irrigation, small-scale water harvesting and storage, delivery and application methods, precision irrigation technologies (as drip, sprinklers); and soil and water conservation through mulching, zero or minimum tillage, bed planting and laser levelling (Sharma *et al*. 2009). This article discusses about the water productivity of different CA treatments with detailed quantification of benefits of mulch and no-tillage practices on the water balance, and puts forth the possible pathways to improve the WP in conservation agriculture systems.

## Impact of Improved WP

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, 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 include 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. 1) explains the parameters used in estimation of water productivity.

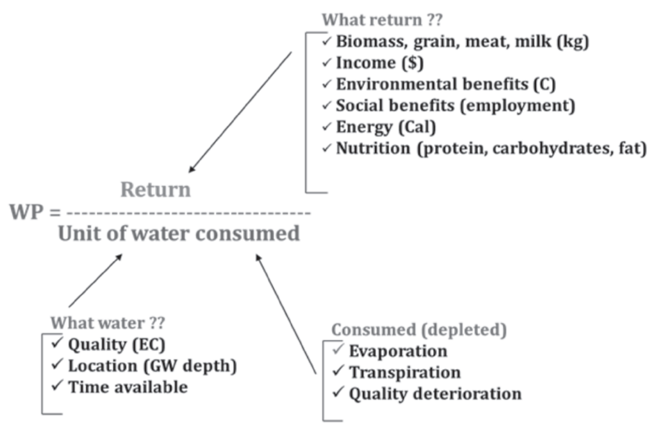



**Fig. 1** Water productivity assessment framework

## Water Management in CA

Water management is critical to CA particularly in arid and semi-arid regions of the world. Farmer friendly CA practices and supplemental irrigation technologies should be promoted for adoption by small and marginal farmers. Approach adopted for water management should reduce the effects of water stress on crops and consequently the crop yields. Although water is limited in semi-arid to arid areas, it is often the spatial and temporal distribution of water that affects crop growth and final yields. Many a times there are longer dry spell even during the monsoon season that hampers the success of CA and needs to be carefully handled. Effective rainfall, which is the portion of total rainfall consumed by the crops is in the range of 36–64% of the seasonal rainfall on average (Barron *et al*. 2003), indicating large proportion (about 50%) of non-productive water flow (Nyamadzawo *et al*. 2012). CA systems typically result in increased crop water availability and agro-ecosystem productivity, reduced soil erosion, increased soil organic matter and nutrient availability, reduced labor and fuel use, and increased biological control of pests. But the effectiveness of conservation agriculture on land and water productivity depends on soil type, crop water use requirements, rainfall distribution and amount, and soil-water storage capacity (Hemmat and Eskandar 2004). Increase in the available water content under conservation tillage, particularly in the surface horizon, increases the consumptive use of water by crops and hence improves the WP.

## Effect of Tillage Practices on WP

Impacts of CA practices on WP vary with the soil and agro-climatic characteristics of the region. This necessitates the assessment of CA systems locally. Recent studies have reported that CA improved crop productivity by 20–120% and water productivity by 10–40%. Many previous researchers showed that switching from conventional tillage to conservation tillage improved soil-water storage capacity and crop yields (Li and Gong 2002; Gicheru *et al.* 2005; Govaerts *et al*. 2005), in contrast to these findings, many other researchers observed no significant difference among tillage systems in volumetric water content in and water productivity (Merril *et al*. 1996; Tan *et al*. 2004; Lampurianes *et al.* 2002; Mark and Mahdi, 2005). The practice of CA is being adopted in many parts of the world. Most of these studies have been in irrigated areas and have resulted in positive results. The CA treatments generally involved variations in the number and intensity of tillage operations and compared their feasibility with conventional tillage. Crop yields and water productivity have increased (by up to 35%) following the implementation of reduced tillage practices (Wang *et al*. 2007). Under no-till, crop yields are equivalent to or higher than those from conventional tillage methods, especially in dry years. However, during wet years yields have tended to be lower (by 10%-15%) with no-till.

In an experiment (Hu *et al*. 2016), four tillage and stubble retention patterns were implemented: (a) no-till with 25 cm wheat stubble standing in the field (NTS, stubble standing), (b) no-till with 25 cm height of wheat stubble chopped and spread evenly on the soil surface (NTM, stubble mulching), (c) reduced tillage with 25 cm height of stubble was incorporated into the soil (RTS, stubble incorporated), and (d) conventional tillage (CT, tillage without stubble retention as the control). These treatments were piloted for monoculture of wheat and maize and in an integrated system having wheat–maize intercropping with the stubbles, mulch or reduced tillage options. It was observed that the integrated system (i.e., the wheat–maize intercropping with the stubbles, mulch or reduced tillage options) conserved more soil moisture than the monoculture wheat or monoculture maize under the conventional tillage system. Such integrated system increased soil moisture by an average (mm) 8.4% before sowing, 13.1% during the wheat–maize co-growth period, 5.4% after wheat harvest, and 4.7% after maize harvest, compared to the monoculture wheat CT control (Table 1). The improved straw management options (applied in the previous fall) not only influenced the soil moisture status at spring seeding the following year, but also the soil moisture during the entire growing season. Among the water harvesting approaches, no-till in combination with straw mulching (i.e., the NTM system) conserved the highest soil moisture during the wheat–maize co-growth period (Table 2). Similarly, the residue retention on the soil surface increased soil moisture by 10% in 2011 and 14% for the monoculture maize and monoculture wheat.

In another experiment by Nangia *et al*. (2010) the impact of different treatments *viz.* conventional tillage (CT), no-till with straw mulching (NTSM), all-straw incorporated (ASRT) and one-third residue left on the surface with no-till (RRT) was evaluated using DSSAT model in the maize-fallow-maize rotation. The NTSM and ASRT treatments had similar or higher yields (by up to 36%), higher crop water productivity by up to 28% and reduced runoff of up to 93% or 43 mm compared to CT treatment (Fig. 2).

**Table 1. Soil moisture within 0-120 cm depth and ratio of evaporation and transpiration (E/T), and transpiration use efficiency (TUE) in sole wheat, sole maize, and wheat/maize intercropping systems**

| Treatment | Soil moisture, mm | | E/T | TUE kg ha$^{-1}$ mm$^{-1}$ |
|---|---|---|---|---|
| | Co-Growth period | After maize/wheat harvesting[b] | | |
| Monoculture | | | | |
| NTS[a] | 228 | 272/256 | 0.69 | 36.9 |
| NTM | 240 | 280/272 | 0.67 | 37.9 |
| RTS | 212 | 247/255 | 0.7 | 35.2 |
| CT | 210 | 241/250 | 0.72 | 33.9 |
| Integrated system | | | | |
| NTS | 226 | 269/287 | 0.63 | 37.6 |
| NTM | 232 | 272/283 | 0.61 | 39.5 |
| RTS | 219 | 264/283 | 0.67 | 36.3 |
| CT | 212 | 264/264 | 0.73 | 35.7 |
| p-value | 0 | 0.000/0.000 | 0 | 0 |
| LSD (0.05) | 7 | 9/7 | 0.02 | 1.1 |

[a]NTS no-till with stubble standing; NTM no-till with stubble mulching; RTS reduced tillage with stubble incorporated in the soil; CT conventional tillage without stubble retention. [b]Data for the monoculture crops means the measurement was taken in those monoculture plots at wheat/maize intercropping co-growth period.

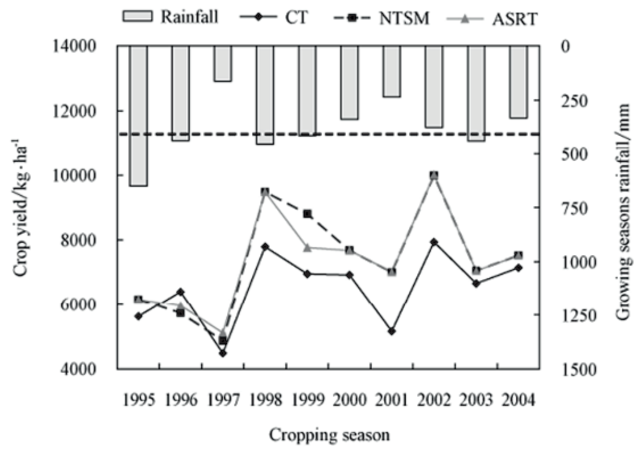



**Fig. 2.** Comparison of predicted crop yields for conventional tillage (CT), no till straw mulching (NTSM) and all straw return till (ASRT) during the 1995-2004 simulation period.

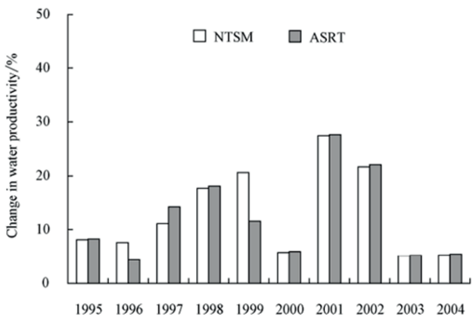
**Table 2. Components of the water balance for the treatments**

| Treatment | 29 April, 2004-15 October, 2004 | | | | | | Yield t/ha | WP kg/m-3 |
|---|---|---|---|---|---|---|---|---|
| | P/mm | T/mm | E/mm | R/mm | D/mm | ΔS/mm | | |
| CT | 331 | 253 | 140 | 24 | 0 | -86 | 7.15 | 1.49 |
| NTSM | 331 | 253 | 141 | 13 | 0 | -75 | 7.53 | 1.57 |
| ASRT | 331 | 252 | 141 | 13 | 0 | -75 | 7.53 | 1.57 |

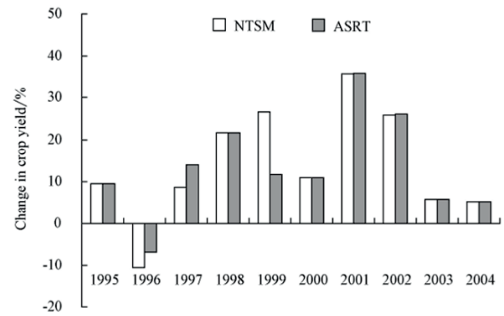
The two conservation agriculture treatments (NTSM and ASRT) performed better than CT in terms of grain yield and water productivity. During 9 out of 10 years, grain yield of NTSM and ASRT was higher than of CT. During 6 out of 10 cropping periods and all 9 fallow periods the evaporation losses of NTSM and ASRT were lower than of CT, however the differences were very small, greatest values being about 10 mm (Fig. 3). This probably reflects the generally dry conditions in this region, and thus the limited scope for mulch to reduce evaporation. The largest benefits of the conservation agriculture treatments were reduced runoff, by up to 43 mm during the cropping season. The conservation agriculture practices increased grain yield by up to 36%, soil-water storage by up to 81%, and water productivity by up to 28%, while runoff was reduced by up to 93%.

## Impact of CA on water conservation

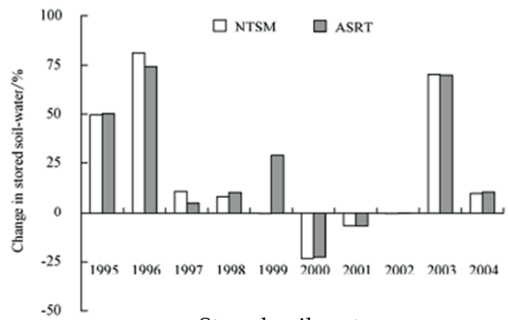
Ploughing promotes the evaporation of water from the soil and reduces available moisture for seed germination and crop establishment in the early part of the growing period. While tillage can initially improve water infiltration in degraded soils, it is only a short-term effect. In the event of rainfall after tillage, the weak structure of the tilled soil often collapses and becomes re-compacted, and its ability to absorb




a. Water productivity




b. Grain yield




c. Stored soil-water

**Fig. 3.** Predicted changes in a. crop yield, b. water productivity (with respect to ET) and c. stored soil water for the two conservation agriculture treatments relative to the CT treatment

further rain quickly is reduced, causing wasteful surface run-off. Consequently, plant emergence was reduced by 20% in the cultivated plots compared to the ZT plots. Improved infiltration of rainfall into the subsoil and less ponding of water on the surface of undisturbed soils means the topsoil is likely to be less sticky after heavy rain, which can enable earlier sowing compared to tilled soils. Reduced water run-off also means improved storage of water in the subsoil and less risk of water erosion, especially on sloping sites.

## CA under Irrigated Conditions

It was observed that biomass and grain yield in irrigated crops is initially similar under ZT or conventionally tilled fields, or in some cases, crop growth may be less as farmers struggle with the initial challenges of ZT i.e. crop residue and rotations. It usually takes several years under to overcome these challenges and to experience the improvements in soil fertility to boost crop productivity. The practices of CA can be implemented under sprinkler, drip or pivot irrigation systems using the same ZT sowing machines developed for rainfed crops. If 'basin flood irrigation' is not compatible with the technology of ZT planting and minimal soil disturbance. Also, this method is not very efficient in water application and a change in irrigation method should be considered if conservation agriculture is to be practiced. In the event that furrow irrigation is being practiced by the farmer, it needs a slight modification to convert it into a raised-bed ZT planting system where the CA can be implemented with minimal soil disturbance. These raised beds can be formed in the field and cab be retained and used year after year. The furrows are reshaped each year with the help of bund former.

## Supplemental Irrigation

Water stress during stages of crop growth is critical to low yields in the rain-fed areas. Timely application of a small quantity of supplemental irrigation in water stress periods will reduce the yield gap. Provision of critical irrigation during periods of water stress has the potential to improve the yields by 29 to 114% for different crops. Water used in supplemental irrigation had the highest marginal productivity and increase in rainfed production above 50% was achievable. Sharma *et al*. (2009) reported that the net benefits improved by about, 3-times for rice, 4-times for pulses and 6-times for oilseeds. Droughts appear to have limited impact when farmers are equipped with rainwater harvesting and application systems. Amarsinghe *et al*. (2008) found that one of the significant methods for improving WP is providing supplemental irrigation. The districts with low CWU have the highest potential for increasing yield by increasing CWU. Many of these districts can increase yield by providing small to moderate irrigation or by increasing the amounts of effective rainfall through in-situ conservation and storage. However, growth in food grain yield with supplemental irrigation decreases in districts with high CWU.

## CA Practices to Improve Water Productivity

Many studies have shown the effectiveness of CA practices in reducing water application, especially at field scale. Zero tillage and laser levelling and bed and furrow planting reduced water applications between 23% and 45% while increasing yield (Kahlown *et al*. 2006). Aadoption of zero tillage in rice-wheat systems resulted saving of water to the tune of 30% (Hobbs and Gupta, 2003). Compared to conventional tillage, zero tilled wheat showed 20% to 35% savings in irrigation water in the rice-wheat belt of the Indo-Gangetic plains. (Gupta *et al*. 2002). Both zero tillage and laser levelling are perceived by Pakistan Punjab farmers to result in substantial savings in water application (24% for zero tillage and 32% for laser levelling), fuel (52% and 16%) and labor (52% and 14%). With the adoption of zero tillage and laser levelling, the crop yields increased and cultivation cost was decreased leading to increase in net income. Studies at Kurukshetra showed that tube well operational hours in 'bed planted' wheat were much lower as compared to wheat in conventional fields. This was very well reflected in improved water productivity under bed planted wheat as compared to conventionally planted wheat (Fig. 4). Providing incentives to small farmers for RCT adoption, improving the performance of canal water supplies and by minimising evaporation losses in the rice-wheat areas can help in achieving the real water savings at the river basin scale (Ahmad *et al*. 2007).

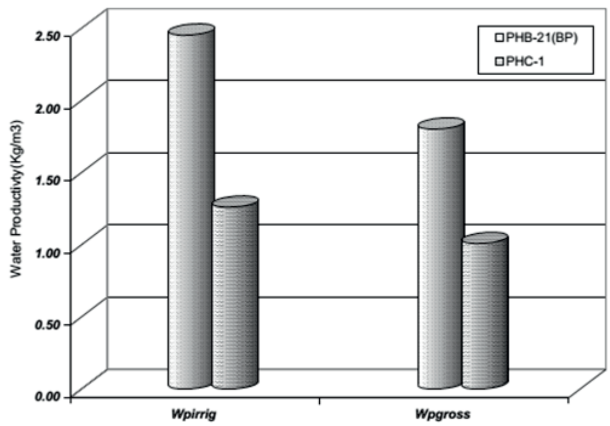



**Fig. 4.** Comparison of water productivity (irrigation and gross) in bed planted wheat and conventional wheat at Kurukshetra, India.

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# Enhancing Water Productivity through Use of Drip Irrigation in Vegetables

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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 advantageirrigation 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 | 0.30 m |
| Medium texture | 0.65 m |
| Fine texture | 1.20 m |

The drippers are small-sized emitters made up of high quality plastics. They are mountedon small soft pipes at frequent spaces. Water enter the dripper emitters at approximately 1.0 bar and is delivered at zero pressure in the form of continuous droplets at low rates of 1.0 -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 first 30 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 and 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 competitionof 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 accumulateat 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 desiredroot 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 incrop production*, expressed as crop production per unit volume of water".

### Significance of water productivity

The significance of waterproductivity 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 Bangladesh drip irrigation resulted in higher yields of tomato as compared to furrow method (Biswas *et al*. 2015). Increasing drip irrigation from 0.3Epan 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.

