System Based Conservation Agriculture

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Foreword

The challenge of ever increasing pressure on agricultural/arable lands for producing more with less has encouraged the adoption of conservation agriculture (CA) in India. The economization of resources through efficient use under CA not only reduces the cost of cultivation but also benefits the environment. The trend of depleting natural resources under conventional agricultural systems could be favourably reversed to the soil organic carbon build up, lesser fuel consumption and higher water productivity. A diversified cropping system under CA improves soil biodiversity, resists insect-pest-disease outbreaks, and prevents deterioration of natural resource base. The significance of wide-scale adoption of CA becomes more pertinent when we are at the verge of facing serious threats like declining partial factor productivity, climate change, and land degradation.

Globally 157 million hectare area, which constitutes 10.9% of the total arable area is currently under CA. There are enough research evidences which show this huge shift towards adopting conservation systems ensures soil health and production quality improvement brought through enhanced soil biological processes, indigenous nutrient supplying capacity and organic recycling. On the other hand, the emerging issues like nutrient stratification, misalliance of farm machinery and weed shift under CA need to be scientifically addressed. Further, CA technologies would also have to be standardized for specific crops under diverse ecologies in cropping system perspectives. Likewise, fabrication of appropriate machines can overcome the biasness of clean cultivation and constraints in adoption of CA technologies.

A remarkable success has been made in developing CA technologies for rice-wheat cropping system in Indo-Gangetic Plains of India, but the location-specific most critical intervention to break yield barrier through resource conservation technologies is still lacking. This book is a perfect compilation of consorted efforts of various researchers done in the direction of development, standardization and dissemination of the refined CA technologies. The emerging concerns of environmental unsustainability raised in the book necessitates the development of a policy framework promoting CA. I strongly believe that the book would be of great value to various stakeholders in addressing the goals of achieving sustainable agricultural systems through conservation agriculture.

Arvind Kumar

Preface

Conservation agriculture (CA) benefits agro-ecosystems by improving soil health and preserving biodiversity. Facilitation of good agricultural practices *viz.* land preparation, crop establishment, water management and stress management etc. through conservation agriculture ensures environmental safety and resource savings. Agricultural production intensification through diversified cropping systems and integration of various enterprises under CA could offer economically viable options for more than 86% small farm holders of the country. The minimum soil disturbance due to controlled traffic promotes biological tillage. An established CA system could address the emerging issues of nutrient imbalance and reliance upon the external organic inputs. The principles of CA are universally applicable, however its implementation through the set of practices has to be standardized in situation and cropping system perspective. Since, CA in India is still in its nascent stage, through this book, the authors have made an attempt to suggest the possible package for wide scale adoption of CA.

The chapter 1, compares the scope and significance of adoption of CA in India with the global scenario. The chapter 2, 3, 4 and 5 discuss the nutrient dynamics, management alterations as per CA principles with both macro and micro nutrients perspectives. The chapter 6 and 7 carries a comprehensive assessment of water use, its efficiency and the possible ways to augment water productivity under CA. The chapter 8 has focused upon the differences to be considered at the time of weed management under CA as the weed expression, growing pattern and seed dispersal mechanism is altogether different than conventional systems. The chapter 9 discusses the role of mechanization and the need for suitable modifications in the existing machinery in terms of residue management and challenges offered in sowing with zero tillage. The chapters 10, 11 and 12 have focused that if CA technologies need to be up-scaled in wider domain, it has to be standardized for wider crops including pulses and oilseeds and also to the different soil types. The development of decision support system and soil quality indices for evaluation of CA based systems in long-term perspectives has been discussed in the chapter 13, 14 and 15. The higher on-farm resource use efficiency and by-product recycling through integrated farming system and organic farming for targeted crops and areas with CA principles for livelihood security on a sustainable basis has been discussed in chapter 16 and 17. The concluding chapters have shown the enhanced long-run profitability due to reduced inputs, higher resource use efficiency and higher economic returns due to stable yields.

We express our sincere gratitude to Dr. Trilochan Mohapatra, Secretary (DARE) & Director General, Indian Council of Agricultural Research (ICAR), New Delhi for his kind patronage and keen interest in conservation agriculture. During the process of compilation of this information, the continuous encouragement extended by Dr. A.K. Singh, (Director, Indian Agricultural Research Institute, New Delhi and Deputy Director General, Agril. Extension, ICAR) and Dr. Arvind Kumar, Vice-Chancellor, Rani Lakshmi Bai Central Agricultural University, Jhansi (Ex. Deputy Director General, Agril. Education, ICAR) was a great source of inspiration to us. In fact, this publication is the improved version of lectures delivered during the winter school "System based conservation agriculture" by selected resource persons/ subject matter specialists. We place our sincere thanks to all the contributors for their timely action for improving their write up as per requirement. The help extended by Drs. Kapila Shekhawat (Senior Scientist, Agronomy), Pravin Kumar Upadhyay and Rishi Raj (Scientist, Agronomy) in proof reading is thankfully acknowledged. We assume that our efforts in the form of this publication will be useful to all the stake holders involved in agricultural production in general and conservation agriculture in particular.

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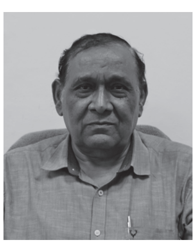
About the Editors

Dr. V.K. Singh, is Head, Division of Agronomy at ICAR-Indian Agricultural Research Institute, New Delhi. Prior to this he was ICAR National Fellow and Principal Scientist at Indian Institute of Farming Systems Research, Modipuram. Dr. Singh had made significant contribution towards improving soil organic matters content and nutrient use efficiency in different cropping systems. Dr. Singh has made significant contribution in developing nutrient and water management protocols under conservation agriculture based system. In collaboration with international research organizations like IRRI, CIMMYT, ICRISAT, IPNI, TSI-FAI-IFA, Dr.V.K. Singh has generated findings of practical significance to restore the soil organic carbon and sustained productivity under different cropping systems. As ICAR-National Fellow, he explored the possibility of use of GIS in precision nutrient management under different cropping systems in Indo-Gangetic Plain. He has published more than 100 research papers in journals of repute, besides a number of review papers, popular article, bulletins and book chapters. Dr. Singh has excellent academic record, and is a recipient Fellow of Indian Society of Agronomy, NAAS Fellow/ Associate, NAAS Young Scientist Award – National Resource Managment (2005-06), Young Agricultural Scientist (Natural Resource Management) Award (2003-04) by UPCAR, PPIC-FAI Award-2004, IPNI- FAI award 2014, ISSS-Dr. J.S.P. Yadav Memorial Award for Excellence in Soil Science (2011), P.S. Deshmukh Young Agronomist Award-2001 by Indian Society of Agronomy and the Sriram Award and Dhiru Morarji Memorial Award by the Fertilizer Association of India.



Dr. B. Gangwar, Ex-Director of Indian Institute of Farming System Research, Meerut has served as Project Coordinator (Agronomy/Diaraland) for five years (1994-1999) and Principal Scientist (Agronomy)/programme Facilitator (Cropping System Management) for 10 years 2000-2009. He has served in various positions in Andaman-Nicobar Islands for 18 years. Dr. Gangwar is a recipient of Fakhruddin Ali Ahmad Award (1986-87) for outstanding agronomic contributions in remote area of Andaman & Nicobar Islands, Bharat Excellence Award for outstanding contributions in Agricultural Research and Management (2009) and Shriram Award (2002, 2010 & 2012). He has series of recognitions to his credit such as Fellow of Indian Society of Agronomy, Fellow, Indian Society of Coastal Agricultural Research, Fellow of Society for Recent Developments in agriculture and Honorary Fellow of Hi-tech Horticultural Society. Scientific contributions in his credit involving 118 research papers, 104 popular articles, 15 book chapters, 15 manuals, 15 research/extension bulletins and 33 edited publications.

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Conservation Agriculture: Global Status and Recent Trends in South Asia

H.S. Jat, M.L. Jat, Yadvinder Singh, R.K. Sharma, R.S. Chhokar and R.K. Jat

The 'Green Revolution' paradigm for production intensification in South Asia has been guided by improvement of genetic potentials of crops; high application of external inputs (nutrients, water, pesticides) and increased mechanization. The approach of 'more inputs- more output' is generally ecologically intrusive and economically and environmentally unsustainable, and has led to sub-optimal factor productivities and yield levels that are difficult and expensive to maintain over time. Conservation agriculture (CA) is a knowledge-intensive farming 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 (FAO, 2014). Conservation agriculture does not define a fixed set of practices, its principles are universal but implementation varies considerably depending on the context. It can include diverse practices such as livestock and fodder management, improved fallows, agro-forestry, watershed management, and community protected areas. There is no universal template for CA based management and production practices that are applicable to all farmers, but the actual practices employed for CA always require a process of refinement and localization to optimize system performance in different environments. Conservation agriculture fits within the sustainable intensification paradigm for preserving the natural resource base and its productive capacity over time. Thus, it is not intensification in the classical sense of greater use of inputs to obtain greater output but rather the intensification of knowledge, skills and management practices, and the complementary judicial and precise use of other inputs. In CA systems, outputs of desired products and ecosystem services are built on three interlocked principles of minimum mechanical soil disturbance, maintenance of permanent soil cover and diversified cropping system. The basic principles of CA are not location or cropping system specific but provide the foundation to tailor and integrate needed strategic crop management practices (seeders/implements, crop residue management, cultivars, weed, disease and pest control practices, fertilizer and irrigation management etc.) that must be developed, tested and modified as needed for application to a given crop production system. The CA principles supported by other “good agricultural practices” provide a sustainable ecological fundamental to any rainfed or irrigated production systems, thereby predisposing them to respond efficiently to any applied production inputs to achieve intensification. This approach does not attempt to have no impact on the environment, but to limit any footprint to a level below the natural environmental recovery capacity.