### 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 2.2 m) conditions should be used with care. They obtained lower yields of cabbage crop under drip as compared to furrow irrigated crop, which was contrary 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/m$^2$) 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 (7.36 t/ha) than furrow irrigation scheduled at 0.6 Epan (6.08 t/ha) and 0.8 Epan (6.12 t/ha) level. Reducing irrigation application through drip by scheduling at 0.4 Epan during reproductive stage drastically reduced the yields. A comparison of drip and minisprinkler systems with surface method as control was studied both at Navsari and Pantnagar. While at both places the water savings with minisprinkler was almost same (19-20%) the water saving recorded ofr drip at Navsari was as low as 37 per cent as against 67% 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*. (2016) 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 (6148.31 kg/ha/cm ) 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/day). An improvement in yield from 16 to 63 per cent and the saving in water to the tune of around 50 per cent were also reported from Patna (Annual Report, 2015-16). 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. PusaSawani. 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 studyconducted 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, and WUE was 0.262 t/ha/mm, while drip irrigation with black mulch produced 57.9 t/ha, with a WUE of 0.238 t/ha/mm. However cucumber yield and WUE declined in the no mulch treatments of DI and SI to reach 44.1 t/ha with 0.153 t/ha/mm and 37.7 t/ha with 0.056 t/ha/mm, 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

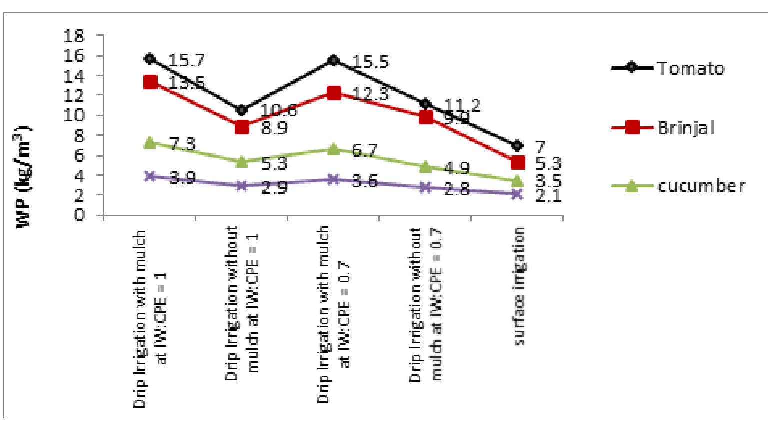


**Fig. 1.** Effect of irrigation and mulch on water productivity (kg/m$^3$)

crop. Irrigation through drip saved 28.2% and 22% irrigation water as compare to surface irrigation in cucumber and ridge gourd, respectively (Annual Report 2015-16).

## 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*. (2017)

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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# Use of Solar Energy in Agriculture for Improved Farm Profitability

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Eastern India states such as Assam, Bihar, Chhattisgarh, Jharkhand, Odessa, Eastern Uttar Pradesh and West Bengal with geographical area of 71.84 million ha are having human population more than 520 million (Planning Commission, 2012). This region has the distinction for its fertile land, excellent environment and vast potential of groundwater reserve. However, the food production and productivity of this region is often been risky and relatively of low return due to erratic rainfall and lack of assured irrigation (Lobell *et al.* 2008; Held *et al.* 2005). To save the crops from long dry spells, farmers are solely dependent on groundwater for supplementary irrigation. The intensity of groundwater utilization in this region is quite apparent from the fact that there are about 5.5 million pumps of which 84% are diesel operated with average annual duration of operation per pump is 450 hours (Shah, 2009). In absences of grid electricity farmers of this region are forced to use diesel pumps irrespective of their land holding sizes. In general, they use 5 horsepower pump which consumes nearly 1.15 liters of TMT diesel per hour. As one litre of diesel generate carbon emission of 0.732 kg (Nelson and Robertson, 2008), therefore, total annual emission of carbon by these many diesel pumps to be 1.71 million tons! In coming decades the numbers of pumping hours are bound to increase due to climate change and widened uncertainty in rainfall. This will further accelerate the diesel consumption and therefore the carbon emission. The ever increasing diesel prices is reducing the profitability of these smallholders and therefore they are at the verge to leave the farming and to migrate to the villages in search of labour work. This situation would definitely dent the food security commitment to the burgeoning population.

**Fig. 1.** Solar Groundwater pumping with storage tank

In general, in most part of the region the water depth, below the ground level, is ranging from 2 - 10 m with annual fluctuations of ± 2 to ± 4 m. This region also blessed with immense solar energy potential of 6.4 - 4.3 kWh/m$^2$/day with 250 -300 clear sunny days per year, and could be a year round reliable source of energy for groundwater pumping (Rahman and Bhatt, 2017). Therefore, solar energy based groundwater pumping has tremendous scope in this region. Farmers of this region traditionally perform surface irrigation which led overexploitation of groundwater and ecosystem damage. Therefore, the use of pressurised irrigation technology would be an additional water management strategy for optimizing groundwater use. The solar powered groundwater pumping coupled with pressurised irrigation systems could be an appropriate alternative in minimizing diesel consumption and judicious exploitation of groundwater. This will be reducing the carbon emission, improving water and fertilizer-use efficiency and therefore would be increasing the crop yield. Since, different crops differ in water requirement and this requirement also fluctuate with crop growth, therefore, proper choice of crop succession and combination are of decisive importance in sizing of a solar pump. Uninterrupted crop rotation and continuous cropping systems of high value such as fruit, vegetables and spices are to be grown to reduce the payback time of solar system. However, for effective implementation of solar groundwater pumping technology an appropriate pumping unit along with good delivery system is essential. Solar PV water pumping system is most cost effective water pumping option particularly in those locations where grid electricity is not available and if available, there is a frequent power cut and voltage fluctuation.

## Solar use for Groundwater Pumping and Irrigation

In solar photovoltaic water pumping, three different system configurations could be adopted.

(i) Solar photovoltaic electricity drives a surface or submersible pump to abstract groundwater and injected directly into the irrigation network which could be piped network or open channel.

(ii) Solar photovoltaic electricity drives a surface or submersible pump to abstract groundwater into an overhead tank. This tank serves as an energy store and supplies the pressure needed for pressurised irrigation system.

(iii) Solar photovoltaic electricity drives a dc surface or submersible pump or an submersible pump to abstract groundwater into a ground tank/pond and a surface pump delivers water out of tank to irrigation fields (Fig. 1). As, groundwater pumping unit is decoupled with water delivery unit, the drafted groundwater per day is high due to reduced TDH. This sort of configuration enables the user to abstract more groundwater with low capacity pump even from a deeper depth and to irrigate more cropped area. Further, as the delivery pump is extracting water out of a grounded tank, therefore, it encounters a very low suction head and hence its delivery head is high. Therefore, with this configuration irrigation can be performed by surface or by pressurised methods of irrigation by coupling delivery pump directly with irrigation network. Apart from this, high delivery head enables the users to carry irrigation water to distant fields. In addition to this the storage tank serves as reservoir for low insolation period and could be used for fish farming, duck farming and growing additional aquatic crops like chest nut and makhana.

(iv) In a solar radiation region of intensity 6.4 - 4.3 kWh/m$^2$/day, a 3HP solar pump can extract groundwater, ranging from 100- 170 m$^3$/day while a 2HP solar pump could extract groundwater between 35-65 m$^3$/day and therefore well suited for small holders, if pumping depth is less than 10 m.

## Solar Energy use for Livestock & Fishery

Solar PV system can also be used for watering livestock (Fig. 2). The dairy cattle need plenty of water every day and loss of even 20 percent of total body water could be fatal. Increase in environmental temperature due to climate change further enhances water requirement. Therefore, a good supply of water is necessary to enhance resilience against climate variability. This can be met by use of solar pumps of desired capacity. The ambient temperature and humidity negatively affects the milk production and fertility of dairy cattle. The temperature range 24 -27°C is a critical maximum temperature for cows. Therefore, the most challenging task in dairy cattle management is to maintain appropriate microclimate such as temperature and humidity. Some of the management practices include the use of humidifiers and shades. Solar energy can also be used to develop humidifier for animal sheds.

Solar photovoltaic system can also be used to develop aerators for high stocked fish ponds, where level of dissolved oxygen is a matter of concern for growth and health of the fishes. A sprayer type solar aerator is shown (Fig. 3). This spray pond water high in to the air through a perforated pipe. Due to relatively high speed with surrounding air, jets break up into smaller droplets which increase the surface area manifold. This manifold increase in surface area accelerates the oxygen diffusion at water droplets-air interface. System increases the dissolved oxygen level of pond wa-

**Fig. 2.** Solar watering system for animal shed.

**Fig. 3.** Solar aerator for fishpond.

ter and breaks thermal stratifications and therefore improves dissolved oxygen of water column by mixing up top oxygenated water with sub layers.

## Water Heating

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. Heating, if necessary, requires large amounts of energy**.** For this, solar heating systems (Fig. 4)**,** with proper design, can be incorporated in farm buildings. If someone is raising poultry or pens, equipments must be cleaned periodically. Simple solar water heaters are available to provide low to medium temperature hot water for this purpose and can provide water at 60-70°C in any amount needed.


**Fig 4.** Solar water heater

## Solar Dryer

The sun drying of crops and grains is the most widely used applications of solar energy. This is the simplest and least expensive technique (Fig. 5). It allows crops to dry naturally in the field after harvesting by spreading fruits or grains out in the sun. In this method, however, the crops and grain are subject to damage by birds, rodents, wind, and rain and contamination as it takes several days to get required moisture level. Modern solar crop driers are simple, more effective and hygienic. 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, the moisture content of the material, the humidity in the air, and the average amount of solar radiation available during the drying season.

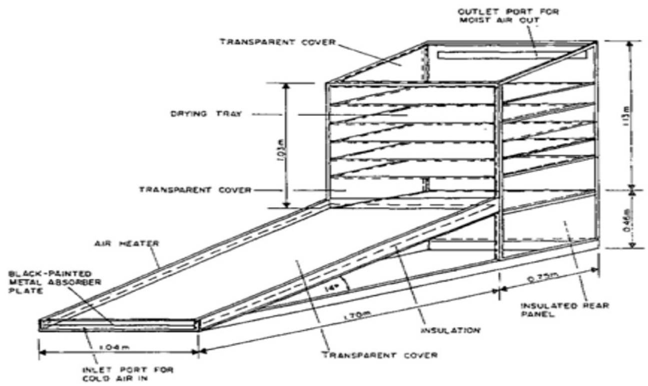


**Fig. 5.** Solar dryer

## Solar Greenhouse

Another agricultural application of solar energy is greenhouse heating (**Fig.6)**. Solar greenhouses are designed to utilize solar energy for both heating and lighting. A solar green house has thermal mass to collect and heat solar heat energy and insulates to retain this heat for use during night and cloudy days.

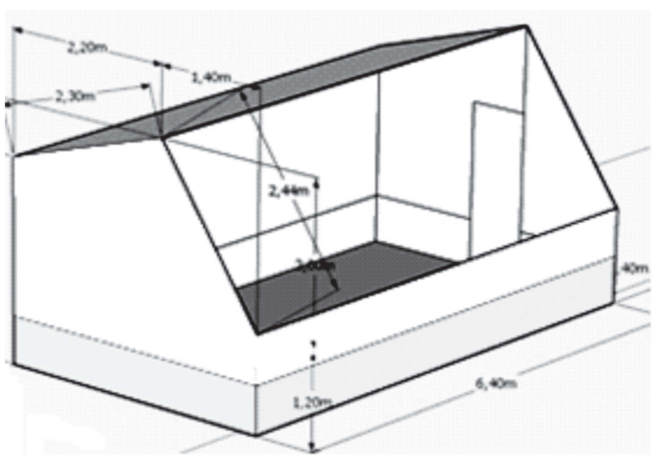


**Fig. 6.** Solar greenhouse

## Solar lighting and ventilator

Even when grid power is available, using solar PV to charge batteries for lighting may be the cheapest option for houses. A simple PV system can operate low- or high-pressure sodium lights, as well as fluorescent and incandescent bulbs. Solar PV is also used to run aeration fans in grain storage bins. Certain agriculture enterprises such as chicken and other avian farms must have constant ventilation during the hot summer months. The body heat from thousands of birds in close proximity to each other can quickly kill them**.** Since solar PV powered ventilation operates when the sun makes the air the warmest. Thus, solar PV can be an ideal power source in these instances.

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# Role of Agroforestry in Eastern IGP

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Indo-Gangetic Plains (IGPs) consists of a large alluvial plain abound with rivers Indus, Ganges, and Brahmaputra and this region is considered to be one of the most fertile alluvium soil. Eastern Indo-Gangetic Plains (E-IGP) is comprised of Lower and Middle Gangetic Plains with an area 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). Agricultural and allied activities remained the largest working sector in this region. However, 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. 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. According to Nair (1979) agro-forestry is a land use system that integrates trees, crops and animals in such a way that is scientifically sound, ecologically desirable, practically feasible and socially acceptable to the farmers. 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 Systems in E-IGP

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 Table 1.

**Table 1. Traditional agroforestry systems practiced in E-IGP region of India**

| Traditional agroforestry system | Characteristics |
|---|---|
| Home gardens | 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 | Agri-silviculture (Irrigated condition) | *Eucalyptus, Albizia lebbeck* | Paddy |
| | Agri-horticulture (Irrigated condition) | *Mango/Banana/Litchi* | Wheat, Paddy, Maize |
| | Silvipasture | *Morus alba, Albizia lebbeck* | *Dichanthium, Pennisetum* |
| Middle Gangetic Plains | Agri-silviculture (Irrigated condition.) | *Populus deltoides* | Sugarcane-Wheat |
| | Agri-silviculture (Irrigated condition) | *Eucalyptus* spp. | Rice-Wheat |
| | Agri-silviculture | *Dalbergia sissoo* | Sesamum |
| | Agri-horticulture (Irrigated condition) | *Mango/Citrus spp.* | Rice-Wheat |
| | Silvipasture | *Albizia lebbeck* | *Chrysopogon, Dichanthium* |

## Agroforestry and Crop Diversification

Agroforestry have the potential to meet the ever increasing demand for diversified products such as food, fiber, fodder, fruit, fuel and timber. Challenges in diversification of existing farming systems warrants development of suitable agroforestry models for popularization and further adoption by the farmer (Singh *et al*. 2017). 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%. Agroforestry can be considered as the viable alternative option for monocropping system. For examples, homegarden/homesteads a diversified agroforestry system which have been practiced across the E-IGP region are considered as ecologically friendly and less intensive practice as compared to monocropping system. 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.

## Agroforestry and Socio-economic Upliftment/Employment Generation

Agroforestry has the potential to uplift the socio economic status of the rural and poor people by providing employment or increasing their farm incomes. For examples, 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)

**Table 3. Some of the reported B: C ratio in E-IGP**

| Zone | Tree | Number of trees/ha | Crops | Years | B:C ratio at 15% discount factor |
|---|---|---|---|---|---|
| Lower Gangetic (rainfed) | *Acacia auriculiformis* | 60 | Jute | 15 | 1.17 |
| Middle Gangetic (rainfed) | *Dalbergia sissoo* | 280 | Sesamum | 20 | 1.15 |
| Middle Gangetic (non-arable land) | Bamboo | 250 | Marvel grass | 10 | 1.76 |

*Source:* Planning Commission, (2001)

## Agroforestry and Soil Improvement

The integration of trees in agroforestry plays a significant role in soil and water conservation. The presence of woody perennials in agroforestry systems may affect several bio-physical and bio-chemical processes that determine the health of the soil substrate through continuous addition of litter on agroforestry floor and its decomposition activities (Nair, 1993). Trees in agroforestry system improve soil physical, chemical and biological properties by providing good vegetative cover by reducing the runoff and soil losses thus, facilitate water infiltration into the ground. Roots help to bind the soil colloids against the erosive force of water.

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.

### Major constraints in adopting agroforestry

- Mostly farmers of this region are small and marginal land holder
- Lack of supply for quality tree planting materials to farmers
- Long gestation period of trees
- Lack of agroforestry demonstration and training programmes
- Lack or improper implementation of agroforestry policy
- Non availability of market for agroforestry produce
- Astringent and restrict rules for tree felling and transportation

## Conclusion

Agroforestry played 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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# Role of Conservation Agriculture in Horticultural Crops

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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". 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.

## 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 *Vicia 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*. (2018) 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.

## 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.

## 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 perennial 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), Egg-plant, 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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# Strategies for Developing Rice Genotypes for Drought-Prone Ecology

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Rice (*Oryza sativa* L.) is one of the major staple food crop for about 65% of the world's population, most of whom live in Asia. According to the USDA estimates rice is cultivated in 162.2 million hectares (M ha) and production was 490.19 MT in 2016-17 (USDA, 2018). It is cultivated under diverse ecologies ranging from irrigated to rainfed upland to rainfed lowland to deep water. Irrigated rice accounts for 55% of world's area and about 75% of total rice production. Rainfed ecosystem represents about 38% of total rice area, accounting for 21% of world rice production. In India, the total area under rainfed lowland and upland rice is 14.4 and 6.3 M ha, respectively (Singh, 2009). Drought is considered one of the main constraints that limit rice yield in rainfed and poorly irrigated areas. Drought is the most widespread and damaging of all environmental stresses, affecting 23 M ha 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. 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 accounting for 27.26 M ha rice area, out of which 16.2 M ha is rainfed and nearly 4.28 M ha area is prone to frequent drought (IRRI, 2013). 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.

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. In eastern India, reproductive stage drought is one of the major factors limiting grain yield, mainly because of mono-modal distribution of rainfall which ceases at about 1st or 2nd week of September. Most of the current high-yielding varieties of rice grown in rainfed areas are bred for irrigated ecosystems and they are highly susceptible to water scarcity (drought) condition. 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 national level contributed from eastern region.

## 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 states accounting for 27.26 M ha rice area, of which nearly 4.28 M ha area is prone to frequent drought (Table 1). 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.

**Table 1. Drought prone rice areas in eastern states of India**

| States | Geographical areas (M ha) | Area % of total India | % Area irrigated | Rice area (M ha) | Drought prone rice area (M ha) | % Rice drought prone area |
|---|---|---|---|---|---|---|
| Bihar | 9.41 | 2.86 | 60.6 | 3.20 | 0.725 | 23 |
| Eastern UP | 8.64 | 2.62 | 74.9 | 5.92 | 0.985 | 17 |
| West Bengal | 8.87 | 2.69 | 48.4 | 5.94 | 0.956 | 16 |
| Assam | 7.84 | 2.38 | 20.3 | 2.50 | 0.221 | 9 |
| Odisha | 15.57 | 4.73 | 36.7 | 4.35 | 0.631 | 14 |
| Jharkhand | 7.97 | 2.43 | 12.0 | 1.67 | 0.243 | 15 |
| Chattisgarh | 13.51 | 4.10 | 26.5 | 3.66 | 0.521 | 14 |
| Eastern India | 71.84 | 21.85 | 46.88 | 27.26 | 4.281 | 16 |

*Source:* IRRI (2013)

## Status of Present 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;* IR36, IR64, Swarna, Sambha Mahsuri, MTU 1010, MTU 1001, Sarjoo 52, Rajendra Sweta,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. In rainfed as well as poorly irrigated areas drought stress can occur at any stage of the rice crop or it can be intermittent drought depending upon the rainfall pattern and distribution. 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, Shusk Samrat, CR Dhan 40, Anjali, Vandana, NDR 97, NDR118, Hazaridhan, Swarna Shreya, DRR 42 and Indira Barani Dhan) are already released for eastern India (Table 2).

Cultivation of these drought tolerant varieties will be helpful for sustaining food security in eastern states. Details 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 stress 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

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

| Varieties | Duration (days) | Yield (t/ha) | | Grain type | Favorable land for cultivation | Recommended state for cultivation | Resistant/ Tolerant |
|---|---|---|---|---|---|---|---|
| | | Stress | 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 | Leaf blast, brown spot and sheath blight |
| Shushk Samrat | 110-115 | 2.5-3.0 | 3.5-4.0 | Long – slender | Rainfed upland & medium lowland | Eastern UP, Bihar, Jharkhand and Odisha | Moderate resistant to brown spot and leaf blast |
| Swarna Shreya | 115-120 | 2.5-3.0 | 4.0-4.5 | Long – bold | Rainfed medium lowland (aerobic condition) | Chhattisgarh, Madhya Pradesh and Bihar | Resistant to leaf blast and moderately resistant to neck blast, brown spot, sheath rot & RTD |
| CR Dhan 40 | 95-100 | 2.5-3.0 | 3.5-4.0 | Short-bold | Rainfed upland (direct seeded) | Jharkhand & Bihar | Moderate resistant to brown spot and leaf blast and complete resistant to gall midge |
| Narendra Dhan 97 | 95-100 | 2.0-2.5 | 30.40 | Long – slender | Rainfed upland & medium lowland | UP, west Bengal, Bihar and Chhattisgarh | Brown spot, blast and sheath rot |
| Narendra Dhan 118 | 90-95 | 2.0-2.5 | 30.35 | Medium slender | Rainfed upland & medium lowland | Uttar Pradesh & Bihar | Moderate resistant to brown spot and leaf blast |
| Anjali | 90-95 | 2.5-3.0 | 3.5-4.0 | Short-bold | Rainfed upland | Bihar, Odisha, Jharkhand, Assom & Chatishgarh | Resistant to brown spot and gall midge and moderately resistant to leaf blast; |
| Vandana | 95-100 | 2.5-3.0 | 3.5-4.0 | Long – bold | Rainfed upland | Jharkhand, Bihar, Odisha & Chatishgarh | Resistant to termite, brown spot and leaf blast |
| Hazaridhan | 115-120 | 2.0-2.5 | 3.5-4.0 | Long-slender | Rainfed upland & lowland | Jharkhand & Bihar | Resistant to brown spot and leaf blast and moderate resistant to leaf blight |
| Indira Barani Dhan | 111-115 | 2.5-3.0 | 4.0-4.5 | Long-slender | Rainfed upland & medium lowland | Chhattisgarh & MP | Resistant to brown spot, BLB, leaf blast and stem borer |

(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 stress and 4.0-4.5 t/ha without stress.

### 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 under direct seeded and transplanted condition, respectively. It is moderately resistant to brown spot and leaf blast.

### Anjali

This variety was released by CRURRS, Hazaribag for drought prone upland areas of Bihar, Jharkhand, Odisha, Assom and Chhattisgarh 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 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.

### 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, early maturity (110-115 days), high yielding ability and good grain quality. Further, its short growth duration and high harvest index give better opportunities for double cropping in drought-prone areas of eastern India. 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.

### 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 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.

### Hazari Dhan

This variety was released by CRURRS, Hazaribag in 2003 for drought prone rainfed upland and shallow lowland areas of Jharkhand and Bihar of eastern region. Its parents are IR42 and IR5853-118-5. Rice variety Hazaridhan is drought tolerant, semi-tall (90-95cm) and medium duration maturity (115-120 days) variety. Days to fifty percent flowering (DFF) of Hazaridhan is 85-90 days. Grain type of this variety is long slender. Its yield potential is 3.0 and 4.0-4.5 t/ha under direct seeded and transplanted condition, respectively. It is resistant to brown spot, sheath blight, leaf blast and Gundhi bug and white backed plant hopper and moderate resistant to bacterial leaf blight.

### Narendra Dhan 97 (NDR 97)

Rice variety 'Narendra Dhan 97' was developed by Narendra Dev University of Agriculture and Technology, Faizabad for drought prone rainfed upland and medium lowland areas of eastern Uttar Pradesh, Bihar, West Bengal and Chhattisgarh. Its parentage is N-22 and Ratna. It has been released and notified in year 1992. NDR 97 having semi dwarf (75-80 cm) stature, with 10-12 panicle bearing tillers/plant, early maturity (90-95 days), high yielding ability and good grain quality. Grain type of this variety is long slender. Its yield potential is 3.0-3.5 and 4.0-4.5 t/ha under direct seeded and transplanted condition, respectively. It is resistant to BLB, brown spot, blast and sheath blight.

## Characters for Drought Tolerant Variety

- High yield under normal situation
- Good yield under stress condition
- Tolerance to drought at seedling, vegetative and reproductive stage
- Tolerant to major 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
- Efficient dissemination support

## Effect of Drought Stress on Rice Growth, Physiology and Yield

Among abiotic stresses drought identified as key stress which severely hampering rice plant 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 (Pantuwan *et al*. 2001). Drought impacts include alterations in growth, yield, membrane integrity, pigment content, osmotic adjustment, water relation and photosynthetic activities (Praba *et al*. 2009). 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 stress causes lowering test weight, spikelet fertility and grain yield. Kumar *et al*. (2014a) 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.

## 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 stressed and non – stressed 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*. (21014b) 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. Test weight (1000 grain weight)
2. Spikelet fertility (%)
3. Grains/panicle
4. Effective tillers/$m^2$
5. Grain yield
6. Leaf curling and tip drying
7. Pollen viability
8. Relative water content (RWC)

9. Membrane stability index (MSI)
10. Photosynthetic rate
11. Leaf chlorophyll content
12. Stomatal conductance
13. Stem carbohydrate re-mobilization
14. Drought susceptibility index (DSI)

## 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. Adoption of high yielding drought tolerant rice varieties like Sahbhagi Dhan, Swarna Shreya, DRR Dhan 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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# Strategies for Identifying Wheat Genotypes under Climate Change Scenario

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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 (IPCC, 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$^{o}$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**

| | |
|---|---|
| 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, Halna, HD3120, DBW 14 and HD2987 |
| Drought tolerant wheat varieties | C 306, HD2987, HD2888, WH147, K7903, HI1563 |

## 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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# Management of Low Temperature Stress in *Boro* Rice

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*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 80,000-1,00,000 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 t) | Yield (t/ha) |
|---|---|---|---|
| 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 November-December 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°C during mid December to mid January. Minimum temperature falls down to as low as 6-10°C during seedling stage, 15°C in the vegetative stage 15-20$^0$ during PI stage and 35-40°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 ( °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 |

**Fig. 1.** Leaf yellowing in *boro* rice due to cold

**Fig. 2.** 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$^{o}$C inside the polythene tunnel as compared to the ambient minimum temperature.

**Fig. 3.** 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 @ 1 kg/ $m_2$ 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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# Weed Management Strategies under Conservation Agriculture

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Sustainability in agricultural production systems is the burning issue at global scenario. Widespread adoption of input-intensive conventional agriculture systems for crop production have reportedly caused various problems, such as fall in factor productivity, rapid exhaustion of ground water table, development of salinity hazards, degradation in soil fertility and soil physical environment, declining biodiversity, rise in air and ground water pollution and stagnating farm incomes. Intensive soil tillage employed in conventional agricultural systems is the main culprit responsible for loss of soil fertility, mainly due to the oxidation of soil organic matter and the exposure of bare soils to wind and rain accelerates run-off and surface erosion of the fertile top soil. This form of agriculture is hazardous for soil health and hastens the loss of soil by increasing mineralization and erosion rates. Rapid depletion of natural resources especially soils by intensive crop production systems endanger future food production. In this context, there arises an urgent need for addressing these problems and prevent further losses and to enhance the status of natural resources.

## Conservation Agriculture Systems- Need of the Hour

Improper utilization of natural resources and other inputs under conventional agricultural production system leads to large scale resource degradation problems, especially land and soil fertility degradation. Besides these, several other factors like declining labour availability, rising fuel cost, energy shortages, increasing production costs, pollution hazards, residue burning, development of new farm machinery, availability of new biocide molecules for efficient weed, insect, pest and disease control have compelled all stakeholders to modify the methods for crop production for enhancing productivity and resource-use efficiency. Conservation agriculture (CA) is a resource-conserving agricultural production system that avoids or minimizes soil mechanical disturbance (reduced or no-tillage) along with crop residue cover on soil and crop diversification/ rotation. It enhances biodiversity and natural biological processes above and below the ground surface, which contributes to increased water and nutrient use efficiency and to improved and sustained crop production. However, weed management may be critical for successful implementation of CA.

## Weed Menace - a Serious Concern in Conservation Agriculture Systems

Tillage generally contributes to weed control by uprooting, dismembering, and incorporating weeds into soil deep enough to prevent their further emergence. It also moves weed seeds both vertically and horizontally, and changes the soil environment; thereby affecting weed seed germination and emergence. Reduction in tillage intensity and frequency, as practiced under CA, generally increases weed infestation. Compared to conventional tillage, presence of weed seeds is more in the soil surface under no-tillage, which favours relatively higher weed germination (Singh *et al*. 2015). Minimum and no-tillage induce shifts of weed population particularly towards perennial weeds, thus creating a long-lasting weed problem (Ranaivoson *et al*. 2016). In general, small-seeded weeds that require light to break dormancy will likely to become the dominant weed species in minimum and no-tillage systems, including in the first years of adoption of CA.

Complete or partial absence of tillage under CA warrants reliance on other measures for weed control. Due to unavailability of labour especially at peak weeding period and escalating labour cost, manual weeding is not a viable option in CA. Thus, effective weed management is a critical issue in minimum and no-tillage based CA systems and determines its success.

## Weed Management options under Conservation Systems

Various approaches are available for successfully weed management in CA systems which include preventive approaches, ecological approaches (like competitive crop cultivars, crop rotation, crop residue as mulches, intercropping, cover cropping, manipulation in sowing time and crop geometry etc.) and use of herbicides and herbicide-tolerant crops.

**Preventive approaches:** These are the first and most cost effective means of managing weed, in general and especially under CA systems. Basically, they attempt to arrest/prevent the entry and spread of alien weeds into new region which can be achieved by the following ways:

(i) Use of good quality weed-free crop seed and planting materials as weed seeds resembling the shape and size of crop seeds are often the major source of contamination in crop seeds
(ii) Screening of irrigation water, restriction in livestock movement, cleaning of machinery/implements to check spread of weeds from one field to another
(iii) Application of well-decomposed manure/compost free from any viable weed seeds
(iv) Removal of weeds before flowering or harvesting weed seed prior to seed shedding
(v) Adoption of stringent weed quarantine laws to check the spread of seeds/propagules of alien invasive and obnoxious weeds into the state.

**Ecological approaches**: These approaches chiefly rely on three principles- reduction in weeds recruitment from the soil seed bank, modification of crop-weed competition in favour of crop and a steady diminishing of the size of the weed seed bank.

Following ecological strategies can be adopted and incorporated in weed management under CA systems:

**Suitable crops or cultivars:** Several certain traits in crop species and varieties like faster seedling emergence, quick canopy establishment and higher growth rates in the early stages, profuse branching or tillering and production of allelochemicals have been highlighted for competitiveness with weeds. Use of these crops and their varieties will reduce the need for direct weed control measures (e.g. herbicides or cultivation).

**Sowing/planting time:** Change in crop sowing/planting time can minimize emergence of weeds and/or strengthen crop competitive ability, however this effect may vary with crop species and environment. For example, early planting of crops leads to early establishment of crop before weeds and avoids terminal heat stress. Spandl *et al*. (1998) reported better control of *Setaria viridis* in the spring-sown cereal as compared to autumn-sown wheat due to lower weed emergence (single flush) in spring season. Early planting of wheat in North India gives the crop a competitive advantage over *Phalaris minor*, a noxious grassy weed species (Chauhan and Mahajan 2012).

**Crop rotation:** Rotation of crops is an efficient method to regulate seed and root weeds by creating an unstable and inhospitable environment for weed establishment and survival. For different crops different cultural practices are followed, which interferes with growing cycle of weeds and, as such, prevents selection of the flora towards increased abundance of problem species. On contrary, continuous cropping favours those weed species that are similar to the crop and tolerant to the weed control methods adopted (e.g. herbicides) as same cultural practices are followed year after year. The diversification of rice-wheat system by including summer legumes/green manuring even for a short period significantly reduced the weed menace. Rotating maize with soybean in CA system reduces weed species diversity through suppressing weeds during the growing weeds (Muoni *et al*. 2017).

**Optimum plant spacing and population:** Optimum growing conditions promote proper crop plant development and improve their ability to compete against weeds. Plant spacing of a crop determines solar radiation interception, leaf area index, canopy coverage and biomass accumulation which have cumulative effect on its yield and weed suppressive ability. High planting density of a crop develops canopy rapidly and suppresses weeds more effectively, and in contrast, widely spaced plants encourage weed growth. In order to apply this approach, the limiting weeds must be known and the seasons in which they occur. Narrower rows and/or higher population densities of crops ensure rapid canopy development, enhanced canopy radiation interception, thereby increasing crop growth rates and yields and suppressing weed growth and competitiveness. Sunyob *et al*. (2012) observed that with the decrease in plant spacing weed dry matter decreased but aerobic rice yield increased thus indicating the potential of closer spacing as a vital tool in the integrated weed management program for aerobic rice.

**Cover crop:** Growing of cover crops prevent growth and development of weeds through niche pre-emption in which they capture the space and resources that would otherwise available to weeds. Also, incorporated or mulched cover crop residues can inhibit or retard the germination, emergence and establishment of weeds due to both allelopathic and physical effects. In CA systems, cover crops are maintained as living mulches, acting as buffer zones or break crops, which help in promoting in-field biodiversity and contributing to weed management. Several crops like cowpea, rye, black mustard, sesbania and sunhemp are grown between two main crops to suppress weed growth and exhaust weed seed bank. These cover crops are then killed by application of non-selective herbicide like glyphosate. Residues of the dead cover crop minimize weed germination and emergence through releasing allele chemicals and reducing light availability to the weed seeds. Also, the presence of residue may delay or prolong seedling emergence which have less effect on crop yield (Chauhan and Johnson, 2010).

**Inter-cropping:** Intercropping increases diversity in the cropping system and enhances the utilization of resources like light, space and water. Also, it helps in suppressing weeds growth thus limiting herbicide application in the cropping system. Owing to its potential to reduce yield loss by weeds, intercropping can be used to control weeds in systems such as organic production systems where herbicides are not used. Intercropping of short-duration, quick-growing and early-maturing legume crops (like cowpea, black gram, green gram, groundnut etc.) with long-duration and wide-spaced crops (like maize, sugarcane, cotton etc.) leads to quickly ground cover, with higher total weed suppressing ability than sole cropping. This technique enhances weed control by increasing shade and crop competition. Intercropping of maize with cowpea has been reported to reduce the use of herbicides to control weeds (Gomes *et al*. 2007).

**Establishment methods:** Transition of crop establishment method from conventional tillage system to conservation tillage system induces significant change in weed flora and their density. Cultivation of direct seeded rice (DSR) under bed planting and no-till has been reported to markedly reduce weed density and its dry weight over conventionally tilled DSR (Chongtham *et al*. 2015). Similarly, planting wheat crop on raised beds significantly reduced weed density and biomass as compared to the conventional method of flat seedbed (Dhillon *et al*. 2005).