1. GLOBAL CONSERVATION AGRICULTURE STATUS

Conservation agriculture principles are universally applicable to all agricultural landscapes and land uses, with locally formulated/adapted practices. Currently, CA covers around 157 m ha of arable cropland globally (10.9% of cropland) in more than 50 countries. Argentina, Australia, Brazil, Canada and America constitute more than 90% of area under CA. Asian countries have seen considerable uptake of CA in the past 10-15 years, and since 2008/09, CA area is increased nearly threefold (291%), from around 2.7 m ha in 2008/09 to about 10.3 m ha in 2013 (Table 1). In 2008/09, CA area was reported in only two countries in the Asia region, but in 2013, CA area was reported in 11 countries. The current area under CA in India is around 1.5 m ha and is expanding rapidly (Table 1). In Central Asia, 2.0 M ha (12.5 % of crop area) are “real” CA with permanent no-till and rotation that puts Kazakhstan amongst the top ten countries in the world with the largest crop area under CA systems (Nurbekov *et al*., 2014). Area under CA in Syria and Iraq has continued to increase due to shortages of fuel (Piggin *et al*., 2015). In China, the adoption of CA increased during the last few years and the technology has been extended to rice production system (6.7 m ha). In South Asian Indo-Gangetic plains (IGP) extending across India, Pakistan, Nepal and Bangladesh, in the rice-wheat (RW) system, there is large adoption of no-till/zero-till (NT/ZT) wheat on about 5 m ha area but only modest adoption of permanent no-till systems and full CA (Kassam *et al*., 2015). The exception appears to be India, where the adoption of NT practices by farmers has occurred in the RW double cropping system, and also in the rainfed upland areas involving crops such as maize, cotton, pigeon pea and chickpea. In Indian context, NT with residue retention technology in RW system has been reported to help in adapting wheat to terminal heat effect which is an emerging concern globally in view of climate change (Jat *et al*., 2009). Conservation agriculture also provides an alternate approach to achieving sustainable intensification in low-input agriculture using traditional varieties and methods of maintenance of soil fertility. Conservation agriculture is an example of the agro-ecologically based sustainable intensification approach that requires lower amounts of all production inputs including energy, seeds, agro-chemicals, machinery, and time, and offers greater productivity than the non-CA counterpart systems of South Asia.

Table 1. Area under conservation agriculture in the world

Area in the World Continent	*Area (M ha)*
Asia	10.29
Africa	01.23
America	120.34
Europe	7.28
Oceania	17.86
Total	157.00 (10.9%)*
Area under CA with particular reference to Asia	
Middle East and Near East: Azerbaijan, Iraq, Lebanon, Syrian Arab, Republic and Turkey	0.09
Central Asia: Kazakhstan, Kyrgyzstan, Uzbekistan	2.00
South Asia: India	1.50
East Asia: China, DPR Korea	6.69

*Figures in parenthesis indicates the % of total crop land area; Conservation agriculture area (>30% ground cover) as a % of Agricultural Land.

Source: Anonymous, 2015

2. CONSERVATION AGRICULTURE BASED TECHNOLOGIES IN SOUTH ASIA

At the dawn of 21st century, the problem of food security with added challenges of natural resource degradation and climate change has further been surfaced and intensified with indiscriminate use of resources, sharp rise in the cost of production inputs, diversion of youth and capital from agriculture and shrinking farm holdings. In South Asia, the ever increasing population growth is interlinked with production challenges and the natural resources in the region are 3-5 times more stressed due to population, economic and political pressures compared to the rest of the world. In the region, the inefficient use and mismanagement of production resources, especially land, water, energy and agro-chemicals, has vastly impacted the health of the natural resource base and contributing to global warming led climatic variability. Studies by Sivakumar and Stefanski (2011) showed that there would be at least 10% increase in irrigation water demand in arid and semi-arid region of Asia with a 1°C rise in temperature. Thus, climate change could result in the increased demand for irrigation water, further aggravating resource scarcity. This will also increase the price of water for irrigation, making small-holder agriculture more risky venture. Moreover, while maintaining a steady pace of development, the region will also have to reduce its environmental footprint from agriculture. Considering these multiple challenges, agricultural technologies that promote sustainable intensification and adapting to emerging climatic variability yet mitigating GHG emissions (climate smart agricultural practices) are scientific research and development priorities in the region. There are a wide range of agricultural practices that have the potential to increase adaptive capacity of the production system, reduce emissions or enhance carbon storage yet increasing food production (Table 2). However, the magnitude of benefits of CA based technologies tends to be site and situation specific and cannot be overly generalized across farming systems and the regions.

Table 2. Potential benefits of the key interventions in terms of potential benefits, food security (FS), climate risk management (CR), adaptation (A) and mitigation (M) potential to conventional practices

Climate smart practices	*Potential benefits relative to conventional practices*	*FS*	*CR*	*A*	*M*
Laser land levelling (LLL)	Reduce GHG emissions, increased area for cultivation and crop productivity	x x	x x	x x	x x x
Zero tillage	Reduced water use, C sequestration, similar or higher yield and increased income, reduced fuel consumption, reduced GHG emission, more tolerant to heat stress	x x	x x	x x x	x x
Direct seeding of rice (DSR)	20-30 % Less requirement of irrigation water, time saving, better post-harvest condition of field, deeper root growth, more tolerance to water and heat stress, reduced methane (CH_4) emission	x	x x	x x x	x x
Alternate wetting and drying in rice (AWD)	Reduces methane (CH_4) emission by an average of 48% compared to continuous flooding, reduce irrigation requirement by 15-20%	x x	x	x x x	x x x
Crop diversification	Efficient use of natural resources (water, soil and energy), increased income, increased nutritional security, conserve soil fertility, reduced risk	x x x	x x x	x	x
Permanent raised bed planting	Less water use, improved drainage, better residue management, less lodging of crop, more tolerant to water stress	x x	x x	x x x	x x
Leaf colour chart (LCC)	Reduces fertilizer N requirement, reduce N loss and environmental pollution, reduced nitrous oxide emission	x x x	-	x	x x x
Nitrification inhibitors	Increase N use efficiency, reduce N loss and environmental pollution	x x	x	-	x x x
Green seeker	Optimize fertilizer N requirement, reduced N loss and environmental pollution, reduced nitrate leaching	x x x	-	x	x x x
Nutrient Expert-decision support tool	Optimize fertilizer requirement, reduced nutrient losses and environmental pollution, reduced GHG emission	x x x	-	x	x x x
Crop residue management/ mulching	Moderates soil temperature, improves soil quality, reduces soil erosion, reduces evaporation losses and conserves soil moisture, increases C sequestration, avoids burning and reduces environment pollution, increases tolerance to	x x	x x	x x	x x x

(Contd.)

Climate smart practices	*Potential benefits relative to conventional practices*	*FS*	*CR*	*A*	*M*
	heat stress, reduces weed infestation.				
Micro irrigation system	Increases water and nutrient use efficiency, reduces GHG emissions, increased productivity	x x	x	x x x	x x x
Agroforestry	Sequester carbon in the soil and prevent soil erosion, enhancing biodiversity, improve the ecosystem	x	-	x x x	x x x
ICT services to access weather and agro advisories	Vital source of information on climate change, weather forecasts, new seed varieties, climate smart farming practices and tips on CA, helps in overall behaviour change towards adapting to climate change and in the uptake of new practices and technology	x x	x x x	x	-

Source: Wassmann *et al*., 2009; Jat, 2014

Integration of these CA and precision agriculture (PA) based technologies and their interaction with farm management system acts as potential strategies to manage variability within and between fields for sustainability and conservation of the resources to boost farm profitability, making crop production resilient to changing climate. It also has the potential to reduce environmental footprint of agricultural production system for sustainable food security. Adaptation in the agricultural sector is being given a high priority within this effort because of the inherent sensitivity of food production to climate and the strong inter-linkages that exist between climate, agriculture, and economic growth and development. The purpose is to identify and summarize potential climate change impacts on agriculture in various regions, examine the causes of vulnerability, provide information on where investments are needed to better climate-proof agriculture, and describe the relevance of current efforts to achieve more sustainable agriculture to that of managing climate risks for adaptation.