**Nutrient management:** Proper nutrient management of crop can realize an ideal growth of the crop, which enhances growth of the crop over weeds. Increasing rates of fertilizer application may encourage more weed growth than crop growth in absence of weed control measure. Pre-sowing N fertilization can promote crop competitive ability against weeds in crops with vigorous growth at early stages, but this effect is modulated by the type of weeds prevailing in a field. Delay of top-dressing N application may increase crop competitive ability with dominance of late- or early-emerging weeds respectively Localised application of fertilizers along with or near the crop row can aid to weed management as it enhances the relative opportunity of crop to capture nutrients (especially N) over weeds. Targeted fertilization of nitrogen and phosphorus has been reported to significantly reduce infestation of root parasitic weed *Striga* on cereal crops (Sims *et al*. 2018).

**Water management:** Irrigation plays an important role in crop–weed competition as it induces selective stimulation to germination, growth and establishment in different weed species thus results in varying weed dynamics and competition in crops. Greater weed competition was observed in rice under non-flooded furrow-irrigated conditions than with full-field flooding. Flooding is commonly employed to reduce weed germination and growth in rice crop. However, if the flooding is maintained for a longer period it affects the aerobic soil life, which may be detrimental in CA systems (Sims *et al*. 2018). For instance, flooding is not advisable immediately after sowing in zero-tilled DSR as rice seeds are unable to germinate and survive under completely submerged conditions. To address this problem, development of rice cultivars capable of germinating under anaerobic conditions is essential to facilitate effective weed management through flooding in DSR. Targeted irrigation such as drip irrigation can provide an advantage to the main crop over weeds.

**Trap crops:** Trap crops are known to exude stimulants that induce selective seed germination of parasitic weeds like *Orobanche* and *Striga* but weed seedlings withers away and die up due to non-availability of host plants to attach and ultimately their seed bank in the soil gets exhausted. Several varieties of cowpea (*Vigna unguiculata* (L.) Walp.), soybean (*Glycine max* (L.) Merr.) and peanut (*Arachis hypogaea* L.) have been identified to induce suicidal germination of the seeds of *Striga* (Gbehounou, 2000). Rotation of pea, bean, flax, alfalfa, wheat, oat, sesame, brown Indian hemp, Egyptian clover and mungbean (Sirwan *et al*. 2010) in fields infested with *Orobanche* has been reported to reduce seed bank of the weed.

**Chemical weed management:** Herbicide application has been one of the most popular methods of weed management as herbicides are relatively cheaper than traditional weeding methods, less labourious, easier in tackling difficult-to-control weeds and flexibile in execution. Complexity in weed control in CA systems due to presence of perennial weeds warrants increased use of herbicides, especially in the early years of CA adoption. Diverse weed flora that emerges in the field after harvesting the preceding crop in CA system must be killed using non-selective herbicides like glyphosate and paraquat. These herbicides can be applied before or after crop planting but prior to crop emergence in order to minimize further weed emergence. However, to sustain CA systems, herbicide rotation and/or integration of weed management practices is preferred as continuous use of a single herbicide over a long period of time may result in the development of resistant biotypes, shifts in weed flora and negative effects on the succeeding crop and environment. Right selection of herbicide formulations for use under CA system is essential for increasing their efficacy. For example, presence of crop residues on soil surface in CA reduced the efficacy of liquid pre-emergence herbicides as herbicide droplets get intercepted by residues and consequently reduced the quantity of herbicide that reaches the soil surface. The extent of herbicides intercepted by crop residues may range from 15% to 80% of the applied herbicides thus reducing efficacy of herbicides in CA systems (Chauhan *et al*. 2012). In this context, application of granular pre-emergence herbicides will ensure weed control than liquid formulations. Besides, pre-emergence herbicides, the effectiveness of post-emergence herbicides have been reported to reduce due to interference by crop residue in CA systems. It is to be noted that post-emergence herbicides need be applied after weeds are established as the timing of weed emergence is less uniform in CA systems than in conventional-tilled systems.

**Herbicide tolerant crops:** Conventionally bred and genetically modified herbicide-tolerant (HT) crops have become an important tool for managing weeds in production of commodity crops like soybean, maize, cotton, canola etc. at global scenario and they are compatible with CA systems. Among these, Genetically Modified HT crops is being adopted at faster pace due to its low cost, easy and flexible weed management options through use of broad-spectrum, non-selective herbicides (especially glyphosate) with lower risk for crop injury, and their compatibility with reduced-tillage or no-till systems. Through this approach, control of rather genetically identical and troublesome weeds can be accomplished easily. For instance, introduction of imazamox-tolerant CHT rice varieties enables effective control of weedy rice (Ziska *et al*. 2015). However, one of its biggest demerits is shift in weed flora and rapid selection of herbicide-resistant weed biotypes due to continuous use of a single herbicide or herbicides with similar mechanism in the same field for longer period. At present, 32 weed species have evolved resistance to glyphosate, a non-selective herbicide used commonly for weed management in HT crops in the world. Several weeds like *Sorghum halepense*, *Euphorbia heterophylla* and certain species of Amaranthus, Ambrosia, Conyza, Lolium, (Powles, 2008) have been reported to evolve resistant against glyphosate.

## Integrated Weed Management

Due to its diverse and complex weed flora, weed management in CA systems is a herculean task for which no single method is capable for effective weed control. So, it is imperative to adopt integrated approaches of weed management for a CA system by wisely selecting and combining various weed management strategies (physical, chemical, cultural and biological methods) for widening the weed control spectrum and efficacy for sustainable crop production (Fig. 2). According to Thill *et al*. (1991), integrated weed management (IWM) means the integration of effective, environmentally safe, and socially acceptable control tactics that reduce weed interference below the economic injury level.

While selecting weed management strategies for CA systems, it should be noted that they should be restricted to those that align and are feasible with the components of CA. For example, tillage and residue burning cannot be included for weed control in CA. Combining preventive (like quality seed, clean farm machinery, quarantine etc.) and ecological practices (i.e; proper fertilizer and water management, intercropping, crop rotation, cover crop and its residues on the soil surface) can enhance the effectiveness of herbicides and crop competitiveness against weeds. Integration of herbicides along with brown manuring of sesbania in DSR improved weed control than sole herbicides alone (Chongtham *et al*. 2016). Emerging problems in CA system like of dominance of secondary weeds and evolution of herbicide resistant weed biotypes due to continuous use of a single herbicide or herbicides with a similar mode of action can be tackled by IWM by adopting herbicide rotation, herbicide combinations and crop rotation for developing sustainable and effective weed management strategies under CA systems.

## Conclusions

Adoption of CA enables use of natural resources more efficiently through integrated management of soil, water and biological resources along with external inputs. However, complexity of weed management in CA systems due to shift towards perennial weed species requires a well-planned approach. Wise integration of any compatible weed management strategy (preventive, ecological, chemical approaches, HT crops etc.) to the existing cultural weed management of CA (crop residue mulching and crop rotation) is essential to fulfil the multiple tactics of IWM. Advocacy for IWM system does not imply to completely ignore selective, safe and efficient herbicides but includes a sound strategy to promote careful utilisation of herbicides along with other safe, eco-friendly, economical yet effective approaches. Through this, overreliance on herbicide in CA systems can be checked by adopting IWM system.

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# Improved Herbicide Spraying Techniques for Efficient Weed Control under Conservation Agriculture

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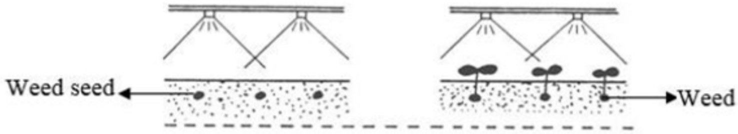
Agriculture experts saying that the success of efficient chemical weed control depends not only upon the quality of herbicides alone but also it depends on its appropriate spraying techniques. Weeds could lead to the loss in the yield of different crops from 20 to even more than 50 per cent. Therefore, 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. Herbicide application techniques are most important as proper spray pump, nozzles, volume of water with optimum herbicide dosage and the time of spray along with uniform coverage certainly help in better weed control.

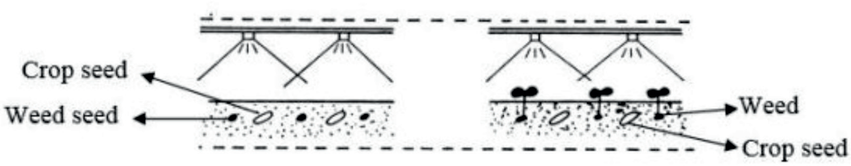
Practically, most of the farmers don't have proper nozzles to fixe with their spray pumps, results the poor weed control. Weed control experts, recommends to the farmers to use flat-fan or flood-jet type nozzles and for uniform coverage of weedicides on the weeds, spray should be done in a straight strip 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.

## Kinds of Herbicides and their Application Methods

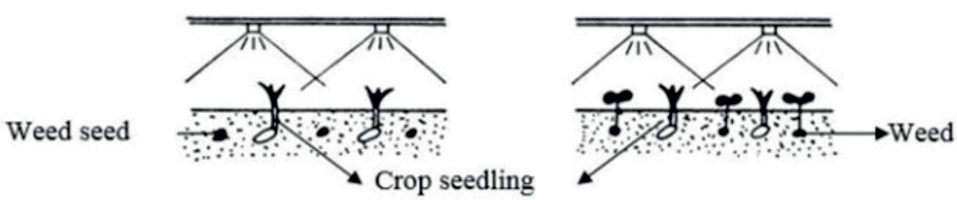
(i) **Pre-planting**: application of herbicides before the crop is planted or sown. Soil application as well as foliar application is done here. For example, fluchloralin can be applied to soil and incorporated before sowing rain fed groundnut while glyphosate can be applied on the foliage of perennial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




## 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.

## 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 Implements for Weed Management

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Weeding is one of the most important farm operations in agriculture and it is a costly operation as well as tedious work. It has been estimated that on an average, weeding accounts for about 25% of the total labour requirement (900-1200 man hours/ ha) during a cultivation season (Mynavathi *et al.* 2016). Weeds are controlled through different mechanized operations, and by using improved and advanced spraying techniques of herbicides. Manual weeding is the most efficient among various weed management techniques. However, economics is just opposite. It requires too many labours. Mechanical weed control not only uproots the weeds between the crop rows but also keeps the soil surface loose, ensuring better soil aeration and increases in water intake capacity. These weeders are simple in design and operation as well as cheap, more efficient and suitable for farmer's situation. It helps in reducing the cost of crop production and improve crop yield to a great extent. To reduce drudgery weeders are designed ergonomically. The efficiency of the work in terms of area covered is significantly better with the weeder than with manual weeding. The physiological demand in using weeders was relatively higher than in manual weeding.

Some of the mechanical manual weeders are hand hoe, two wheel hoe, single wheel hoe, grubber, cono-weeder, peg type weeder and star weeders. A few researchers reported mechanical weeding in different crops with their efficiency. The energy demand in manual weeding is only about 27% where as for weeding with different weeders, the energy goes up to 56%. Burying weeds to 1 cm depth and cutting them at soil surface are the most effective ways to control weed seedlings mechanically (Jones *et al*. 1996). According to Pullen and Cowell (1997), cutting action of the blade hoe is used most efficiently when operated at shallow depth and increasing the working depth does little to improve weed kill but a higher forward speed increases soil covering of weeds and may reduce their survival.

In terms of labour productivity (time requirement) herbicides are more effective, but they are beyond the reach of most of the farmers. The work rates for hand hoe vary from 300-400 man hours/ ha and operation of push-pull type weeders along with rows under favourable soil condition requires 50-125 man hours/ha (Yaduraju *et al*. 2003). Wheel hoe took lowest weeding time (78.33 hr/ ha) and covered maximum area (0.01276 ha/ hr) and minimum cost of operation (Rs.783.30/ ha) with yield increase of 214% over control (Lidhoo, 2004). The rotary hoe breaks the soil crust, thus providing better aeration. It uproots sprouting weeds and works to a depth of 5 cm (Marie-Josee Hotte *et al*. 2000). Effective weed control is obtained following three cultivations with the rotary hoe. Improved grubber is suitable for removing small weeds and has a capacity of 75-100 man hours/ ha depending upon the soil and weed infestation and also stirs soil up to a depth of 200 mm. Gogoi (1997) explained that the plant damage was more during 40 DAS and maximum was recorded under cultivator and also grubber and twin wheel hoe observed lower plant damage in rainfed wheat. Singh *et al*. (1985) reported that hand weeding in rows after inter-row cultivation resulted in an average yield increase of 0.5 t/ha. Inter-row cultivation plus hand weeding in the rows may be able to substitute for the highly labour intensive hand weeding presently used by many farmers.

## Ergonomic Studies to Reduce Drudgery in Weeding Operation

Human labour is the single costliest input in farming operations contributing to major part of the total cost of cultivation. Ergonomics is the scientific study of the relationship between man and his working environment that includes ambient conditions, tools, and materials, methods of work and organization of work. The performance of the weeding tools not only depends on the constructional features but also on the workers operating it. The performance of man – implement system may be poor, if ergonomic aspects are not given due attention. It may also cause clinical or anatomical disorders, and will affect worker's health. Proper attention to ergonomics aspects in design and operation will help in increasing the man implement system efficiency and also in safeguarding the workers' health. Weeding in developing countries like India is performed manually with traditional hand tools like *Khurpi*, *sickle, spade, grubber, cono weeder, mandava* weeder and so on. But these tools are used in squatting and bending postures. In these postures, the energy consumption for a given load is 30-50 % more as compared to standing or sitting posture.

Traditional weeding tools are used in undesirable postures according to ergonomic criteria; involve repetitive movement of body parts which may lead to musculoskeletal disorders. Energy requirement of *Khurpi* is the least but work output is also the lowest as compared to other weeding tools, where as the improved wheel hoes cover maximum area with the acceptable physiological demand, work performance and workers preference.

Real (1994) suggested that mechanical hoeing was effective in the inter-row but along the row, spring tine machines were essential and partially for effective weed control in maize. According to Lidhoo (2004) use of improved weeders increased yield from 169.5 per cent to 329.6 per cent over control. Sarkar *et al*. 2016 reported mechanical weeding experiment in maize using different weeding tools and found 'khurpi' was recorded the highest weed control efficiency (92.9%) followed by grubber (82.8%), spade (75.5%) and wheel hoe (72.2%). The highest human energy was also attained in case of 'khurpi' (567.62 MJ/ha) followed by spade (326.62 MJ/ha), grubber (212.62 MJ/ha) and wheel hoe (167.30 MJ/ ha). The field capacity of wheel hoe was found maximum (0.008 ha/hr) whereas spade was minimum (0.0002 ha/hr). In another study, Sarkar *et al.* (2017) reported there was 10.4% increase in working efficiency with usage of the mandava weeder. The output recorded by Mandava weeder was 168 $m^2$/hr as compared to cono-weeder (149 $m^2$/hr). Energy expenditure was 8.57 kJ/s and cardiac cost 11.15 beats/$m^2$ for cono-weeder. However, in case of

Mandava weeder it was found 7.68 kJ/s and 8.71 beats/$m^2$ of energy expenditure and cardiac cost, respectively. Manduva weeder saved 21.88% cardiac cost and increases efficiencd 10.38%. Manual weeding can give a clean weeding but it is a slow process and causes the human drudgery, hence, the improved mechanical weed management technologies should be used to complete the weeding operation in due time to enhance crop productivity and reduce human health hazards.

**Energy cost of work**

Systematic efforts to evaluate the human energy expenditure of weeding operations are generally non-existent. Hence human energy measurement for weeding operations, performed under different environmental conditions is essential. These measurements are also important from the safety point of view because whenever the physical capacity of a person is exceeded, it is bound to cause considerable fatigue and large reduction in the alertness of the person making the operation unsafe. Thus studies on human energy measurement for weeding operations can provide a rational basis for recommendation of methods and equipment for performing weeding operations and improvement in equipment design for more output and safety.

Various researchers from all over the world, reported that, basal metabolic rate, heart beat rate and oxygen consumption rate are the pertinent parameters for assessing the human energy required for performing various types of operation. It has been reported that the mean oxygen consumption and mean heart rate during the operation varied from 0.499 to 0.625 l /min and 105 to 120 beats/min, respectively for different weeders. The energy requirement for rotary weeding, cono weeding and hand weeding was reported as 26.5, 24.0 and 16.0 kJ/min, respectively for the male workers and 18.0, 15.0 and 9.5 kJ/min, respectively for the female workers.

**Grading energy cost of work**

To perform the manual activity, more muscular movement is necessary which causes stress on the cardio-pulmonary system to meet up the demand of extra energy. But looking at the cardio-pulmonary conditions one can therefore assess the degree of physiological stress going to be imposed on our body and how effectively our body will be capable to maintain that condition. This will further help us in evaluating a manual job from the view point of energy requirement, in determining the correct method of performing a task, in optimizing a product design or in determining a better work posture while performing a job manually. The energy expenditure of some of the weeding tools varies from 7.68 kJ/min (spade), 8.57 kJ/min (cono weeder), 7.68 kJ/min (mandava weeder) and 4.97 kJ/min (*khurpi*).

**Cardiac cost**

The measurement of cardiac cost of human while performing weeding operations in different environmental conditions with different farm tools and with an high task performing work the cardiac study helps to reduce reduction in drudgery and helps to increase work efficiency, which has be derived in beats/$m^2$. The cardiac cost in some of the weeding tools are: spade 274.78 beats/$m^2$, cono weeder 11.15 beats/$m^2$, mandava weeder 8.71 beats/$m^2$ and *Khurpi* 4.16 beats/$m^2$.

### Acceptable work load

During any physical activity, there is increase in physiological parameters depending upon the workload and the maximum values, which could be attained in normal healthy individuals, will be up to $VO_2$ max (190 beats/min for heart rate and 2.0 l/min). However at this extreme workload, a person can work only for a few seconds. The acceptable workload for Indian workers is the work consuming 35 per cent of $VO_2$ max.

### Subject rating scales

Subjective, self-reported estimates of effort expenditure may be quantified using ratings of perceived exertion (grade point scale). Using this scale, ratings of perceived exertion (RPE) values were shown to be approximately one-tenth of exercise heart rate values for healthy, middle-aged men performing moderate to heavy exercise. It has been reported that while working with manual weeders, the postural discomfort (overall discomfort rating) varied from 3.0 to 5.1 on 8-point scale (0 - no discomfort, 8 - extreme discomfort) for a 15-min operation of each weeder. There was a reduction of 4.98 per cent in the average total cardiac cost of work and physiological cost of work while performing weeding with the improved tool (*Saral Khurpi*) when compared to other existing tools.

### Body part discomfort score

For assessment of postural discomfort at work the body mapping technique is used. The subject's body is divided into 27 regions and the subject is asked to indicate the regions, which are most painful. The subject is asked to mention all body parts with discomfort, starting with the worst and the second worst and so on. The subject is also asked to assess total discomfort on a particular body part using a five or seven point scale. The scales are graded from 'no discomfort' to 'maximal discomfort'. Several researchers reported that, the women of age 21 to 40 years felt very severe pain at upper arm, cervical region and moderate pain in lower extremities for weeding operations. They defined fatigue symptom as a general sensation of weariness. They also reported the subjective and objective symptoms *viz.*, subjective feeling of weariness, faintness and distaste for work; sluggish thinking; reduced alertness; poor and slow perception and unwillingness to work.

## Tools and equipments for drudgery reduction in weeding operation

Intercultural operations are performed primarily to destroy the weeds present in the field and create favorable soil conditions for crop growth. Hand hoeing and manual weeding are the most common practices performed for weed control. However, climate and soil type play an important role in the possibilities for mechanical weed control. The success of mechanical weeding depends upon the stage of weeds, crop geometry and climatic conditions.

Mechanical weeding through manual hoes is an effective method of weed control in dryland as well as in wetland condition after chemical weeding. Energy requirement of khurpi is least but the work output is lowest, where as the wheel hoes (push- pull type) and the self propelled power weeders covers a maximum area with acceptable physiological demand, work performance and workers preference. Idea on force exertions is of immense importance while designing a pushing or pulling task. Existing studies have been principally concerned with static tasks despite the knowledge that most of weeding operations are in dynamic nature and involves overexertion of musculoskeletal system and accidents due to slipping or tripping. Researchers reported that, 7 percent of low back injuries are associated with slipping or tripping accidents.

Several researchers have developed a few weeders with due consideration of above said problems to reduce human drudgery and enhance operator comfortness with effective and efficient weeding operations. Some of the weeding tools and implements are listed below:

| S. No. | Weeding tools | Description |
|---|---|---|
| 1 | Khurpi | It is a sharp straight tool, operated in sitting and squatting position. Suitable for inter and intra row weeding of dry land agriculture.<br>Field capacity: 0.002- ha/h<br>Cost: Rs.60-150/- (Approx.) |
| 2 | Spade (Kodal/Phaura) | It is a multipurpose tool used for making bunds, ridges, furrows, shallow trenches for sowing seeds and planting materials, and removal of weeding operation<br>Field capacity: 0.0002 ha/h<br>Cost: Rs.250-300 (Approx.) |
| 3 | 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.<br>Field capacity: 0.003 ha/h<br>Cost: Rs. 400/- (Approx.) |
| 4 | 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.<br>Field capacity: 0.005-0.009 ha/h<br>Cost: Rs. 400/-(Approx.) |
| 5 | 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).<br>Field capacity: : 0.004 ha/h<br>Cost: Rs. 400/- (Approx.) |

| S. No. | Weeding tools | Description |
|---|---|---|
| 6 | 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.<br>Field capacity: 0.015 ha/h<br>Cost: Rs. 800/- (Approx.) |
| 7 | 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.<br>Field capacity: 0.006 ha/h<br>Cost: Rs. 800/- (Approx.) |
| 8 | 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.<br>Field capacity: 0.009 ha/h<br>Cost: Rs. 1100/- (Approx.) |
| 9 | 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.<br>Field capacity: 0.024 ha/h<br>Cost: Rs. 1100-1400/-(Approx.) |
| 10 | Cono weeder | The weeder consists of two rotors, float, frame and handle. The rotors are cone frustum in shape, smooth and serrated strips are welded on the surface along its length. The rotors are mounted in tandem with opposite orientation. The float, rotors and handle are joined to the frame. The float controls working depth and does not allow rotor assembly to sink in the puddle. The weeder is operated by pushing action. The orientation of rotors create a back and forth movement in the top 3 cm of soil and helps in uprooting the weeds.<br>Field capacity: 0.012 ha/h<br>Cost: Rs. 1900/- (Approx.) |
| 11 | Mandava Weeder | It is manually operated equipment widely used for SRI application. It is operated by push & pull action, and useful for uprooting of weeds in lowland paddy field.<br>Field capacity: 0.0168-0.0178 ha/h<br>Cost: Rs. 1100-1300/- (Approx.) |
| 12 | 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.<br>Field capacity: 0.0160<br>Cost: Rs. 1100/- (Approx.) |
| 13 | Brush cutter | Weeding done by rotating a blade or wire at higher speeds parallel to ground. It is best suitable in wider row spaced crops like, pige on pea, cotton, sugarcane etc.<br>Field capacity: 0.1-0.2 ha/h.<br>Cost: Rs. 15,000-25,000/- (Approx.) |

| S. No. | Weeding tools | Description |
|---|---|---|
| 14 | Power weeder | It is a petrol engine operated power weeder with a working width of 22 cm, suitable for row spacing in any dry land conditions.<br>Field capacity: 0.0696 ha/h<br>Cost: Rs. 30,000/- (Approx.) |
| 15 | Lowland paddy power weeder | Engine mounted on a frame, which powers the weeding element. It is suitable to operate in lowland paddy field.<br>Field capacity: 0.1-0.2 ha/h<br>Cost: Rs. 15,000-25,000/- (Approx.) |
| 16 | Dry land rotary weeder (Engine operated) | Engine mounted on a frame, which powers the weeding element. It is suitable to operate from narrow spaced crops to broader spaced crops like soybean, maize, cotton etc.<br>Field capacity: 0.1-0.2 ha/h<br>Cost: Rs. 15,000-50,000/- (Approx.) |
| 17 | Self-propelled power weeder: | Weeding elements are self-propelled type and are operated by engine. It is best suitable in wider row spaced crops like sugarcane, cotton, maize, etc.<br>Field capacity: 0.18-0.25 ha/h<br>Cost: Rs. 50,000-75,000/- (Approx.) |
| 18 | Tractor operated sweeps/ earthing-up bund former: | The weeding unit (duck foot sweeps/ earthing-up unit etc.) is mounted on three point linkage and dragged by tractor drawbar. It is best suitable in wider row crops like sugar-cane, cotton, maize, potato etc.<br>Field capacity: 0.25-0.35 ha/h<br>Cost: Rs. 30,000-80,000/- (Approx.) |
| 19 | Tractor operated inter-row rotary weeder: | The rotary weeding unit is mounted on three point linkage and operated by tractor P.T.O. It is best suitable in wider row crops like sugarcane, cotton, maize etc.<br>Field capacity: 0.25-0.35 ha/h<br>Cost: Rs. 50,000-1, 00,000/- (Approx.) |

## Conclusion

Manual weeding operations are full of drudgeries, which accounts 25 percent of the total labour requirement during a cultivation season. Energy requirement of Khurpi is the least but the work output is also the lowest, where as the wheel hoes (push - pull type) and the self propelled power weeders covers a maximum area with acceptable physiological demand, work performance and workers preference. Hence, use of improved weeding tools *viz.*, grubber, wheel hoes, and power weeders etc. is essential to reduce human drudgery and to enhance operator comfortness in weed management.

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# Impact of Climate Change on Insect-pests and their Management

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Increased population has led to an ever increasing demand for agricultural production and poses a high risk on food security which is greatly influenced by occurrence of storms, drought, flooding, precipitation, increased Carbon dioxide ($CO_2$) and increased temperatures. Evidences suggest that anthropogenic activities lead to an increase in greenhouse gas concentrations especially of $CO_2$ which ultimately leads to climate change. Plant physiological processes directly respond to the various climatic factors such as temperature, solar radiation, precipitation, relative humidity and wind speed (Tripathi *et al*. 2016).

Climate change impacts on pest population include change in phenology, distribution, community composition and ecosystem dynamics that finally leads to extinction of species (Walther *et al*. 2002). The effect of climate change could either be direct, through the influence that weather may have on the insects' physiology and behavior. In addition, indirect effects can occur through the influence of climate on the insect's host plants, natural enemies and inter-specific interactions with other insects. Climate change related factors have a very strong influence on the development, reproduction and survival of insect pests and as a result it is highly likely that by any changes in climate will affect the insect-pest population. Other changes include expanded pest ranges, disruption of synchrony between pests and natural enemies, and increased frequency of pest outbreaks and upheavals (Parmesan 2007). The quicker the life cycle, the higher will be the population of pests. The general prediction is that if global temperatures increase, the species will shift their geographical ranges closer to the northern pole or to higher elevations, and increase their population size. A key factor regulating the life history pattern of insect pests is temperature. Because insects are poikilothermic (cold blooded) organisms, the temperature of their bodies is approximately the same as that of the environment. Therefore, temperature is probably the most important environmental factor influencing insect behaviour, distribution, development, survival and reproduction.

## Effects of Temperature on Insects

The increase in temperature due to climate change have impacted insect populations in several complex ways like extension of geographical range, increased over wintering, changes in population growth rate, increased number of generations, extension of development season, changes in crop pest synchrony, changes in inter-specific interactions, increased risks of invasions by migrant pests and introduction of alternative hosts and over wintering hosts. But all these effect of temperature on insects largely overwhelms the effects of other environmental factors (Bale *et al*. 2002). Some insects take several years to complete one life cycle and these insects (cicadas, arctic moths) will tend to moderate temperature variability over the course of their life history. It has been estimated that with a 2°C temperature increase insects might experience one to five additional life cycles per season (Yamamura and Kiritani 1998). Increased temperature will accelerate the growth and development of insects damaging the crops, possibly resulting in more generation results in more crop damage per year. Temperature is one of the key factors underlying the geographical distribution of aphids, which are well adapted to regions with a cold winter, during which they survive in the form of eggs having a high level of cold hardiness. These insects multiply only within a certain range of temperatures. The minimum temperature at which aphid development occurs is generally around 4°C, but this figure varies within and between species. Optimal temperatures and upper limits are also variable but usually in the range of 20 to 25°C and 25 to 30°C, respectively. Thus, the rate of development in aphids is directly dependent on temperature. A female aphid requires a certain number of degree-days above the developmental threshold to reach adulthood (Harrington *et al*. 1995). Global warming should therefore, in principle, favour the development of aphid populations. Other biological functions influenced by temperature include dispersal and reproduction. Occurrence of *Helicoverpa armigera* as an invasive pest in Brazil and North America has been attributed to the climate change (Czepak *et al*. 2013; Tay *et al*. 2013).

Rabindra (2009) reported that the elevated $CO_2$ levels as well as temperature reduce the activity, longevity, fertility and fecundity of entomophages like parasitoids. Natural enemy and host insect populations may respond differently to changes in temperature. Parasitism could be reduced if host populations emerge and pass through vulnerable life stages before parasitoids emerge. Hosts may pass though vulnerable life stages more quickly at higher temperatures, reducing the window of opportunity for parasitism. Temperature may change gender ratios of some pest species such as thrips and potentially affecting reproduction rates (Lewis 1997). Insects that spend important parts of their life in the soil may be gradually affected by temperature changes than those that are above ground simply because soil provides an insulating medium that will tend to buffer temperature changes more than the air (Bale *et al*. 2002). Some insects are closely tied to a specific set of host crops. Temperature increases that cause farmers not to grow the host crop any longer would decrease the populations of insect pests specific to those crops. The same environmental factors that impact pest insects can impact their insect predators and parasites as well as the entomopathogens that infect the pests, resulting in increased attack on insect populations.

## Effects of Increasing Carbon Dioxide on Insects

Another important aspect of climate change is the effect of increasing concentrations of carbon dioxide on crop and pest. Generally $CO_2$ impacts on insects are thought to be indirect - impact on insect damage results from changes in the host crop. Indeed, increases in $CO_2$ concentration stimulate plant growth, but decrease the nutritional quality of plants for phytophagous insects (Lincoln *et al*. 1993). Hamilton *et al*. (2005) found that during the early season, soybeans grown in elevated $CO_2$ atmosphere had 57% more damage from insects than those grown in today's atmosphere and concluded that the enhanced levels of simple sugars in the soybean leaves under elevated $CO_2$ may have stimulated the additional insect feeding. Kranthi *et al*. (2009) reported *Spodoptera litura* (Fab.) as serious pest under higher levels of $CO_2$. Some other researchers have observed that insects sometimes feed more on leaves that have lowered nitrogen content in order to obtain sufficient nitrogen for their metabolism (Hunter 2001). Increased carbon to nitrogen ratios in plant tissue resulting from increased $CO_2$ levels may slow insect development and increase the length of life stages vulnerable to attack by parasitoids (Coviella and Trumble 1999). Whittaker (1999) reviewed the impacts and responses at population level of herbivorous insects to elevated $CO_2$ and concluded that till date, the only feeding guild in which some species have shown increases in population density in elevated carbon dioxide are the phloem feeders. Chewing insects (both free-living and mining) generally have shown no change or reduction in abundance, though relative abundance may be greatly affected. Roth and Lindroth (1994) studied the effect of elevated $CO_2$ on the relationship between the gypsy moth, *Lymantria dispar* and its parasitoid *Cotesia melanoscela* and found that the parasitism mortality was higher in the elevated $CO_2$ treatments.

## Effects of Precipitation on Insects

There are fewer scientific studies on the effect of precipitation on insects than temperature. Some insects are sensitive to precipitation and are killed or removed from crops by heavy rains, this consideration is important when choosing management options for onion thrips. Flooding the soil has been used as a control measure for some insects that over-winter in soil (Vincent *et al*. 2003). One would expect the predicted more frequent and intense precipitation events forecasted with climate change to negatively impact these insects. As with temperature, precipitation changes can impact insect pest predators, parasites, and diseases resulting in a complex dynamic. Fungal pathogens of insects are favored by high humidity and their incidence would be increased by climate changes that lengthen periods of high humidity and reduced by those that result in drier conditions.

## Impact of Pesticides on Insects

Change of climate may affect our ability to control pests. High temperature seems to be a double edged sword. There are a few reports indicating sharp drop in resistance in certain insect-pests to some molecules. Humidity levels can also modify their efficacy, as can the timing and amount of rain following their application. Recently, field populations of susceptible diamondback moth (S-DBM) and resistant DBM (R-DBM) displayed 18.3 fold resistance to methamidophos and 74 fold resistance to avermectins, respectively; when reared at higher temperature exhibited sharp drop in resistance in R-DBM (Liu *et al*. 2008). It is also documented that at high temperature conditions fenpyroximate brings about rapid kill of red spider mites. Increased $CO_2$, moisture and temperature seems to be having more negative implications on the efficacy of pesticides. The more frequent rainfall events predicted by climate change models could minimize residues of contact insecticides on plant that triggers farmers to use repeated sprays of them. Systemic products could be affected negatively by physiological changes that slow uptake rates due to physiological changes, such as small stomatal opening or thicker epicuticular waxes in crop plants growing under high temperatures (Bayaa, 2008). The activity of biological control agent *Beauveria bassiana* was greatest at 25$^o$C and was adversely affected by temperature, suggesting it needs optimum range to be more virulent (Amarasekare and Edelson 2004).

## Strategies to Mitigate the Effects of Climate Change

Shifts in species abundance and diversity of insect-pests due to climate change may result in reduction in the efficacy of insect pest management programs; hence the need to sharpen existing monitoring tools and develop new ones to help detect potential changes in pest distribution, population ecology, damage assessment, yield loss and impact assessment (Sharma 2016; Dhaliwal *et al*. 2010). Potential changes in pest survival strategies may need broader and stronger inter-center partnerships to develop new IPM options. Several botanicals and biologically based products are being used now these days as eco-friendly products for insect-pest management. However, many of these products of pest control are highly sensitive to the environment. Increase in temperatures and UV radiation, and a decrease in relative humidity may render many of these control tactics to be ineffective (Niziolek 2012). Therefore, there is a need to develop appropriate strategies for pest management that will be effective under changing climatic scenario. Host-plant resistance, natural plant products, biopesticides, natural enemies, and agronomic practices offer a potentially viable option for integrated pest management. But, the relative efficacy of many of these control measures is likely to change as a result of global warming. Biological control which is considered as the important and effective component of IPM programs is severely affected by climate change, since the relationship between natural enemies and host pests will be affected. Almost all the insect control methods including cultural practices, natural enemies, host plant resistance, bio-pesticides, and synthetic pesticides are highly sensitive to the environment. Thus a more robust and climate adaptable pest management technologies are needed for managing insect pests. For sustainable agriculture and to mitigate the climate effects on agriculture, evaluating the effects of climate change on crop production and development of climate smart crops is important. Climatic and crop models need to be developed for land use criteria, and soil productivity and the methods for tailoring insecticide inputs to weather need to be developed. Further, advanced cropping methods and cropping systems need to be explored that would reduce the risk of attack and competition. The alarming point is the transition of insect pests to new territories in absence of natural enemies as it will lead to pest outbreaks. The main challenge ahead is to develop successful prediction models that would pave way for their management. The pest forewarning systems based on weather are important decision support tools that help farmers to evaluate the risk of pest outbreaks under different climatic conditions. The information on weather, crop, and insects, is very important for the warning systems for taking necessary action to prevent pest outbreaks and avoid economic losses.