3. CONSERVATION AGRICULTURE AND INDO-GANGETIC PLAINS

The IGP comprise one of the most productive agricultural land in South Asia, providing staple food for 400 million people, primarily through RW system practiced on 13.5 m ha . Yields of rice and wheat in this highly intensive system have stagnated and, in some cases, declined over the past few decades (Ladha *et al*., 2003). The UN Food and Agriculture Organization (FAO) estimates that South Asia will need to increase its cereal output by almost 50% over the next three decades to meet increasing demand; yet, given current projections of agricultural output and regional population growth, the region will have an estimated 22 mt cereal deficit by 2030. Deterioration of the natural resource base, over exploitation of ground water, loss of soil fertility and soil nutrient imbalances, and a build up of pests and pathogens are important factors contributing to diminished productivity of the RW system. This has to be reversed if the region is to meet the future food demand of the region. Conservation agricultural practices can contribute to making agricultural systems more resilient to climate change for experiencing the climate-proof agriculture. Adaptation in the agricultural sector is being given a high priority in South Asia because of the inherent sensitivity of food production to climate and the strong inter-linkages that exist between climate, agriculture, and economic growth and development. In South Asia the term ‘resource conserving technologies’ (RCTs) has been coined in 20th Century to improve resource or input-use efficiency (including water, air, fossil fuels, soils, inputs, and people) and provide immediate and demonstrable economic benefits such as reductions in production costs, savings in water, fuel and labour requirements and timely establishment of crops. Laser land levelling, bed planting, zero tillage, direct seeding rice (DSR), residue management, alternate wetting and drying (AWD) in rice, site specific nutrient management (leaf colour chart, Greenseeker, Nutrient Expert decision support tool) diversification/intensification, and alternate land uses/agroforestry are some innovative RCTs, which are able to quickly respond to critical needs that address the concerns (e.g. farm economics and climate change) faced by South Asian agriculture (Sharma *et al*., 2002; Ladha *et al*., 2009; Saharawat *et al*., 2012).

4. RESOURCE CONSERVATION TECHNOLOGIES: THE PROSPECTS IN SOUTH ASIA

The past experiences with resource conservation technologies especially adoption of ZT on large scale by the farmers in RW system in IGP indicates the benefits which needs to be extrapolated to other areas of the country as well as to cropping systems other than RW. The national programme has gradually graduated from intensive tillage to reduced tillage to ZT and now moving towards efficient management of crop residues so as to avoid crop residue burning which is causing environmental pollution leading to animal and human health problems. Adoption of CA practices is the need of the hour to reverse the trend in natural resource degradation and global warming. So far, the main focus was on one principle of the CA i.e. minimum soil movement/disturbance and to some extent on residue cover and diversification by integrating short duration green gram after wheat in RW system. Now, it is time to integrate all the components in more precise manner for increasing the input use efficiency while reducing the environmental footprints but not on the cost of food security. Some of the research evidences pertaining to South Asia are given here as under:

4.1. Tillage Management

Intensive tillage, especially wet tillage for growing rice, results in the decline of soil organic matter due to increased oxidation over time, leading to soil degradation, loss of soil biological fertility and resilience. Tillage costs money in the form of fuel for tractors, wear and tear of equipment, and the cost of the operator.

Greenhouse gas emissions from the burning of the diesel fuel add to global warming. Tillage exposes bare soil which is prone to wind and water erosion. The tractor wheels compact the soil below the surface. Cultivation practices such as ZT (which involves seeding directly into the soil instead of sowing on ploughed fields) conserves resources and enhances input-use efficiency (Chauhan *et al*., 2000; Sharma *et al*., 2004; 2005; Erenstein *et al*., 2008). In 2008, 20-25% of the wheat in RW system in three Indian states (Haryana, Uttar Pradesh and Punjab) was cultivated using minimum or zero tillage. The main driver behind the rapid spread of ZT wheat is the significant, immediate, identifiable and demonstrable economic benefits, and savings in water, fuel and labour requirements 'that makes adoption profitable corresponding with a 15-16% saving on operational costs (Erenstein *et al*., 2008). The yield effect, where it exists, is closely associated with enhanced timeliness of wheat establishment after rice. Wheat yield potential reduces by 1-1.5% per day of delayed planting after 20th November (Hobbs and Gupta, 2003). In spite of the success of the RW cropping system with ZT practices in irrigated agriculture in the IGP, the full environmental benefits offered by CA have yet to be fully realized (Gupta and Seth, 2007). Experimental data have shown that water saving with ZT in wheat could be 36%, on an average. Reduction of water use in first irrigation varied from 30-50% while for subsequent irrigations it ranged between 15-20%. Water use could be further reduced if ZT is used in combination with other technologies like raised bed planting and laser land levelling (Gupta and Seth, 2007). It has been reported that direct seeded rice (Kumar and Ladha, 2011) proved more cost effective, more water efficient, less labour intensive, and more eco-friendly (with lessening of methane emission). Other benefits included higher tolerance to water deficits, less cracking in soil, earlier crop maturity by 7 to 15 days, less incidence of insect-pest and diseases due to better aeration in crop canopy, and overall higher profits.

4.2. Efficient Water Management

With the increase in demand of water from allied sectors, agriculture must improve water use efficiency in irrigated ecosystem. Adding climate change to this mix only intensifies the demands on water use in agriculture. Climate changes will burden currently irrigated areas and may even outstrip current irrigation capacity due to general water shortages, but farmers with no or less access to irrigation are clearly most vulnerable to changed scenario. In South Asian region, the inefficient use and mismanagement of production resources, especially land, water, energy and agro-chemicals, has vastly impacted the health of the natural resource base and contributing to global warning led climatic variability. Studies (Sivakumar and Stefanski, 2011) show that there would be at least 10% increase in irrigation water demand in arid and semi-arid region of Asia with a 1°C rise in temperature. Water availability is expected to decline whereas global agricultural water demand is estimated to increase by about 19% in 2050 (UN-Water, 2013).

As per the Asian Development Bank (2009) by 2050, due to climate change induced heat and water stress yields decrease by 17% for maize, 12% for wheat, and 10% for rice. Rice is the greatest guzzler of irrigation water among all crops consuming about 80% of the total irrigated fresh water resources in Asia (Bouman and Tuong, 2001; Maclean *et al*., 2002). By the year 2025, it will be necessary to produce about 60% more rice than is currently being produced to meet the food needs of a growing world population (Fageria, 2007). Alternate wetting and drying (AWD), precise land leveling, bed planting and drip irrigation substantially save irrigation water without any reduction in grain yield and WUE (Kang *et al*., 2000; Sharma *et al*. 2005; Jat *et al*., 2011; 2015).

There is a need for technologies and investments that improve water use efficiency, access to irrigation or to find ways to improve incomes with less secure and more variable water availability. Surface irrigation methods are utilized in more than 80% of the world's irrigated lands yet its field level application efficiency is often 40-50% (Von Westarp, 2004). Pressurized irrigation or micro-irrigation systems (sprinkler, surface, and subsurface drip) have the potential to increase irrigation water use efficiency by providing water to match crop requirements, reducing runoff and deep drainage losses, reducing soil evaporation and increasing the capacity to capture rainfall (Camp, 1998). There are few reports of the evaluation of these technologies in field crops in South Asia. Kharrou *et al.* (2011) reported that drip irrigation gave 28% higher wheat yield and 24% higher WUE compared to surface irrigation. Irrigation contributes to CO_2 emissions because energy is used to pump irrigation water. Pathak *et al*. (2011) reported that CH_4 emission was zero in the sprinkler irrigation technologies because of the absence of reduced conditions in rice field.

4.3. Efficient Residue Management

In IGP of South Asia, rice–wheat is the main cropping system. There are few options for rice straw because of poor quality for forage, bioconversion, and engineering applications. Farmers Burnt the rice straw to establish the wheat crop timely where labour is limited. Presently, more than 80% of total rice straw (22 Mt) produced annually in Indian Punjab is burn to clear the fields for timely sowing of wheat (Yadvinder-Singh *et al*., 2010). The field burning of crop residues is a major contributor to reduced air quality (particulates, greenhouse gases), human respiratory ailments, and the death of beneficial soil fauna and micro-organisms. During burning of crop residues around 80% of carbon is lost as CO_2 and a small fraction is evolved as CO. Apart from loss of carbon, up to 80% loss of N and S, 25% of P and 21% of K occurs during burning of crop residues (Ponnamperuma, 1984; Yadvinder-Singh *et al*., 2005).

While in-field retention of crop residues can play an important role in replenishing soil quality and reducing environmental pollution from stubble burning, until recently, there has been no suitable technology for seeding wheat in rice residues. To address this need, a series of prototypes (Happy Seeders) were developed over the past 10 years. Retention and incorporation of rice residue in the field depends on residue condition, its amount and the time left for wheat sowing. Rice straw can be managed successfully *in situ* by retaining on soil surface using 'Turbo Happy Seeder' during sowing of the wheat (Sidhu *et al*., 2015). The benefits include; reduced fuel consumption and cost of crop establishment, ability to sow as soon as desired after harvest thereby enabling early/timely sowing, reduced weed population and ensuring the possibility of reducing the need for irrigation. Turbo seeder wheat sowing is a perfect climatic adaptation and mitigation strategy because it reduces the GHG emissions, reduces crop lodging due to abnormal weather conditions and increases the crop yield as it was evidenced in wheat crop of 2014-15 and maize crop of 2015 in western IGP of India. The incorporation of rice residue into the soil typically had a small effect on wheat yield during the short term of 1-3 years but the effect appeared with in the fourth year of incorporation (Yadvinder-Singh *et al*., 2005; Gupta *et al*., 2007). Crop residues when applied to soil have a significant effects on soil organic matter, and physical, chemical and biological properties of soil (Kumar and Goh, 2000; Bijay- Singh *et al*., 2008; Chauhan *et al*., 2012). The adoption of Turbo Happy Seeder technology for sowing wheat into rice residue has been low to date, despite a ~50% price subsidy by the state governments of NW India. Constraints to adoption include the low window of operation of the machine (25 days/year), the low machine capacity compared with conventional seed drills, the inability to operate in wet straw, and the lack of straw spreaders on combine harvesters. Removal of subsidies for diesel and electricity (for pumping groundwater) and implementation of the policy banning in-field straw burning would help to accelerate adoption of technology for direct drilling wheat into rice residues (Sidhu *et al*., 2015).

Das *et al*. (2014) reported that permanent broad beds with residue addition (permanent raised beds +residue plots, PRB+R) had a 3.1 t/ha of higher wheat equivalent yield in cotton-wheat system over the farmers' practice. The PRB + R plots also used 14% less water and resulted in 48% more mean system water productivity and 36% higher net income compared with coventional till. There is a need for long-term studies in different agro-ecologies to address food, nutrition, economic and environmental problems. From a 5-year study on rice-maize system in NW India, Singh *et al*. (2016) reported that grain yield of conventional transplanted rice (TPR) was 5–7% higher compared to conventional till or ZT direct-seeded rice (DSR). Grain yield of following maize under ZTDSR/ZT maize was significantly higher by 4.0% and 14.2% compared to CTDSR/CTM and TPR/CTM, respectively. Gradual improvement in soil physical health in ZTDSR/ZTM + crop residue system resulted in higher and stable crop productivity and profitability over conventional system.

4.4. Efficient Crop Diversification

Crop diversification is useful in providing higher protection against risk associated with climate change in addition to assured net returns to the farmers. Risk reduction through crop diversification related to abiotic and biotic vagaries particularly in fragile ecosystems and commodity fluctuations will contribute to improved food security and income generation for resource-poor farmers while protecting the environment (Behera *et al*., 2007). Replacing rice with cotton, maize and basmati rice in summer season and wheat with oil-seed (rapeseed mustard) crops and chickpea in winter season can lower evapo-transpiration (ET) and reduce irrigation requirement. Hira (2009) suggested for reducing rice area in Punjab by about 1 m ha and cultivating BT (*Bacillus thuringiensis*) cotton, *kharif* maize, soybean and groundnut, which require 2-5 number of irrigations against the 30-35 irrigations in rice. System diversification/ intensification through resilient cropping system and management scenarios were compared using a wide range of indicators (crop rotation, tillage, crop establishment, crop, water and residue management) with business as usual farmer management scenario in the region to address the issues of deteriorating natural resources, plateauing yields, water, labour and energy shortages and emerging challenges of climate being faced by the farmers. On system basis, three years average data recorded 14% increase in yield in scenario III compared to farmers' practice (scenario I), while saving other resources. Similarly, the futuristic system (scenario IV) showed 11% increase in yield compared to scenario I (Table 3). A substantial reduction of around 33% in water applied in scenario III on system basis compared to scenario I, whereas, in scenario IV, only 29% water applied to that of scenario I (Sharma and Jat, 2014). In a period of 3 years around 34, 44 and 50 tons of crop residues were recycled in scenario II, III and IV, respectively which resulted an increase of SOC by 13, 22 and 26% in the respective scenario from the initial soil SOC (0.45%).

Liak *et al*. (2014) compared four scenarios involving a range of crop and resource management practices with crop rotations (including legumes) in RW system. Zero tillage in wheat and inclusion of mungbean increased the yields of wheat and the succeeding rice crop by 26% and 8%, respectively. The yields of wheat and rice increased further by 50% and 17%, respectively, with the inclusion of more CA components. In the 4^{th} scenario, which was designed to include higher cropping intensity and diversification (potato+maize–rice–cowpea rotation) with CA components, 154% higher rice equivalent system productivity was attained. Irrigation water productivity was higher by 44 to 138% and 16 to 80% during winter and rainy season, respectively with different CA management options. Results further demonstrated that the crop productivity and better economics can be obtained with fewer resources (labor, water, energy), thereby minimizing degradation of the resource base.

Table 3. System yield, irrigation water saving and energy saving in different scenarios

Scenario (S)	*System*	*Residue management*	*System yield (Rice equivalent))*	*Irrigation water (mm)*	*Energy use (MJ/ha)*	**SOC (%)*
S I- farmers practice	Rice-wheat (CT/TPR)	No residue	13.0	2687	73832	0.46
S II-partial CA based	Rice-wheat-mungbean (CT/TPR-ZT-ZT)	Retention of full (100%) rice and anchored wheat residue, while full mungbean residue were incorporated	15.8	2073	56543	0.52
S III- full CA based	Rice-wheat-mungbean (ZT-ZT-ZT)	Retention of full (100%) rice and mungbean; anchored wheat residue	14.8	1793	51582	0.56
S IV- full CA based	Maize-wheat-mungbean (ZT-ZT-ZT)	Retention of maize (65%) and full mungbean; anchored wheat residue	14.5	766	36457	0.58

*SOC-soil organic carbon content

4.5. Information and Communication Tools (ICTs)

Assessing vulnerability to climate change and its variability is an important first step in evolving appropriate strategies for adaptation and mitigation to climate change. Current information on vulnerability to climate change will help in evolving appropriate adaptation and mitigation strategies for climate proofing particularly in handling the drought, heat stress and extreme events during crop cycle. Spreading ICT based value-added agro-advisories and related agro-information through mobile phones is helping to reach farmers. The service has two major components: push component through which agro-advisory is disseminated to the farming communities (both in voice and text through mobile phones), and the pull component through which farmers are provided advisories on their real time problems in farming. Farmers could ask questions using helpline and get instant advisories/suggestions on farming operations. In this way, a two-way communication is possible between the experts and farmers. The voice messages delivered through mobile phones are a minute each covering diverse areas of farming systems (crop management, horticulture, plant protection, weather information) which are contextualized in the local language. Farmers receiving voice SMS facilities on their mobile regarding information on weather forecast and crop management from Kisan Sanchar (farmer's communication centre) of State Agricultural Department. Weather-based agro-advisories to accurately access weather data is critical to formulate and disseminate agro-advisories at the micro-level (district, block, village etc). Successful adaptation to climate change requires long-term investments in strategic research and new policy initiatives that mainstream the climate change adaptations into development planning. For this we need:

(i) Documentation of the indigenous practices followed by farmers to cop up with climate change

(ii) Quantification of the adaptation and mitigation potential of the existing best bet practices for different farming systems

(iii) Long term strategic research planning to evolve new tools and techniques including crop varieties and management practices.

The increasing probability of floods and droughts and other uncertainties in climate may seriously increase the vulnerability of resource-poor farmers to global climate change. In such cases, adaption to environmental change could be in the form of crop insurance, subsidies, incentives, pricing policies, and change in land use. Necessary provisions need to be included in the development plans to provide protection to the farmers, if their farm production is reduced due to natural calamities. Weather derivatives could greatly help in adapting to increase climatic risks. Modern tools of information technology like mobile apps, TV channels, FM radio etc. could greatly facilitate this. Policies to support the diffusion of this information and to help interpret these forecasts in terms of their agronomic and economic implications are required to help farmers in a big way.

4.6. Efficient Carbon Management

Maintenance or improvement of soil organic carbon (SOC) is a widely promoted benefit of CA systems. Since most of the agricultural soils of South Asia are low in SOC, significant potential for C sequestration is expected. Zero tillage reduces the unnecessarily rapid oxidation of SOC as wells as the mulch to CO_2 which is induced by tillage. Potentially one-third of the carbon emitted in current fossil fuel use could be offset by implementing CA globally in the next decade. Conservation agriculture has been proven to reduce the greenhouse gas emissions by restricting the release of soil carbon thus mitigating increase of CO_2 in the atmosphere and enhance its role as carbon sinks. Conservation agriculture can also substantially reduce GHG emissions through reduced diesel use and increased sequestration of C in the soil, and by reducing or eliminating the burning of crop residues. Studies showed that CA can enhance soil carbon sequestration at a rate ranging from about 0.2 to 1.0 Mg/ha/year depending on the agro-ecological location and management practices (Corsi *et al*., 2012). Sequestration of soil organic carbon (SOC) would: (i) help mitigate greenhouse gas emissions contributing to global warming and (ii) increase soil productivity and avoid further environmental damage from the unsustainable use of intensive tillage systems. However, most of the soil carbon sequestered is not permanent and can be lost if the improved management practice is stopped. Some (Powlson *et al*., 2014) consider soil C sequestration as that C which is held in the more recalcitrant or protected forms and thus less susceptible to losses from decomposition. Improved agricultural management enhances resource-use efficiencies, often reducing emissions of GHGs.CA has the potential to slow/reverse the rate of emissions of CO_2 and other greenhouse gases such as methane and nitrous oxides, by reducing tillage and residue burning and improving N use efficiency. The effectiveness of these practices depends on factors such as climate, soil type, input resources and farming system. About 90% of the total mitigation arises from sink enhancement (soil C sequestration) and about 10% from emission reduction (Ortiz-Monasterio *et al*., 2010).