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# Disease Management in Major Field Crops

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Plant disease is an impairment of the normal state of a plant which modifies or interrupts its vital functions. The prevalence of plant diseases varies 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 up to 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 caused 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 that ranges from microclimate to global scale and hence affects the plant disease epidemics (Garrettt 2006). The classic plant disease epidemic triangle includes interactions between hosts (plant), 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). Under conservation agriculture, crop residues incorporation suppresses weed but associated with an increased incidence of crop diseases (Yadvinder-Singh and Sidhu 2004). Under zero till systems, soil-borne diseases become more severe because of the retention of crop stubble on the soil surface and lack of soil disturbance. Residue-borne diseases are also favoured because the pathogens are protected from microbial degradation by residence within the crop debris (Bijay Singh *et al.* 2008). The crop residue act as an inoculums source but on the other hand, mulch may suppress soil-borne pathogens due to increased population of soil micro- and meso-fauna. Sharma *et al* (2007) reported low incidence of *Tilletia indica* (Karnal bunt) infection in rice-wheat cropping systems with no-till wheat planted into rice-residue. Decisions on crop-residue management should be made keeping in view the health of previous crop(s) and the potential susceptibility of subsequent crops. For the effective and economical management of diseases, 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 measures.

**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 methods

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**

Lack of soil disturbance under conservation agriculture may lead to inoculums build up so after about three years of cultivation, deep summer ploughing should be done. It leads to exposure of pathogen propagules to high temperatures and physical killing of the pathogen. 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 soilborne pathogens may be related to lack of $O_2$, increased $CO_2$ or various microbial activities under anaerobic conditions like production of toxic substances to the pathogen (Bruehl 1987). Flooding results in high $CO_2$ content in the flooded soil, $CO_2$ 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 thermosanitation and described many examples of diseases management by fire and flaming. The basic idea behind use of fire and flaming is 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. Also the concept of conservation agriculture does not encourage this practice.

**(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. Volunteerplants present in field also act as source of inoculum. So incorporation of previous year crop residue carrying inoculums (from symptomatic crop plant) should be discouraged.

**(g) Time of seeding**

Time of sowing also plays 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) Rouging of diseased plants**

Removal of diseased plant reduces the spread of a destructive disease. Virus diseases are examples where rouging 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 thegermination 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. These methods 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 forreduction 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 or55°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 ofred rot in some varieties of sugarcane by hot air treatment of 54ºC for 8 hours. Similarly, grassy shoot disease of sugarcane has been controlled byhot 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 seedbornediseases. It is widely used in managing sugarcane diseases. As a gas, itmoves 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. Itis 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 (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 transparentpolyethylene sheet to increase soil temperature (10-15°C above normal temperature) enough to kill the mostof 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 properlymature 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 ofbiological 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/chemicalinterference,**) Indirect antagonism (**Competition and Induction of host resistance**).** *Trichoderma* and *Pseudomonas* based bioformulations are mostly used in soil borne diseasemanagement. 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 Tools 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

### Rice

**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)

**Rice blast (*Magnaporthe oryzae*)**

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

**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)

### Wheat

**Wheat rust (*Puccinia* spp.)**

**Management:** 1) Grow resistant varieties like HD 3043 (brown and yellow rust), HI 1563 (All the three rust) etc. 2) Spray plantavax @ 0.1% 3) Spray of propiconazole (Tilt 25 EC @ 0.1 per cent) at rust initiation (January-February) is also recommended.

## Maize

### Bacterial Stalk Rot : (*Dickeya zeae)*

**Management:** 1) Ensure proper drainage to avoid waterlogging 2) Planting of the crop on ridges rather than flat soil 3) Grow tolerant varieties like PAU 352, Pusa Extra Early Hybrid Maize 5, 4) Bleaching powder @ 10 kg/ha as soil drench at pre-flowering stage

### Charcoal-Rot : (*Macrophamina phaseolina)*

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

## Pigeonpea

### Pigeon pea wilt: (*Fusarium udum)*

**Management:** 1) Practice long term crop rotation 2) rotating pigeon pea with sorghum andtobacco 3) Solarize the field in summer to help reduce inoculums 4) Seed treatment with Thiram 2g/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.

### 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.

## Chickpea

### Ascochyta blight: (*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.

### 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.

### Wilt (*Fusarium oxysporum)*

**Management:** 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 Thiram 2g/kg seed 5) *Trichoderma* @ 5-8 kg/ha or Seed dressing with *Trichoderma* 8 g/kg of seeds along with stickers.

## Sugarcane

### Red rot of sugarcane: (*Colletotrichum falcatum*)

**Management:** 1) select setts for planting from healthy plants 2) Crop rotation with rice for oneseason and other crops for two seasons 3) Growing resistant and moderately resistant varieties *viz.*, Co 09022 (Karan-12) (MR), Co A 05322 (Res to all races) 4) Removal of the affected clumps at an early stage and soil drenching with Carbendazim 50 WP (1 gm/lit water) 5) The setts should be dipped in Bavistin solution@0.2% 6) Hot water treatment at 54 °C for 8 hr.

### Ratoon stunting (*Leifsonia xyli subsp. xyli*)

**Management**: 1) Healthy Sett selection 2) Avoidance of ratooning3) Disinfecting cutting knives with antiseptic solution of 5-15 lysol or 50-70% ethanol or Agallol 4) Hot water treatment 50°C/2 hr or 52°C/30 min 4) Grow resistant cultivars.

### Grassy Shoot Disease (*Phytoplasma*)

Management: 1) Growing resistant varieties viz., CoM 7125 (Sampada) 2) Avoid ratooning if Grassy Shoot Disease incidence is more than 15 % in the plant crop 3) Rogue out infected plants 4) Treat the setts with aerated steam at 50°C for 1 hour to control primary infection 5) Treating them with hot air at 54°C for 8 hours 6) Spray dimethoate @ 1ml in 1 litre of water to control insect vector.

## Cotton

### Wilt (*Fusarium oxysporum f.sp. vasinfectum*)

**Management:** 1) Resistant varieties like DB–3–12, Ak–145, Sanjay, Digvijaya, G.cot–11,G.cot -13 , LD – 327, PA – 32 2)Treat the acid delinted seeds with Carboxin or Carbendazim at 2 g/kg 3) Remove and burn the infected plant debris in the soil after deep summer ploughing during June-July 4) Apply increased doses of potash with a balanced dose of nitrogenous and phosphatic fertilizers 5) Apply heavy doses of farm yard manure or other organic manures. Follow mixed cropping with non-host plants 6) Spot drench with Carbendazim 1 g/ litre 7) Treat the seed with 4 g *Trichoderma viride formulation.*

## Potato

### Late blight of potato (*P. infestans*)

**Management:** 1) Use potato tubers for seed from disease-free areas 2) The infected plantmaterial in the field should be properly destroyed 3) Select well drained soils and practice high ridging 4) Less use of nitrogenous fertilizers 5) As soon as the weather conditions become congenial for late blight, irrigation should be stopped wherever applicable. Only light irrigationmay be given later, if required 6) Fungicidal sprays with Dithane M-45 or Metalaxyl or Dithane Z-78 (2.0 g/litre of water) 7) Resistant varieties: North western hills: Kufri

Girdhari, Kufri Himalini and Kufri Shailja, north eastern hills: Kufri Girdhari, Kufri Himalini, Kufri Megha, and Kufri Kanchan, southern hills : Kufri Swarna, Kufri Muthu, Kufri Neela and Kufri Neelima, sub-tropical plains: Kufri Anand, Kufri Arun, Kufri Badshah, Kufri Chipsona-1, Kufri Chipsona-2, Kufri Chipsona-3, Kufri Himsona, Kufri Lalit, Kufri Pukhraj, Kufri Sadabahar, Kufri Sutlej.

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# Profitable Rice Farming through System of Rice Intensification (SRI) under Conservation Agriculture

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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 large amount of water. To produce one kg of rice 3000-5000 liters of water is required. Decreasing water availability for agriculture threatens the productivity of the irrigated rice ecosystem and ways must be sought to save water and increase the water productivity of rice (Guerra *et al*. 1998). Improving water-use efficiency of rice culture is therefore, a pre-requisite for food security in Asia. By modifying management of rice plants, soil, water and nutrients to improve growth environments, farmers can get higher-yielding, more vigorous and resilient plants nurtured by larger root systems and greater diversity/abundance of beneficial soil organisms. More productive phenotypes from available genotypes enhance farmers' income and security while reducing their costs and water requirements.

The System of Rice Intensification (SRI) is a methodology aimed at increasing the yield of rice produced in farming. It is a low water, labor-intensive, method that uses younger seedlings singly spaced and typically hand weeded with special tools. It was developed in 1983 by the French Jesuit Father Henri de Laulanié in Madagascar (De Laulanié 2011). Since 2000, SRI has been spreading to other countries, and it has been estimated that more than 10 million farmers are benefiting from the application of this methodology in more than 50 countries (SRI-Rice 2016a; FAO 2016; World Bank 2010). The central principles of SRI are:

- **(i) Manage water to avoid both flooding and water stress**: Rice field soils should be kept moist rather than continuously saturated, minimizing anaerobic conditions, as this improves root growth and supports the growth and diversity of aerobic soil organisms.
- **(ii) Minimize competition among plants:** Rice plants should be planted singly and spaced optimally widely to permit more growth of roots and canopy and to keep all leaves photosynthetically active.
- **(iii) Encourage early and healthy plant establishment:** Rice seedlings should be transplanted when young, less than 15 days old (8-12 days) with just two leaves, quickly, shallow and carefully, to avoid trauma to roots and to minimize transplant shock.

**(iv)** Build up fertile soils that are well-endowed with organic matter and beneficial soil biota

These principles interact with each other and result in:

- Early, quick and healthy plant establishment
- Reduced plant density
- Improved soil conditions through enrichment with organic matter
- Reduced and controlled water application

The most distinctive *features* of plants grown according to SRI management are:
*More profuse tillering*, starting about a month after transplanting,
*More and larger panicles of grain*, often but not always with higher grain weight,
*Much larger and healthier root systems* that remains functioning throughout the crop cycle.

**Advantages of SRI:** SRI technology emphasizes on making effective utilization of resources, especially water and use of organic manures. The benefits of SRI are multi-fold, especially in resource conservation (water, land, energy, seeds and labour), rice production and addressing the challenges of climate change. Uphoff and Kassam (2009) and Uphoff (2012) suggested the following advantages of SRI:

- Depending on current yield levels, rice yields are improved by 20-50% or more.
- Increased income due to higher yield, better grain quality and lower water requirement.
- Since SRI fields are not kept continuously flooded, water requirements are reduced, generally by 25-50%.
- The system does not require purchase of new varieties of seed, chemical fertilizer, or agrochemical inputs, although commercial inputs can be used with SRI methods.
- The minimal capital costs make SRI methods more accessible to poor farmers, who do not need to borrow money or go into debt, unlike many other innovations.
- Costs of production are usually reduced, usually by 10-20%, although this percentage varies according to the input-intensity of farmers' current production.
- With increased output and reduced costs, farmers' net income is increased by more than their augmentation of yield.
- SRI is a greater resilient system as this system maintains productivity under unfavourable conditions, including climate variations, drought, storms, pest and disease pressure.
- SRI system reduces the emissions of greenhouse gases (GHG) like methane, nitrous oxide, when continuous flooding of paddy soils is stopped and other rice-growing practices are changed. Total global warming potential (GWP) from rice paddies was reduced with SRI methods in the above studies by 20-30%, and up to 73% in one of the studies (Choi *et al.* 2015).

## Recommended SRI Management Practices

**Land preparation:** Land preparation in SRI is similar to conventional rice; however, care should be taken to level the land properly, so that water can be efficiently distributed in small amounts across the entire surface. There should be proper drainage system inside and around the field to drain out the excess water in heavy rainfall event. There is scope for reducing soil disturbance in Conservation Agriculture. This provides additional means to optimize resource use in SRI-based rice production.

**Nursery management:** SRI nurseries should be on raised beds, and unflooded, as this will improve the root growth and vigor of the seedlings (Mishra and Salokhe, 2008). Seedlings are raised in a thin layer of soil on trays or pans or on banana leaves, or in plastic trays/cups. This makes it easy to transport seedlings to the field and to handle them gently. Some grow seedlings in a fibrous mat that can be rolled up and carried.

**Seed priming:** Seed priming can improve seed germination rates and enhance seedlings' vigour and early growth. Using a salt-water solution to separate the more viable seeds (which sink to the bottom of a container) from lighter, less developed seeds (which float) can add 10-20% to yield just by having more vigorous seedlings resulting.

**Transplanting of young seedlings:** Seedlings at the 2 leaf-stage, usually between 8 - 12 days old, i.e. before the start of the 4$^{th}$ phyllochron, are transplanted. The objective of transplanting younger seedling is to preserve the plants' vigour and growth potential for tillering and root development (Stoop *et al*. 2002). The single seedling, instead of a clump of 3-4 seedlings (to avoid root competition), should be transplanted within 30 minutes of uprooting from the nursery protecting the seedlings' roots and minimizing the transplanting shock. Seedlings should be transplanted very shallow (1-2 cm) by pushing them straight down into the soil.

**Spacing and planting pattern:** To encourage greater root and canopy growth, seedlings should be transplanted in a square grid pattern at 25 x 25 cm distances between rows and hills. The higher yield with reduce population results from the increase in panicle-bearing primary tillers per unit area, and also more spikelets and filled grains per panicle, as well as usually higher grain weight.

**Water management:** In addition to using very young seedling in SRI, proper management of water is another impotent factor. Only a minimum of water is applied during the vegetative growth period. This avoids the suffocation and degeneration of rice plant roots (Kar *et al.* 1974) and also supports more abundant and diverse populations of aerobic soil organisms that provide multiple benefits to the plants (Randrimiharisoa *et al.* 2006). Alternate wetting and drying (AWD) method of irrigation, where 1-2 cm layer of water is introduced into the field, followed by letting the plot dry until cracks become visible, at which time another thin layer of water is introduced. During flowering a thin layer of water is maintained, followed by alternate wetting and drying in the grain filling period, before draining the paddy 2-3 weeks before harvest. The other methods like sprinkler system may also be used in SRI as this system is highly water efficient. In a three years study (2015-17) at ICAR-RCER, Patna, it was observed that micro sprinkler saved 43% water with 0.7 kg/m$^3$ water productivity as compared to maintaining 2.5 cm standing water all throughout. However, it may suit to only affordable farmers (Rs. 2.0 lakhs/ha as system cost). The greater economic returns that SRI methods can give should provide farmers with strong incentives to cooperate, and they can justify considerable investment by government and donor agencies since water is becoming ever scarcer and more valuable.

**Nutrient management:** In SRI, major soils are improved through organic matter additions (Farm yard manure, compost, vermicompost, poultry manure, etc.) as many nutrients become available to the plant from the organic matter. However, mineral fertilizer can also be used as a part of integrated nutrient management, if farmers do not have access to enough biomass to enhance soil organic matter. The organic matter content soils in a SRI-based cropping system can be improved through crop diversification with legumes, an integral part of Conservation Agriculture.

Weed management: Weeds are major problem in unpuddled, non-flooded paddy fields. Weeds grow more vigorously, and need to be kept under control at an early stage. A rotary hoe or cono weeder is used starting at 10 days after transplanting, repeated ideally every 7-10 days until the canopy is closing. Use of mechanical weeders breaks up the surface soil as it turns weeds into mulch, stimulates root growth by root pruning, conserving their nutrients as they decompose in the soil. The use of the weeder contributes to homogeneous field conditions, creating a uniform crop stand and leading to increased yields. This practice, especially if done several times, can add 1 to 3 tons/hectare to yield without other soil amendments, by inducing better soil health and more nutrient cycling and solubilization through microbial activity.

It is believed that the three key elements of Conservation Agriculture (CA) viz., no-till/minimum soil disturbance; soil cover with organic matter; and crop rotation would enhance the performance of System of Rice Intensification (SRI) methods. This is because ecologically CA includes soil organic matter build-up, soil biota promotion, and soil porosity enhancement. This apply also to SRI systems. Systematic research is required to evaluate and adapt SRI systems for CA so that soil puddling can be minimized or done away with, and direct-seeded rice without puddling can be promoted. Work in North Korea indicates that this is possible and can offer further cost reductions and environmental benefits (Uphoff and Kassam, 2009). However, from experiments conducted at initial stages of SRI at ICAR-RCER, Patna revealed that the weed infestation was very severe. Nevertheless, CA-based SRI-System followed by system of wheat intensification (SWI) would offer robust sustainable production systems that would harness the advantages of both SRI and CA systems.