The global warming potential of conventional till wheat with *ad-hoc* nutrient management was significantly higher than in ZT with precision nutrient management (Precision-Conservation Agriculture) (Sapkota *et al*., 2014). On an average, by adopting of ZT for land preparation in rice-wheat system of IGP, farmers could save 36 liter diesel/ha equivalent to a reduction in 93 kg CO_2 emission ha/yr. Thus the goals of increasing SOC content by 0.001–0.01% per year through crop residue management, conservation tillage and restoration of degraded soils can effectively mitigate the current rate of increase of atmospheric CO_2 concentration estimated at 3.2 Pg/yr (Lal, 1997). With increased efficiency of the production system, precision-conservation agriculture (PCA) can act as one of the strategies for adaptation to uncertain climatic conditions as well as reducing environmental foot prints while improving food production on sustainable basis. Therefore, there is need to frame policies and incentives that would encourage farmers to sequester carbon in the soil and thus improve soil health, and water use and energy more efficiently. With increased efficiency of the production system, precision-conservation agriculture (PCA) management technologies can act as one of the strategies for adaptation to uncertain climatic conditions as well as reducing environmental foot prints while improving food production on sustainable basis.

4.7. Efficient Nutrient Management-Nitrogen

Traditionally, farmers in South Asia apply fertilizer nutrients uniformly as a blanket recommendation for large area. Many farmers often use uniform rates of fertilizers based on expected yields (yield goal) that could be inconsistent from field-to-field and year-to-year depending on factors that are difficult to predict prior to fertilizer application. Large temporal and spatial variability of soil nutrient supply restricts efficient use of fertilizer nutrients when broad based blanket recommendations are used (Jat *et al*., 2011). This leads to sub-optimal crop yields, low nutrient use efficiency, lower economic profitability and greater environmental pollution. Under such situations, in season site-specific nutrient management through modern tools (LCC, Green seeker, Nutrient Expert tool etc.) can effectively enhance the nutrient-use efficiency, economic profitability with lower environmental footprints. However, quantifying the spatial and temporal variability of soil properties at scale using soil test based approach seems a wearisome task keeping in view of number of holdings and available resources in the region. Nutrient Expert® for South Asia, a fertilizer decision support tool developed by International Plant Nutrition Institute (IPNI) in collaboration with International Maize and Wheat Improvement Center (CIMMYT) and Indian National Agricultural Research System (INARS), has been chosen as the best innovation in the "ICT solutions". Nutrient Expert® tools for Maize, Rice and Wheat for South Asia, developed and validated over the last five years, provide location specific fertilizer recommendation for individual farm fields. Large-scale on-farm validation trials showed that the tool-based recommendations improved crop productivity, farm profitability, and significantly reduced greenhouse gas emission from farm fields as compared to existing nutrient management practices. The emissions of oxides of nitrogen also can be reduced through alternate practices of N fertilization management (33% application at planting time and remaining post-planting) matched N fertilization better with crop demand (green seeker based) and reduced combined NOx and N_2O emissions by more than 50% and NO_3^- leaching by more than 60% (Matson *et al*., 1998). Optimizing fertilizer application rates and synchronizing them with crop development will further increase yields while reducing costs and emissions of N_2O (Verhulst *et al*., 2011).

4.8. Efficient Genotype x Environment x Management Interaction

It is evident that the yield of any crops or cropping systems is a resultant of Genotype x environment x management interacton. Genotype governed the yield potential, pest and disease resistance, lodging, abiotic stress resistance of crop, however, environment is influenced or modified by rainfall, sunlight, temperature, day length etc. and management by cropping system, establishment, fertility, pest etc. crop plants frequently encounter different environmental conditions. The physiological and behavioural responses to these conditions depend on the genetic makeup of crop. Genotype generally remains constant from one environment to another, although occasional spontaneous mutations may occur which cause it to change. However, when the same crop genotype is subjected to different environments and management, it can behave different phenotypically. These phenotypic variations are attributable to the effect of the environment on the expression and function of genes influencing the trait. Changes in the relative performance of genotypes across different environments are referred to as genotype–environment-management interactions.

Higher crop productivity in South Asian countries were the result of improved crop production environments for high yielding varieties induced by best-bet land and crop management practices. Crop productions with CA are closure to natural ecosystem, and hence, if applied properly as per site specific demand, can help farmers to produce enough additional food for the burgeoning populations. The higher productivity realized with CA under different cropping systems can be further consolidated through the development/selection of appropriate cultivar for the defined agro-ecosystem. There is a need that the genetic variability present in the germplasm is explored/exploited for designing cultivars for good crop stand establishment under CA environment and use genotype x management interactions. Studies show that genotype was modified by the tillage system suggesting that selection under CA should be considered in crop improvement programs. This consideration not only applies to genotype development but will also assist the identification of physiological traits that enhance system crop performance under CA.

5. CONCLUSION AND WAY FORWARD

To support food security and boost incomes, agricultural systems in developing countries will be under pressure to increase productivity sustainably and strengthen the resilience of agricultural landscapes. Climate change is likely to threaten the food security and livelihoods of millions of people in South Asia. Consistent warming trends and more frequent and intense extreme weather events (cold wave, heat wave, drought, and floods) have been observed in recent decades which greatly influence the production of food crops. Therefore, there is a need for using modern science combined with indigenous wisdom of the farmers to enhance the resilience of modern agriculture to climate change. The basic principles of CA are not location or cropping system specific but provide the foundation to tailor and integrate needed strategic crop management practices (seeders/implements, crop residue management, cultivars, weed, disease and pest control practices, fertilizer and irrigation management etc.) that must be developed, tested and modified as needed for application to a given crop production system. Development of CA based best bet management, efficient input and resource management with multiple stresses tolerant varieties (genotype x management interaction) can help in mitigating the adverse impact of climate change and variability.

Conservation agriculture based sustainable intensification not only helps in improving productivity and resource use efficiency but also in reversing the trends of natural resource degradation and environmental quality, making agriculture climate smart. Researchers and policy framers should develop a comprehensive adaptation and mitigation strategies for coping the adverse impact of climate change. Policy decisions for promotion of smart agricultural systems promoting CA, precise land levelling, resource conservation and management, judicious use of waters, site specific nutrient management, integrated weed and pest management, development of multiple stress tolerant crops and capacity building for weather and risk forecasting mechanisms and adaptation of climate resilient technologies must be in place both at local and regional level to cope up with the future problems and ensuring future food security.

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2

Soil Health Management through Conservation Agriculture

V.K. Singh, P.K. Upadhyay, Kapila Shekhawat and S.K. Singh

The intensification of agriculture using high-yielding crop varieties, fertilizers, irrigation and pesticides has increased the agricultural production globally but overstretched the resource use. During this process, the second generation problems mainly related to the soil health *viz.* soil organic corban depletion, emergence of multi-nutrient deficiency, soil physical health degradation, and poor soil bio-diversity caused production fatigue and in efficient resource use efficiency. In the face of further land use intensification to meet global demand for food, increasing water and energy demand managing soils for sustained carbon stocks is of crucial importance. Since 19^{th} century, around 60% of the carbon in the world's soils and vegetation has been lost owing to land use (Houghton, 1995), which has threatened the very base of the agricultural production system. Therefore, urgent goal is to increase the production while conserving environmental resources on a sustainable basis. In this context, conservation agriculture (CA) which utilizes soils for the production of crops with the aim of reducing excessive ploughing of the soil and maintaining crop residues on the soil surface in order to minimize damage to the environment has paramount significance (FAO, 2001). The basic principles of CA like continuous no or minimal mechanical soil disturbance, permanent soil cover by crop residues and diversified production portfolio are applicable to a wide range of crop production systems ranging from low-yielding, dry, rainfed conditions to high-yielding, irrigated conditions. Globally, over 160 m ha of land is under conservation agriculture. In India, efforts to promote resource conservation technologies have been underway but it is only in the past 5-6 years that the technologies are finding rapid acceptance among the farmers. Since soil is the most important natural resource base in agricultural production system and the above principles of CA revolve around sustainable management of soil health, it is pertinent to adopt appropriate CA based crop management strategy to harness the maximum benefit.

Soil is the natural base for practicing agriculture. A healthy soil is the prerequisite for sustainable agriculture. The deterioration of soil health in many of productive crop zone of the world is the major cause of concern. The soil health deterioration is characterized by low organic matter, poor physical properties, poor water infiltration, poor nutrient cycling, declining productivity, increasing pathogens load, nutrient deficiencies and low soil biological diversity. All these cause of soil heath degradation are well addressed in conservation agriculture.

1. EFFECT ON SOIL PHYSICAL PROPERTIES

Intensive or inappropriate tillage practices have been a major contributor to soil physical health degradation. The important soil physical processes like soil erosion and carbon loss are aggravated by deterioration of soil physical health. Recent report by Singh *et al*., 2016 have clearly demonstrated that soil physical properties are generally more favorable with no-till than tillage-based systems.

1.1. Soil Structure and Aggregation

Soil structure is often expressed as the degree of stability of aggregates. The stability of soil structure is the ability of aggregates to remain integral whilst exposed to diverse stresses. Zero tillage with residue retention improves dry aggregate distribution compared to conventional tillage. Therefore, soils under ZT with residue retention turn into more stable and less susceptible to structural deterioration, while conventionally tilled soils are prone to erosion. Physical disturbance of soil structure through tillage results in a breakdown of soil aggregates, increases turnover of aggregates (Six *et al*., 2000), and exposes fragments of roots and fungal hyphae, which are major binding agents for macro-aggregates (Bronick and Lal, 2005).

A medium term study conducted at Modipuram, India showed that ZTDSR/ZTM (zero-tilled direct seeded rice/zero-tilled maize) under rice-maize system had 35% and 47% higher for >2 mm size and 4.1% and 15.2% for 0.25–2.0 mm size water stable aggregates (WSAs) compared to CTDSR/CTM (conventionally till dry direct-seeded rice/conventional till maize) and TPR/CTM (puddled transplanted rice/ conventional till maize), respectively (Table 1). The soil aggregation is also influenced by the crop and their root systems because plant roots are important binding agents at the scale of macroaggregates. A soil under wheat was found to have more large macroaggregates than a soil under maize. Residue retention/incorporation (+R) increased the WSA of >2 mm and 0.25–2.0 mm size by 23% and 10.1% over residue removal (–R), respectively. The proportion of smaller size (< 0.053 mm) WSA was lower for +R compared to –R treatment (Table 1). The minimal soil disturbance under ZT (–R/+R) system has been reported to reduce decomposition and thereby conservation of SOC. Consequently, ZT with residue retention resulted in increased WSA as well as mean weight diameter (MWD) compared to CT and ZT-R (Govaerts *et al*., 2009).

Table 1. Effect of tillage and crop establishment (TCE) technique and residue management options (R) on soil aggregate fractions (g/100g of soil) in 0–15 cm soil depth after five years of rice-maize system.

Treatment	*>2 mm*	*0.25–2.0 mm*	*0.053–0.25 mm*	*<0.053 mm*
TCE technique				
TPR/CTM	6.08	46.8	30.8	16.4
CTDSR/CTM	6.58	51.8	28.0	13.7
ZTDSR/ZTM	8.88	53.9	26.4	10.8
LSD (P< 0.05)	0.26	2.49	1.34	2.36
Residue management option (R)				
— Residue	6.43	48.4	27.1	18.1
+Residue	7.93	53.3	29.6	9.1
LSD (P < 0.05)				
TCE	0.26	2.49	1.34	2.36
R	0.26	2.46	1.71	3.30
TCE×R	ns	ns	ns	ns

Source: Singh *et al*, 2016.

1.2. Soil Bulk Density and Porosity

Soil bulk density is an important indicator of the change of soil structure and water retention capacity under different tillage systems. It has been widely reported that the soil bulk density is higher in the surface layer of ZT than conventional tillage, but lower below 30 cm. Again, the top 3-5 cm of the soil can have a lesser bulk density (Db) under ZT. The relatively higher bulk density in the conventional tillage indicates the development of a compacted "hard pan" beneath tillage depth, caused by the traffic associated with tillage. The effect of tillage and residue management on soil bulk density and porosity is mostly confined to the topsoil. While in deeper soil layers beyond plough zone, soil bulk density is usually analogous in zero and conventional tillage.

Studies conducted by Singh *et al*., 2016 indicated that soil bulk density was higher in the TPR/CTM than in the CTDSR/CTM and ZTDSR/ZTM treatments, irrespective of residue management at 0–15 and 15–30 cm soil depth. Puddling (wet tillage) in rice is known to increase soil bulk density immediately below the plough layer due to (i) destruction of soil aggregates, (ii) filling of macropores with finer soil particles, which ultimately reduces the porosity, and (iii) direct physical compaction caused by the tillage implements (Gathala *et al*., 2011). Soil bulk density values were higher at 15–30 cm than at 0-15 cm depth and it was significantly lower in +R compared to –R plots (Table 2). Positive effect of crop residues on soil Db at the surface 10 cm depth has been reported previously by many researchers (Govaerts *et al*., 2009).

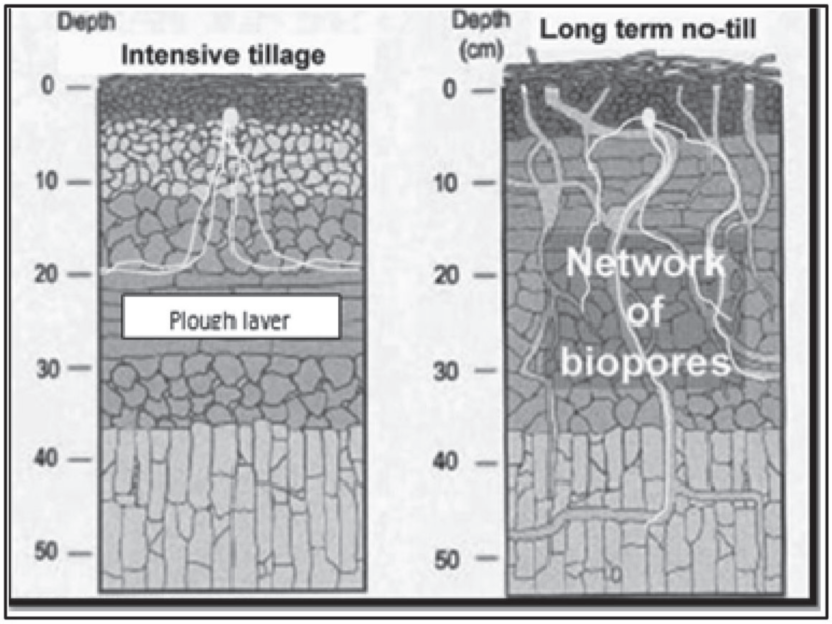

Plate 1. Effect of zero tillage and soil structural improvement and root proliferation
Source: http://www.omafra.gov.on.ca/english/environment/bmp/no-till.htm

Table 2. Soil bulk density (Mg/m) at two depths under different tillage and crop establishment techniques and residue management after 5 years of rice-maize system.

TCE technique	*0–15 cm*			*15–30 cm*		
	–Residue	*+Residue*	*Mean*	*–Residue*	*+Residue*	*Mean*
TPR/CTM	1.53	1.48	1.50	1.59	1.51	1.55
CTDSR/CTM	1.46	1.43	1.45	1.52	1.49	1.50
ZTDSR/ZTM	1.45	1.42	1.44	1.52	1.47	1.50
Mean	1.48	1.44		1.54	1.49	
LSD (P< 0.05)						
TCE		0.009		0.016		
R		0.008		0.015		
TCE×R		0.014		0.027		

Source: Singh *et al.*, 2016

Likewise, the cropping systems that produce higher crop residue reduce soil bulk density and increases total porosity. The more mulch left on the surface, the lower the bulk density, and this effect is very clear in the 0–3 cm and to a lesser extent in the 3–10 cm layers. Further, decreased soil bulk density led to more soil aggregation and better root proliferation of roots (Plate 1) and ultimately caused more water and nutrient uptake.

1.3. Soil Resistance

The soil infiltration, storage and drainage of water, the gaseous changes, and the penetration ease by growing roots are determined by soil porosity. The pores are made by abiotic forces (tillage and traffic, freezing and thawing, drying and wetting) and by biotic factors (root growth, burrowing fauna). Numerous reports indicate that ZT along with surface residues improves soil aggregation, decreases bulk density and ultimately penetration resistance to root growth reduces. Under surface retained residues condition reduction of soil penetration resistance is always more in upper 10 cm profile as compared to lower layers (Singh *et al*., 2016).

1.4. Surface Seal and Soil Crust

The formation of soil crust is not desirable for growth and productivity of the crop plants. The crust formation due to rain drop on surface is high in conventional tilled soils. Due to the formation of soil crust, aeration, soil water infiltration and its conductivity are decreases. This resulted in higher bulk density, decreased hydraulic conductivity, reduced air and water movement, negative heat fluxes, more soil erosion and hampered the seedling emergence. The retention of crop residues on the soil surface in CA plays important role in preventing the formation of soil crust. Further, the crop residue on soil surface abolishes the chances of formation soil crust even in the soils with low organic matter content and high silt percentage. It is reported that crop residues on soil surface minimize surface compactness, surface sealing and crusting, and decreases dispersion and breakdown of soil aggregates (Acharya and Sharma, 1994).

1.5. Hydraulic Conductivity and Water-holding Capacity

The hydraulic conductivity of a soil is a measure of the soil's ability to transmit water when submitted to a hydraulic gradient, simply the ease with which water can move in the soil. The hydraulic conductivity of soil (saturated and unsaturated) improved under ZT owing to either continuity of pores or flow of water through very few large pores. It is generally higher in ZT (McGarry *et al*., 2000) with residue retention due to the larger macropore. One of the reasons reported for improvement in hydraulic conductivity in no-tillage could be the improved pore characteristics of soil such as pore continuity (Cameira *et al*., 2003), pore diameter (Sharratt *et al*., 2006) and increase in the number of macropores (McGarry *et al*., 2000). The management practices that increase soil organic matter content may have a positive impact on water-holding capacity of the soil. Water-holding capacity increase with increases in soil organic matter, meaning CA has the potential to increase water holding capacity. Water use efficiency has also been reported to be greater in soils under reduced and ZT systems. The soil water storage quantity is reported to be higher up to 25% under ZT. Therefore, to improve soil water storage and increase water use efficiency (WUE) it is recommended to practice conservation tillage.

1.6. Infiltration and Runoff

Infiltration is the entry of water in the soil surface, higher the infiltration better will be water storage in the soil and lesser will be the run off losses. Normally, infiltration rate is higher in ZT with residue retention compared to conventional tillage.