A comparative economic analysis of traditional and SRI system of rice cultivation has been done based on the demonstrations conducted at farmers' fields in 3 districts of Bihar. The cost and expenditure of SRI paddy and traditional paddy cultivation of sample farmers (N=20) of Nalanda and Katihar and Gaya districts of Bihar are given in the table as shown below (Table 1).

**Table 1. The cost of SRI and Traditional rice cultivation**

| S. No. | Cultivation Practices | Expenditure in SRI rice cultivation (Rs. per acre) | Expenditure in traditional rice cultivation (per acre) |
|---|---|---|---|
| 1. | Seed Rate | 500/- (for 2 kgs Hybrid Seed) | 2500/ (for 10 kgs (Hybrid Seed) |
| 2. | Nursery management | 2800/- | 6250/- |
| 3. | Land preparation | 4500/- | 5000/- |
| 4. | Transplanting management | 2000/- | 2500/- |
| 5. | Fertilizer, Manure management | 7250/- | 3640/- (Chemical fertilizer) |
| 6. | Weed management | 3200/- (Cono weeder twice) | 4500/- (Hand weeding) |
| 7. | Insect-pest management | 500/- | 1200/- |
| 8. | Harvesting, threshing and transportation | 7500/- | 7000/- |
| | Total | Rs.28,250/- | Rs. 32,590/- |

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# Farmers Perception in Adoption of Conservation Agriculture

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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 promote 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 technologies 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 % farmers. 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%) andnot 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%), reduction 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 transplanting) 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 disadvantage, 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<br>• Water saving<br>• Timely seeding and crop establishment<br>• Lesser stalk lodging problem<br>• Time saving<br>• Labour saving<br>• No need for nursery, seedling uprooting and transplanting in case of ZTDSR<br>• Improved soil health condition | • Weed problems in ZTDSR<br>• Poor germination in case of low moisture and inappropriate depth of seeding<br>• Undulated land causes difficulty in operating 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.

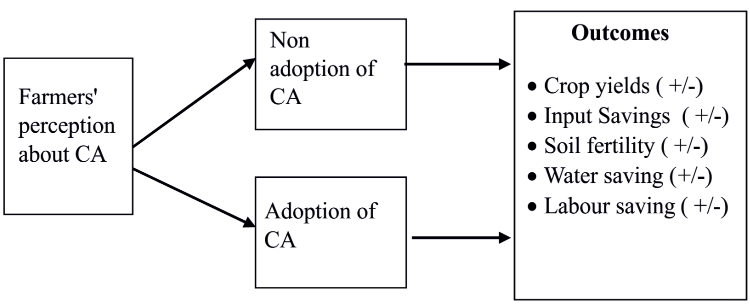


**Fig. 1.** A Conceptual frame work on farmers perception on CA

**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**

| | | | |
|---|---|---|---|
| Name of farmer:<br>Name of spouse: | Age of farmer:<br>Age of spouse : | Gender of farmer: M/F<br>Gender of spouse: Male | Photogrph |
| **What is(are) the CA technology(ies)/ intervention(s) you are using/ testing?** ***(please provide full description):*** | | | |
| **How did you come to know about the CA technology (ies):** | | | |
| **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.* | | | |
| What have been the key challenges/ issues you encountered in relation to the use of the CA technology (ies) ? | | | |
| What do you think are the solutions to these challenges/ issues? | | | |
| Will you continue to use/ adopt the technology(ies)? Why or why not? | | | |
| Any good anecdote(s) by the farmer (male or female) and his/ her family members : | | | |

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# Socio-economic Impact of Conservation Agriculture

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Conservation agriculture (CA) defined as minimal soil disturbance (no-till, NT) and permanent soil cover (mulch) combined with crop 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- genetic Plain ranked fifth in the world in adoption of Zero Till technology (Hobbs *et al*. 2005)

While CA maintains a permanent or semi-permanent organic soil cover, this can be a growing crop on 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 tillage and conservation agriculture is mentioned as under:

A comparison of traditional tillage (TT), 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 |
| Alter infiltration | The 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 |
| 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 | High | Intermediate | Much reduced |

| Issues | Traditional tillage (TT) | Conservation tillage (CT) | Conservation agriculture (CA) |
|---|---|---|---|
| Production costs | Maximum | Intermediate | Minimum |
| Timeliness | Operations can be delayed | Intermediate timeliness of operations | Timeliness of operations more optimal |
| Yield | Can be lower where planting is 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. Thirdly, it fails to account for changes in production that would accrue without the project and thus, it may over estimate the benefits of the project.

## Technical Data Collection

It is very important to collect and analyse 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 2014).

**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.

**Table 1. Input cost differential in rice cultivation in IGP region-adopters vs. non-adopters (in Rs.)**

| Particulars | Bihar | | Haryana | | Punjab | | Uttar Pradesh | |
|---|---|---|---|---|---|---|---|---|
| | Adopter | Non adopter | Adopter | Non adopter | Adopter | Non adopter | Adopter | Non adopter |
| Human & 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 cost | 13367 | 14706 | 16177 | 17506 | 14741 | 16259 | 12169 | 13477 |
| Productivity (t/ha) | 4.0 | 3.9 | 5.0 | 4.8 | 5.4 | 5.0 | 4.3 | 4.1 |

**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 manufactur-

ers, etc.) for transfer of technologies will play a pivotal role in accelerating adoption of new interventions.

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# Extent of Adoption and Effectiveness of Conservation Agriculture Technologies

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Soil is one of the most important natural resource for survival of human being. It supports the production process by supplying nutrients to different crops. Erosion of soil is a natural process caused by various factors viz. running water, winds, coastal waves and glaciers. During last few decades, it has become a serious problem due to increased human interferences. Soil erosion in India is widespread and a serious problem. Among two main agents of erosion namely water and winds in India about 90 per cent role is played by water. Soil erosion on agricultural land is also a major challenge in our country. Much of soil erosion in India is caused by faulty practices of farming. The most outstanding among these are faulty ploughing, lack of mulching and above all, the practice of shifting cultivation. Conservation agriculture (CA) is one of the soil and water conservation method adopted by many across the world. Conservation Agriculture is a farming system that maintains a permanent soil cover to assure its protection, avoids soil tillage, and cultivates a diverse range of plant species to improve soil conditions, reduce land degradation and increase water and nutrient use efficiency. It includes a range of soil management practices that minimise effects on composition, structure and natural biodiversity and reduce erosion and degradation. Largely, the conservation agriculture practices include:

(i) Direct sowing/ no-tillage, reduced tillage/minimum tillage,
(ii) Surface- incorporation of crop residues, and
(iii) Establishment of cover crops in both annual and perennial crops.

These concepts relates to improve soil health condition but do not refer the farm income. To integrate farm income and soil health through conservation agriculture, the Food and Agriculture Organization (FAO), has focussed on this concept as resource-saving agricultural crop production. As per FAO definition (FAO, 2009), the Conservation Agriculture is to:

(i) Achieve acceptable profits,
(ii) High and sustained production levels, and
(iii) Conserve the environment.

It further argues that conservation agriculture is based on enhancing natural biological processes above and below the soil surface. These go beyond zero-tillage and provide a range of technology and management options. Conservation agriculture practices are applicable to virtually all the crops, including cereals, horticulture and plantation crops. However, these are more popular in maize, soybean, rice and wheat. The conservation agriculture practices promises tremendous potential for different soils and agro-ecological systems. These are neutral to size of holdings but their adoption is most urgently required by smallholder farmers to reduce their cost of production, increase profit, and save resources (Derpsch, 2008).

## Information Needs of Farmers for Adoption of CA Technologies

Adoption of improved 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 and 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 appreciation 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.

## Adoption and Effectiveness of Conservation Agriculture Technology

Globally, CA is being practiced on about 125 M ha acre (Table 1). The major CA practicing countries are USA (26.5 M ha), Brazil (25.5 M ha), Argentina (25.5 M ha), Canada (13.5 M ha) and Australia (17.0 M ha). In India, CA adoption is still in the initial phases. Over the past few years, adoption of zero tillage and CA has expanded to cover about 1.5 million hectares (Jat *et al*. 2012; www.fao.org/ag/ca/6c.html). The major CA based technologies being adopted is zero-till (ZT) wheat in the rice-wheat (RW) cropping system of the Indo-Gangetic plains (IGP). In other crops and cropping systems, the conventional agriculture based crop management systems are gradually undergoing a paradigm shift from intensive tillage to reduced/zero-tillage operations. In addition to ZT, other concept of CA need to be infused in the system to further enhance and sustain the productivity as well as to tap new sources of growth in agricultural productivity. The CA adoption also offers avenues for much needed diversification through crop intensification, relay cropping of sugarcane, pulses, vegetables etc. as intercrop with wheat and maize and to intensify and diversify the RW system. The CA based resource conservation technologies (RCTs) also help in integrating crop, livestock, land and water management research in both low and high potential environment.

**Table 1. Global adoption of conservation agriculture systems**

| Country | Area (M ha) | % of Global Area |
|---|---|---|
| USA | 26.5 | 21.2 |
| Brazil | 25.5 | 20.4 |
| Argentina | 25.5 | 20.4 |
| Australia | 17.0 | 13.6 |
| Canada | 13.5 | 10.8 |
| Russian Federation | 4.5 | 3.6 |
| China | 3.1 | 2.5 |
| Paraguay | 2.4 | 1.9 |
| Kazakhstan | 1.6 | 1.3 |
| Others | 5.3 | 4.2 |
| **Total** | **124.8** | **100.0** |

*Source:* FAO, 2012.

In India, efforts to adopt and promote conservation agriculture technologies have been underway for nearly a decade but it is only in the past 8 – 10 years that the technologies are finding rapid acceptance by farmers. 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. 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-ecological regions like rainfed semi-arid tropics and the arid regions of the mountain agro-ecosystems.

In India's rice–wheat systems, adoption of ziro-tillage (ZT) is primarily limited to the wheat crop and concentrated in the NW IGP. The rice-wheat consortium (RWC) used to compile on an annual basis estimates of the scale of adoption of various resource conserving technologies (Gupta 2004, RWC 2004; www.rwc.cgiar.org). These estimates are primarily expert estimates at the state level using a range of indicators. Estimates of ZT area are often based on the sales of ZT drills and average area coverage per drill (Malik *et al*. 2005). In these estimates, it is problematic to separate ZT from reduce tillage (RT) so that these two technologies are typically lumped together (ZT + RT). These estimates also primarily reflect tillage level and the use of ZT drill for individual crops-without explicit consideration of crop residue management.

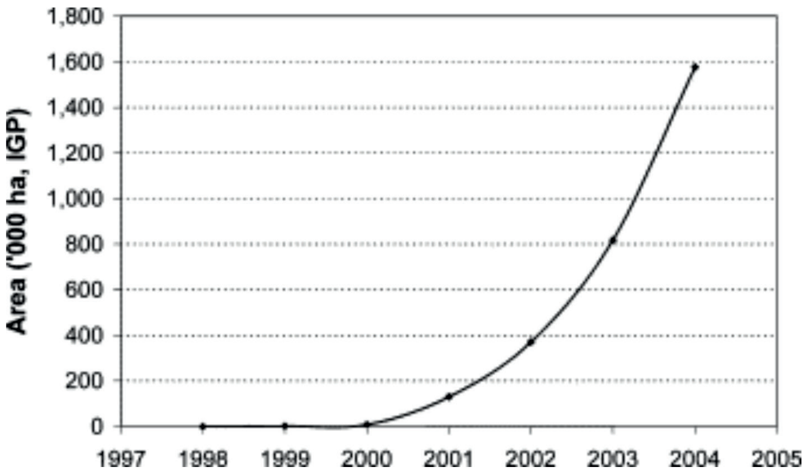


**Fig. 1.** Estimated diffusion of ZT + RT in Indian IGP. (Source: Erenstein and Laxmi, 2008)

Fig. 1 highlights the acceleration of the diffusion of ZT + RT over the recent years. In the second half of the 1990s, the technology was primarily in its testing phase, with farmers' interest in the NW IGP driven by late planting, herbicide resistance, and labor scarcity. With the turn of the century the diffusion started to pick up, aided by the demonstration effect of early adopters and the participatory research for development initiatives by the consortium of international, national and state research organizations, private manufacturers and input agencies including farmers.

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. In addition, raised-bed planting and laser land levelling are also being increasingly adopted by the farmers of the north-western region.

Currently, 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 levelling, residue management practices, alternatives to the rice-wheat system etc.

## Factors Affecting Adoption of CA Technologies

Adoption of CA technologies depends on many important factors. These factors can be associated with the economic parameters like costs and returns, socio-economic characteristics of farmers, farm characteristics, information channels used, biophysical and technical factors and social factors.

**(i) Economic factors:** Several studies across the globe has pointed out that economic factors such as cost of technology, increase in yield, higher profit, reduced cost of cultivation influences the adoption rate of CA technologies. Use of CA reduces the machinery and fuel cost since it involves minimum tillage.

Labour cost is also significantly reduces under CA as compared to Conventional agriculture. Over a period of time, yield of crops under CA increases to a limited extent as compared to conventional system.

(ii) **Farmers' characteristics:** Rate of adoption of any technology varies from farmer to farmer. Awareness of farmers or perception of soil problems in field is frequently found to be positively correlated with CA Adoption. Education level of farmers, their experience in agriculture and sometimes age can also influence the decision to adopt or non adoption of technology.

(iii) **Farm Characteristics:** Farm size is an important factor which generally correlates positively with CA adoption. The presence of soil erosion and other problems of soil in a farm also have positive correlation with adoption of CA technologies. Whether the farm is owned by farmers or is a rented one also affects the adoption rate.

(iv) **Information channels used:** A farmer must be aware about the benefits of CA technologies in order to adopt it. Different information sources *viz.* mass media, individual farmers, extension officers, meetings etc, their availability on time and their credibility influences the adoption rate.

(v) **Biophysical and Technical factors:** The technical factors like characteristics and availability of CA technologies in time are crucial factors for adoption. Biophysical factors such as soil type, rainfall, topography, wind direction etc also can influence adoption in positive or negative manner.

(vi) **Social factors:** CA technology adoption many times can reflect societal interest. Even if, it reduces profitability of farmers, it may be adopted on a large scale just to improve the quality of soil of that area. Availability of social institutions *viz.* SHGs, cooperatives etc can positively influence the adoption of CA technologies.

## Problems in Adoption of CA Technologies

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

1. The old mindset of farmers who were educated extensively and convinced about the intensive agriculture and use of external inputs. In the past, farmers also have realised huge economic benefits by intensive agriculture practices.
2. A complete shift from intensive tillage to zero or minimal tillage needs extensive educational programme for farmers by demonstrating the benefits accrued by conservation agriculture.
3. Higher cost of machines and implements is a major problem. Farmers in the Indo-Gangetic plain are small and poor, thereby may not immediately shift from the existing or available machines to the conservation agriculture machines.
4. 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.

5. Lack of skills development among farmers is another constraint 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.
6. 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.
7. 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.

## Strategies and Policies

Conservation agriculture requires a radical change from traditional agriculture. There is need for policy analysis to understand how CA technologies integrate with other technologies, and how policy instruments and institutional arrangements promote or deter CA. Efforts are required to adapt the CA principles and technological aspects to suit various agro-ecological, socio-economic and farming systems in the region started a few decades ago. Greater support from stakeholders including policy and decision makers at the local, national and regional levels will facilitate expansion of CA and help farmers to reap more benefits from the technology.

Developing, improving, standardizing equipment for seeding, fertilizer placement and harvesting ensuring minimum soil disturbance in residue management for different edaphic conditions will be key to success of CA. Moreover, there is a need for generating a good resource database with agencies involved complementing each others' work. Besides resources, systematic monitoring of the socio-economic, environmental and institutional changes should become an integral part of the major projects on CA.

Policy support for capacity building by organizing training on CA is needed. Availability of trained human resources at ground level is one of the major limiting factors in adoption of CA. Training on CA should be supported at all levels. Also, adopters of CA improve the environment through carbon sequestration, prevention of soil erosion or the encouragement of groundwater recharge. It provides ecosystem services, thus, farmers could be rewarded for such services, which have a great impact on the quality of life for all.

## 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. In view of huge expected benefits, as witnessed during the green revolution period, the conservation agriculture should be aggressively promoted. The advantage of this technology is easy adaptability in heterogeneous agro-ecological and socio-economic environment. The need is aggressive demonstration and information dissemination programmes well complimented by skill development of the farmers. Appropriate institutional arrangements are needed to be evolved so that small and marginal farmers who may not afford to maintain the machines and other equipments for practicing conservation agriculture may get alternative. 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. 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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# Bio-Stimulants: An Approach towards Conservation Agriculture

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The decline of natural resources and environmental misbalance inflicted by current agricultural practices has posed a severe challenge to the sustainability of food and nutritional drift. Global population has been constantly rising (1.13% per annum), resulting in the steady demand for food. The adverse impact of ecological threats as a result of the non-judicial use of chemical fertilizers and pesticides, the sustainable management of soil fertility has become a major concern now a day (Wezel *et al*. 2014). Undesirable changes in soil biological and chemical properties have not only questioned the sustainable food production but alarming malnutrition too. Apart from this, the changing climatic scenario has added huge unforeseen costs in cultivation practices. Today growing food is much costlier economically and environmentally than the last decades. To combat with such situations cost effective and environmentally friendly agricultural practices are essential. In such context, biostimulants are a viable alternative.