In zero tilled soil rate of infiltration have been reported in the range of 80-90 cm/hour. Though the soil infiltration capacity is determined by many factors like the soil properties, crop residues on soil surface, topography, soil moisture etc, but this is very important for deciding the impact of different tillage practices, conservation practices of a particular region. The crop residues on soil surface prevents breakdown of soil macro-aggregates by preventing from the impact of cultural practices and rain drops. and check the formation of surface seals or crusts. Medium term study conducted at Modipuram reveals that soil infiltration rate was significantly higher under zero till direct seeded rice followed by zero tilled maize compared to the conventionally tilled rice and maize (Fig. 1). Similarly keeping residue on surface has pronounced effect on infiltration rate as compare to no residue. In fact, under ZT keeping the crop residue at the soil surface increases the activity of the earthworms, leaving the root channels undisturbed, which in turn leads to the presence of numerous macro-pores and voids resulting in higher rate of infiltration in the soil.

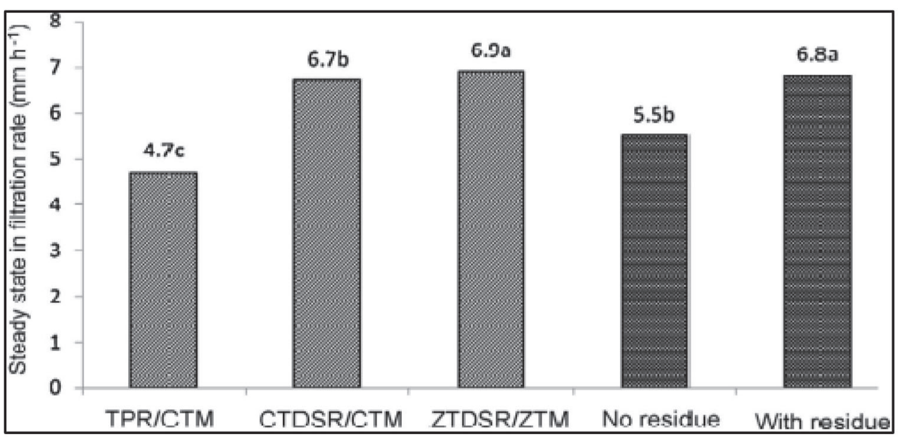

Fig. 1. Steady-state soil water infiltration rate as influenced by tillage and crop establishment techniques and residue management options after 05 years of rice-maize cropping
Source: Singh *et al*, 2016

1.7. Soil Temperature

The soil surface protection through maintaining the crop residues as mulch moderates the soil temperature. Higher soil temperatures in hot tropical regions and low soil temperature in temperate regions are the one of the major constraint to crop production. In tropical and sub tropical countries, it was noticed that after tillage, the soil maximum temperatures exceed >40ºC at 5 cm depth during the crop growth period. The soaring soil temperatures adversely influence the seed germination, crop growth, soil microbial population. The ZT with residue retention recorded 2 to 6^0 C less soil temperature during day time in summer season as compared to the conventional tillage. Studies conducted by Singh *et al*., 2016 under maize crop indicated that the residue retention helped buffering (difference in mean temperature of +R and –R plots) soil temperature by 3.5 to 10.1 ºC during winter period whereas both minimum and maximum soil temperatures were lower by 1.2– 4.7 ºC and 0.5–6.6 ºC, respectively, under +R compared to –R during relatively hot months (March and April) (Fig. 2). The decreased soil temperatures in residue retained plot, especially at grain filling stage have positive effect on reducing canopy temperature and ultimately decreases the impact of terminal heat on the crop productivity (Gupta *et al*., 2010). The residue retention in ZT acts as an insulator against the sharp decline in the soil temperature during night which resulted in less fluctuation in day and night temperature. Thus, in conservation agriculture, growing of the cover crop and retaining crop residues as mulch help in moderating and stabilizing the fluctuations in soil temperature during the crop growth period.

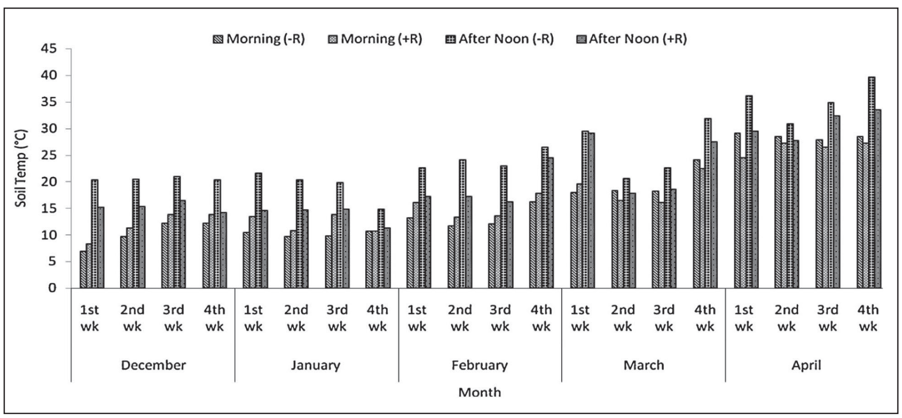

Fig. 2. Effect of residue management options on soil temperature in maize

1.8. Soil Erosion as Influence by Conservation Agriculture

Excessive tillage as practiced in conventional tillage is one of the most important drivers of soil erosion. Due to erosion during last 40 years, about 30 % of the world's arable land has become unproductive and most of it has been abandoned for agriculture. Conservation agriculture is considered as a suitable technique for control of soil erosion (Ghosh *et al*., 2015, Thierfelder and Wall, 2009). The ZT with residue retention lead to formation of stable soil aggregates and ultimately resulted in less soil erosion. Further, the residues left on the surface soil act as barriers, reducing the runoff velocity and giving the water more time to infiltrate.

The residue intercepts rainfall and releases it more slowly. The soils where CA is being practices for long time will have rich bioactivity, better structure, aggregation, and good strength against natural physical erosive forces like raindrops, wind, dry or wet periods etc. CA is therefore, remarkably increases soil aggregate stability which helps in reducing soil erosion, surface crusting and water run-off, and finally benefits the system (Thierfelder *et al*., 2005).

2. EFFECT ON SOIL CHEMICAL PROPERTIES

Soil chemical properties that are usually affected by tillage systems are soil organic carbon (SOC) content, pH, CEC, exchangeable cations, nitrogen, phosphorous, potash and other secondary and micro nutrients. The soil chemical properties of the surface layer are generally more favourable under the no-till method than under the tilled soil.

2.1. Soil Organic Carbon

Soil organic carbon is considered as a primary indicator of soil health. Surface retention of sufficient crop residues under CA increases soil organic matter and biological activity which enhances long term sustainability. It saves non-renewable sources of energy and enhances carbon sequestration. Soil degradation from wind and water erosion, as well as, decline in soil, physical, biological and chemical properties are linked to the excessive levels of tillage and extensive removal/ burning of crop residues. Recent studies conducted by Singh *et al*., (2016) under predominant cropping systems of Indo-Gangetic Plains reveals that SOC stock was significantly higher in the systems where lesser tillage operations were done. Also, higher residue retention as crop cover has great influence on total SOC stocks. Under zero tilled seeding along with the residue retention, the SOC content and stock were more in upper soil profile (0-15 cm) as compare to lower soil depth (15-30 cm). Also residue retention on surface had more SOC as compared to its incorporation in soil (Singh *et al*., 2016).

The crop intensification is the possibility through CA due to a faster turnaround time between harvest and planting. It has been observed that enhancing the rotation intensity results in an increase in SOC. The crop rotation influences the soil carbon content due to increased biomass input, because of the greater total production. The mechanism of capturing C in stable and long term forms might be different for different crop. For instance, legume-based rotations contain greater amounts of aromatic C content (a highly biologically resistant form of carbon) below the plough layer than continuous maize. The labile fraction of carbon increases when tillage intensity reduces. In repeated tilled field, the higher mineralization and leaching rate could be implicated for reduction in organic C and total N. This is the main reason for soil fertility decline in conventionally tilled field.

2.2. Nutrient Availability

Conservation agriculture improves nutrient-use efficiency (NUE) as it reduces soil erosion and prevents nutrient loss from the field. Crop rotations and *in-situ* residue management play a key role in CA systems where they facilitate soil fertility replenishment while at the same time minimising pest and disease build-up (Trenbath 1993). Crop rotations with leguminous crops have the potential to increase soil nitrogen (N) concentration through biological nitrogen fixation (Dwivedi *et al.,* 2003 and Singh *et al.,* 2005; 2006). Nutrient loss may be minimized due to reduced runoff and the appropriate use of deep-rooting cover crops that recycle nutrients leached from the top soil (FAO, 2001). This leads to the greater availability of both native and applied nutrients to crop plants which can have a significant effect on fertilizer efficiency.

2.2.1. Nitrogen

Mineralization of organic carbon regulates the soil N availability to plant. There are reports of lower N fertilizer efficiency when soil microorganisms immobilized mineral N in the crop residues (Verhulst *et al*. 2010). N availability is lower under ZT with residue retention due to the fact of increased immobilization. The net immobilization phase when ZT is adopted could be temporary, as the higher immobilization of N reduces the opportunity for leaching and denitrification losses of mineral N. The significantly higher total N under ZT and permanent raised beds have been reported by Govaerts *et al*., 2009. Repeated tillage increases aggregate disruption, making organic matter more accessible to soil micro-organisms and increasing the release of mineral N from active and physically protected N pools. Under ZT, there will be more stable macro-aggregates and in macro aggregates, C and N in the micro-aggregates-within-macro aggregates are more conserved. In permanent raised beds, residue retention caused more stable macro aggregates and increased the protection of C and N in the micro aggregates within the macro aggregates compared to conventionally tilled raised beds (Lichter *et al*., 2008). Incorporated crop residues decompose 1.5 times faster than surface placed residues and greater losses of N through leaching or denitrification. Thus, ZT with residues retention in long run enhances N availability to the crops. Nonetheless, long-term experiments have indicated an increased release of nutrients owing to microbial activity and nutrient recycling. In addition, increased soil organic matter (SOM) at the soil surface may increase NUE and water-use efficiency (Franzluebbers 2002).