Biostimulant is an organic material neither a plant nutrient nor a pesticide but has a positive impact on plant health when applied in small quantities. The level of response from biostimulants cannot be attributed to the application of traditional plant nutrients (Gallant 2004). Biostimulant consists of various substances and microorganisms (microbial inoculants, fulvic acid humic acid, seaweed extracts, trace minerals, protein hydrolysates, amino acids), which have found to be effective in enhancing plant growth (du Jardin 2012; Calvo *et al*. 2014).

## Bio-stimulant and its Importance in Production Enhancement

Biostimulants are mixtures of one or more things such as microorganisms, trace elements, enzymes, plant hormones, and seaweed extracts rather a chemical fertilizers, meant to correct a severe nutrient deficiency. It has shown to influence several metabolic processes such as photosynthesis, respiration, ion uptake and nucleic acid synthesis. Biostimulants enhance nutrient availability, increase antioxidants, enhance metabolism water-holding capacity, and increase chlorophyll production. Besides many advantages, the use of biostimulants in agricultural practices is proposed as a safe tool to enhance the nutritional properties of food crops.

Agricultural biostimulants comprise diverse formulations of substances, compounds, and microorganisms that are applied to plants or soils to improve crop vigor, quality, yield and tolerance to abiotic stresses. It promotes plant growth and development throughout the crop life cycle from germination to maturity in a number of established ways. Better germination and root development, greater vigor and stress resistance, more efficient energy and nutrient uptake and transport are possible through the use of biostimulants (Fig. 1). By improving the efficiency of the plant's metabolism to induce yield increases and enhanced crop quality it helps in increasing plant tolerance to abiotic stresses and recovering from stresses; facilitates nutrient assimilation, translocation and use; enhances quality attributes of produce, *viz*. sugar content, colour and fruit seeding; enhances soil fertility, mainly by fostering the growth of complementary soil micro-organisms.

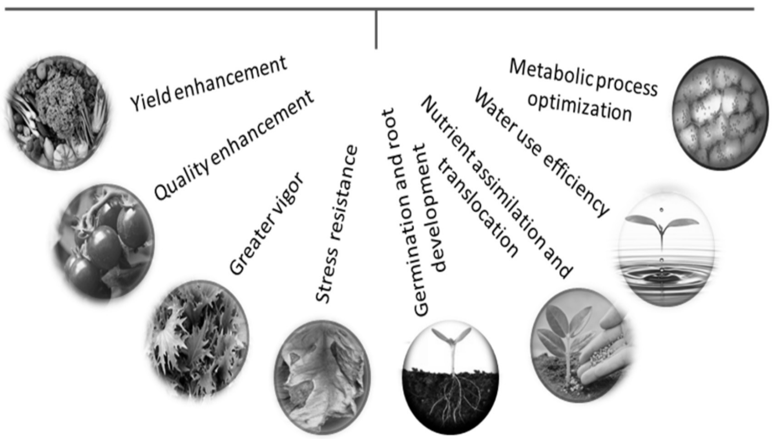


**Fig. 1**. Benefits of bio-stimulant in Crop production

Biostimulants are established as environment-friendly compounds having beneficial effects on plants (Schiavon *et al*. 2008). In particular, they decrease the use of chemical fertilizers by escalating the amount of macro- and micro-nutrients taken up by plants, positively influencing root morphology and plant growth (Nardi *et al.* 2009; Ertani *et al*. 2013). They exhibit hormone-like activity and influence plant metabolism through interacting with the biochemical processes. The manipulate physiological mechanisms, such as nitrogen assimilation and glycolysis to enhance plant quality parameters (Ertani *et al*. 2009). The mechanisms behind the biochemical and physiological effects of biostimulants on vegetable are often unidentified. It is because of the heterogeneity of the raw materials constituents used for vegetable production. These effects are influenced by many components that may act synergistically in different ways. Current studies suggest that the active molecules in biostimulants can promote assimilation of nitrogen through stimulation of the activity and transcription of nitrogen assimilation and Krebs' cycle enzymes (Schiavon *et al*. 2008). The induction of the metabolic pathway linked with the synthesis of phenylpropanoids in plants treated with biostimulants may explain the reason behind the plants to overcome stress situations (Ertani *et al*. 2013).

Pepper is an important agricultural crop known for the nutritional value. It is an excellent source of a wide range of phytochemicals with renowned antioxidant properties. The major antioxidant compounds include capsaicinoids, carotenoids, and phenolic compounds, particularly quercetin, flavonoids and luteolin. In recent studies, the application of certain biostimulant to pepper plants was found to exert affirmative effects on plant growth and yield devoid of fruit quality degradation (Azcona *et al*. 2011). Biostimulants improve nutrient availability at root rhizosphere, enhances water-holding capacity, increases antioxidant activities proliferate metabolism and chlorophyll production (EBIC 2013). It distinguish themselves from traditional crop inputs in three ways: (i) operates through different mechanisms than fertilizers, no matter the presence of nutrients in the products, (ii) act only on the plant's vigour and do not have any direct actions against pests or disease, (iii) plays a complementary role in cropping nutrition and crop protection (EBIC 2013).

## Categories of Plant Biostimulants

The biostimulant includes a diverse group of products, technologies that have different modes of action and are derived from naturally occurring microorganisms, plant extracts, or other organic matter. Worldwide the biostimulants active ingredient sources are majorly classified in three as Humic acid and fulvic acid (51 %), Seaweeds extracts (37%) and microbes, chitin and plant extracts (12%) (Fig. 2). In this section, we are going to discuss the ingredients each in details.

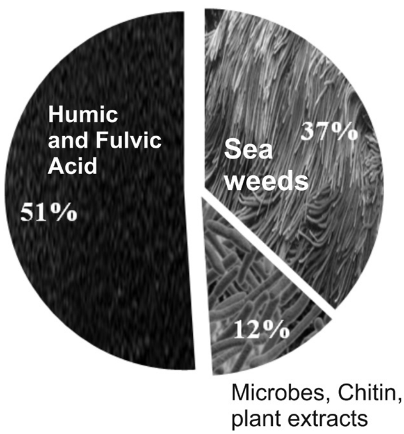


**Fig. 2.** Biostimulants active ingredient sources

## Humus and Humic Acids

Humic substances are natural elements of the soil organic matter, consequential to the decompositions of the animal, plant and microbial residues as a result of the metabolic activity of soil microbes by means of these substrates. The best sources of humic acids are found in layers of Leonardite. It is organic matter alike the soft brown coal but differs by its degree of oxidation. Both the humic acid and fulvic acid have been shown to possess an affirmative impact on plant growth through providing an effective growing environment for plants by increasing surface water infiltration, penetration, and soil water-holding capacity. They also enhance the availability of phosphorus potassium and some essential micronutrients (Gallant 2004). Humic acids play an important role in physiological and morphological effects on plants (Eyheraguibel *et al*. 2008) The Humic acids retain nutrient ions and thus prevent them from leaching. They also act as a buffer for plants from too high concentrations of fertilizer salts. Other than these the humic acids have been shown to boost germination rates and promote greater fibrous root growth (EBIC 2013). Biostimulants act in synergy with plant nutrients. The application of humic acid and nitrogen in combination has promoted better root growth than with only nitrogen. They also enhance chlorophyll content of plant leaves and improve stand uniformity by influencing metabolism.

**Fulvic acids**

The fulvic acids are a kind of humic substances recognized to be powerful organic electrolytes which help to dissolve soil minerals and metals (Huang and Deller 1970). Fulvic acids transform minerals to readily available form for easy absorption by plants (Jackson, 1993). They act more in the plant than in the soil and enhance vitamins, coenzyme, auxin, nutrient, and metabolism, which help significantly to plant health. Furthermore, the fulvic acids help plants to resist wilting indirectly by raising the amount of carbohydrates results in soluble sugars accumulation in the cell. To deal with drought stress, they increase the osmotic pressure on the cell walls. Finally, fulvic acids help to enhance the nutrient uptake by increasing the permeability of the cell membrane.

**Cytokinins**

Cytokinins promote cell division in plants. They have been reported to promote cell expansion, enlarge leaf surface area that results in more chlorophyll production and amplified photosynthesis. A low concentration of cytokinins has been used as a seed treatment to promote lateral root development in young seedlings (Laplaze et al. 2007; Werner *et al*. 2010). They also have the ability to promote nutrient translocation within plants which is responsible for increased plant metabolism (Chang 2013).

**Protein hydrolysates and other N-containing compounds**

Protein hydrolases are actually amino acids and peptides mixtures which are obtained by enzymatic and chemical protein hydrolysis produced from agro-industry as by-products, from both animal (e.g. epithelial tissues, collagen) and plant sources (crop residues) (Calvo *et al*. 2014; Halpern *et al*. 2015). In biostimulants some other nitrogenous molecules like polyamines, betaines, and 'non-protein amino acids' (Vranova *et al*. 2011). Protein hydrolysates are established for having a role in increasing microbial biomass and activity, soil respiration and thus overall soil fertility. Significant improvements in yield and quality traits have been reported in agricultural and horticultural crops (Calvo *et al*. 2014). A number of commercial products prepared from protein hydrolysates of animal and plant origins are available in the European market (Table 1).

**Table 1. Examples of commercialized Bio-stimulants and there use in vegetable disease management**

| Products | Product Origin | Manufacturer | Crop | Disease targets |
|---|---|---|---|---|
| Vacciplant ® | Laminarian extract from brown algae, *Laminaria digitata* | Laboratoire Goemar, France | Tomato | Bacterial spot, Bacterial speck, Grey mould, Powdery mildew, Phytophthora blight, early blight, Anthracnose |
| | | | Egg plant | Powdery mildew, Phytophthora blight |
| | | | Cucurbits<br>-Zucchini<br>-Cucumber<br>-Watermelon<br>-Melon | Powdery mildew, Phytophthora blight |
| | | | Leafy Vegetable<br>-Lettuce<br>-Spinach | Downy mildew<br>Grey mould |
| | | | Cabbage | Downy mildew<br>Grey mould |
| Elexa® 4PDB | Chitosan based natural product | Plant Defence Boosters Inc., USA | Cucumber, Melon, pumpkin, Squash | Downy mildew<br>Powdery mildew |
| | | | Peas | Powdery mildew |
| Milsana® | Alcoholic extract from dried plant part of a weed giant knotweed (*Reynoutria sachalinensis*) | KHH Bioscience, USA; BIOFA AG, Germany | Green house as well as open field Cucumber | Powdery mildew |
| | | | Tomato and pepper | Powdery mildew |
| ChitoPlant ® | Chitosan based natural product | ChiPro GmbH, Germany | Tomato<br>Potato | Powdery mildew<br>Scab |
| | | | Cucurbits | Downy mildew |

## Beneficial bacteria

Biostimulants, in agriculture point of view, can be considered of two types within the taxonomic, functional and ecological diversity: first mutualistic endosymbionts like Rhizobium and second mutualistic, rhizospheric like PGPRs ('plant growth-promoting rhizobacteria'). Rhizobium and related taxa are commercialized as biofertilizers. The PGPRs are multifunctional and influence all aspects of plant life: morphogenesis and development, nutrition and growth, interactions with other organisms in the agroecosystems, response to biotic and abiotic stress etc. (Bhattacharyya and Jha 2012; Gaiero *et al.* 2013; Vacheron et al. 2013). Plant growth promoting rhizobacteria (PGPR) are now increasingly applied in vegetable crops (Table 2). PGPR inoculants are nowadays regarded as some type of plant 'probiotics', *i.e*. efficient contributors to plant nutrition and immunity (Berendsen et al. 2012). Plant growth-promoting rhizobacteria (PGPR) is such group of microorganisms act as bio-stimulant in a wide range of soil and plant interactions include improvement in the availability of nutrients, production of volatile organic compounds, hormone release or hormonal changes within plants and enhancement of tolerance to abiotic stresses and much more. Beside these low cost, easy access and simple mode of application have attracted the agrarian stakeholders.

**Table 2. Plant growth promoting rhizobacteria (PGPR) application in vegetable crops:**

| PGPR spp./strain | Crop | Effect on plant growth | References |
|---|---|---|---|
| *Rhizobium und Nicola; Rhizobium* spp. *Mesorhizobium, R. leguminosarum, Bradyrhizobium, Sinorhizobium meliloti* | Broccoli, carrot, lettuce | Increased yield, enhanced macro and micronutrient uptake, | Yildrim *et al*. (2011), Bhagat *et al*. (2014), Ghosh *et al*. (2015), |
| *Azotobacter chroococcum, Azotobacter* spp. *A. vinelandii Azospirillum lipoferum, A. brasilense,* | Cucumber, lettuce | Increased germination, increased length and weight of roots, improved vigor index of germinating seeds | Fasciglione *et al*. (2012), Mangmang *et al*. (2015), |
| *Pseudomonas P. aeruginosa, fluorescens, P. putida, Pseudomonas* sp. | Broccoli, cucumber, lettuce, | Enhanced nutrient uptake, increased plant growth, increased dry matter and mineral content of fruits, increased yield in terms of number of fruits and weight | Kohler *et al*. (2009), Dursun *et al*. (2010), Tanwar *et al*. (2014) |
| *Achromobacter xylosoxidans, Stenotrophomonas maltophilia, Achromobacter* sp., *A. xylosoxidans* | Cucumber, potato | Increased plant height, dry weight, fruit yield, tuber dry matter | Egamberdieva *et al*. (2011), Dawwam *et al*. (2013) |
| *Bacillus subtilis, B. Megaterium, B. cereus, B. amyloliquefaciens, Bacillus* sp. | Cucumber, pepper | Induced systemic tolerance to drought stress, increased root vigour, increased fresh root and shoot weight and their length | Wang *et al*. (2012), Kokalis-Burelle *et al*. (2002), Lim and Kim (2013) |

## Factors contributing toward the expansion of the biostimulants market in the world

- Rising global population and food demand
- The need for sustainable increase the crop yield

- To minimize the abiotic stress in plants
- The growing concerns about sustainable agriculture
- Eco-friendly properties of biostimulants over pesticides and fertilizers
- The increase in government grants and funding to encourage the use of bio-stimulant products
- Proven performance and acceptance from NGOs, governmental bodies, and academia.
- The rising awareness regarding the use and benefits of bio-stimulants
- The growing popularity of natural and organic ingredient-based agriculture
- Effort on the part of the market players to develop cost-effective products
- Demand from farmers and consumers for environmentally safe and organic products that provide alternatives to synthetic inputs.

There are two indispensable factors for effective adoption of any particular technology knowledge about technology and compatibility of the technology which local condition. This is true for biostimulants too. The knowledge factor can be taken care of through research in applications of biostimulants in vegetable crops. Types of vegetable crops covered with concentration etc. Agronomic field research in vegetable crop particular to Indian condition is very less which needs to be promoted.

The compatibility of a technology depends on several other factors such as the cost of the product, ease of application and efficiency. For that purpose, a detailed studies are required for (i) long-term survival and good self-life biostimulant, specificity in applications in a wide range of agro-ecological conditions in the vegetable crop; (ii) cost reduction mechanisms (iii) suitable conditions dosage, concentration (iv) farm machinery applications of biostimulants.

## Conclusions

In order to enhance the sustainable food production, food and nutritional security with a significant reduction of synthetic fertilizers, agrochemical use and environmental pollution, natural resource productivity enhancement through the use of biostimulants in the vegetable is essential. It promotes plant growth and development throughout the crop life cycle from germination to maturity in a number of established ways. Better germination and root development, greater vigor and stress resistance, more efficient energy and nutrient uptake and transport are possible through the use of biostimulants. India is larger imports of plant biostimulants. For better adoption of biostimulants research and extension both are required. Especially the knowledge and awareness about the biostimulants technology and compatibility of the commercial product which Indian farmers' condition are necessary.

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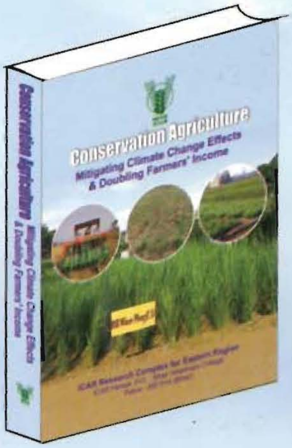


## Conservation Agriculture Mitigating Climate Change Effects & Doubling Farmers' Income

Unsustainable use of land in tillage-based conventional agricultural system and excessive use of external inputs to increase food production has lead to the degradation of natural resources, biodiversity and environment. Conservation Agriculture has been identified as one of the technical options to meet the global challenges of increasing food production and conserving environment, thereby improving food and nutritional security and alleviating poverty. To address the issues of tillage-based conventional agricultural system and enhance the knowledge base of the researchers, policy makers and other stakeholders, and further to expose them to the developments in conservation agriculture and climate change for climate resilient agriculture and increasing farmers' income, Ministry of Agriculture, Government of India, sponsored Model Training Course on 'Conservation Agriculture: Mitigating Climate Change Effects & Doubling Farmers' Income' was organized at ICAR Research Complex for Eastern Region, Patna during 11-18 September 2018.

The present book entitled **'Conservation Agriculture: Mitigating Climate Change Effects & Doubling Farmers' Income'** is the outcome of compilation of lecture notes/book chapters of above training course. This book contains 34 chapters dealing with the conservation agriculture and climate change for climate resilient agriculture and increasing farmers' income 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. We firmly believe that this publication will prove to be highly useful to the researchers, policy makers, students and all those who are engaged in the task of sustainable agricultural development in the region.

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