During the first few years of CA, N is mainly found in organic forms (immobilized) and is not available for plants (Verhulst *et al*., 2010) because the mineralization process in the first years is quite slow and there is a need for application of N fertilizer which can speed up the mineralization process. In the years following the adoption of CA, soil microorganisms will significantly increase and essential plant nutrients will be efficiently recycled leading to less need for fertilizers. Therefore, needs to be managed carefully to avoid N deficiency due to slow mineralization, immobilization, and volatilization, and to avoid excess N fertilization. There are several options that allow sufficient time for soil organic matter (SOM) to decompose before sowing the crop. During sowing, N can be applied in bands to prevent immobilization and provide young seedlings with adequate N. The use of nitrate fertilizers is preferred over ammonium fertilizers as nitrate dissolves easier and is more mobile in soil. Soil mineral N available for plant uptake depends on the rate of C mineralization. There is no clear trend on the effect of reduced tillage on residue retention and N mineralization as ZT is generally associated with lower N availability due to increased immobilization by residues left on the soil surface (Bradford and Peterson, 2000). The net immobilization phase, when ZT is adopted, is transitory and immobilization of N under ZT systems in the longer term reduces the opportunity for leaching and denitrification losses of soil mineral N (Follet and Schimel, 1989). Higher immobilizationin in CA systems can increase the conservation of soil and fertilizer N in the long run, and the higher initial N fertilizer requirements decrease over time because of reduced losses by erosion and the buildup of a larger pool of readily mineralizable organic N (Schoenau and Campbell, 1996). A higher total N content under both ZT and permanent raised beds compared to conventional tillage has been reported (Borie *et al*., 2006; Govaerts *et al*., 2007).

2.2.2. Phosphorus

The biggest problem in phosphorus (P) availability is its fixation in the soil. In ZT soils, reduced mixing of the fertilizer in the soils leading to lower P-fixation and increases P availability to the crop plants. Accumulation of P at the surface of continuous ZT is commonly observed. Tillage disrupts and impairs soil pore networks including those of mycorrhizal hyphae, an important component for phosphorus availability in some soils. Zero-tillage thus results in a better balance of microbes and other organisms and a healthier soil. Conservation agriculture promotes better soil microbial fauna and flora and from theses many of the beneficial microbes act as phosphate solublizer and enhance the availability of native soil phosphorus. The fixed soils phosphorous in Indian soils are in huge quantity and the favorable soil microbial conditions under conservation agriculture enhance the P availability. The moderation of soil pH also helps in reducing the quantity of HPO_4^{-1} and $H_2PO_4^{-2}$ to be fixed in the soil by forming complex with other soil nutrients.

2.2.3. Potassium Availability in CA Soils

The illite derived alluvial soils are rich in potash but continuous potassium (K) mining leads to K imbalanced in the soil. The crop residues are rich source of potash and crop residues retention with ZT have reported beneficial for enriching the soil with available potash. Many of the essential plant nutrients especially K under ZT is conserved with increased availability in the soil surface where crop roots proliferate. Higher extractable K levels at the soil surface are observed when tillage intensity decreases. Increasing residue retention can also lead to an increased K concentration in the topsoil, although this effect is crop dependent. This is one of the soil nutrient, the availability of which became fairly high under conservation agriculture practice.

Crop residues contain large quantities of K, and their recycling can markedly increase K availability in soils (Chatterjee and Mondal, 1996). Recycling of crop residues can improve crop yields at low rates of K application and can decrease crop response to applied K. Studies conducted by Singh *et al.*, 2017 (unpublished) under rice-maize system (R-M) of north-west India has clearly demonstrated that retention of crop residue at the rate of 4t/ha under zero till had pronounced effect on improving crop yields, agronomic and recovery efficiency. Buresh *et al*., (2010) reported that for rice-maize with 5 t/ha rice and 12 t/ha maize yield, the retention of maize residues can markedly reduce the net K export but does not eliminate the deficit in K balance when rice residues are not retained. Retention of all maize and rice residues is required to achieve near-neutral K balances.

2.2.4 Cation Exchange Capacity

Cation exchange capacity (CEC) indicates the capacity of a soil to hold exchangeable cations. CEC is an inherent soil characteristic and is difficult to alter significantly. Conservation agriculture enhances soil organic carbon content in the soil and high organic carbon mean high cation exchange capacity in the soil. Organic matter especially humus has maximum cation exchange capacity and in long term the CA lead to increased stable soil organic pool and consequently higher CEC of the soil. It has been widely reported that exchangeable Ca, Mg, and K were significantly higher in the surface soil under ZT. Busaria *et al*., (2015), reported that the soil organic C and the effective CEC were significantly higher at the end of the two years of study under ZT than under conventional tillage.

3. SOIL BIOLOGICAL PROPERTIES

The CA practices are influencing the rhizosphere activities significantly. This effect of CA on the soil biological property is mainly through its impact on SOC content. Surface residues acting as mulch, moderate soil temperatures, reduce evaporation, and improve biological activity. The soil organic matter to a large extent regulates the soil organism which in turn influences the soil organic matter dynamics. The soil macro fauna like earthworms are vital in soil fertility dynamics as their burrowing activities aid in improvement of soil aeration and water infiltration. A significantly higher earthworm population has been observed under no-till soil than under ploughed soil. Lesser the soil tillage higher is the activities of surface-feeding earthworms. Also, decreased fungal biomass and increased bacterial biomass with increasing tillage operations. Thus, changes in tillage, residue, and rotation practices stimulate main swings in the soil fauna and flora, including both pests and beneficial organisms. Soil microbial biomass (SMB) has commonly been used to assess below-ground microbial activity and is a sink and source for plant nutrients and ZT with residue retention increase the SMB of soil. Increased microbial biomass (MBM) increased soil aggregate formation, increased nutrient cycling through slow release of organically stored nutrients, thus builds soil fertility.

4. CONSERVATION AGRICULTURE AND ENVIROMENTAL POLLUTION

Soil erosion and leaching of applied agricultural chemicals cause severe environmental pollution. Emission of CO_2 by agriculture can be decreased by reducing tillage and maintaining crop residues on the soil surface to increase C sequestration in the soil, especially when combined with the reduced burning of fossil fuels for field operations associated with reduced or ZT. Nitrous oxide emissions are more damaging to the environment than CO_2 which can be reduced by improving N use efficiency and cutting methane emissions by limiting the extent of flooded rice cultivation.

If adequate levels of crop residues are retained on the soil surface and combined with reduced or ZT, the C sequestered will correspond in reduction in CO_2 emissions. CA involving zero-till and surface managed crop residue systems are excellent opportunity to eliminate burning of crop residues which contribute to large amount of green house gases like CO_2, CO, NO_2, SO_2 and large amount of particulate matter. Burning of crop residues, also contributes to considerable loss of plant nutrients, which could be recycled when properly managed. Large scale burning of crop residues is also a serious health hazard

5. CONSRVATION

The conservation agriculture (CA) approach of managing agro-ecosystems is of paramount significance in improving soil health, sustained productivity and maintaining natural biodiversity. Various resource conservation technologies (RCTs) in relation to the specific management regimes have shown noteworthy improvement in soil physic-chemical properties *viz*., soil aggregation, density, penetration, thermo-regulation, water and nutrient interaction for maintaining a favourable soil-water-plant continuum. The diversification of existing production systems by ecologically and socio-economically sound crop associations and sequences maintains soil nutrient balance through varied soil microbial composition. Besides promoting carbon sequestration and enhancing natural resource base, CA in log run compliments in environmental protection by reducing the GHG emission. A focused research/development strategy along with the production protocols, however, is needed for soil health restoration and realization of the potential benefits of CA.

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3

Nitrogen Management under Conservation Agriculture

K. Majumdar, V.K. Singh and T. Satyanarayana

The interest for conservation agriculture (CA) in India is increasing, mainly driven by increasing water scarcity and labor costs. Success of conservation agriculture, however, depends on how well the component technologies, such as water, weed and nutrient management strategies, are developed to support the newly introduced form of agriculture without tillage. The three pillars of conservation agriculture, no tillage and minimum soil disturbance, permanent organic soil cover and diversified crop rotations, including legumes do influence the soil nutrient dynamics. For example, when tillage is reduced greater crop residues accumulate on the soil surface minimizing wind and water erosion and improving the quality of the soil. Crop residues on the soil surface increase water infiltration and reduce evaporation losses, reduce nutrient losses through erosion, and also lower the surface temperature. Cooler soil temperatures will slow nutrient release from soil organic matter, reduce diffusion of nutrients to the plant roots, and can affect root growth. In the absence of frequent tillage, mineralization is slowed and the release of plant nutrients declines, making fertilization more important in producing higher yields. Initially, when no-till is first adopted the increased carbon (C) from the crop residues causes immobilization of soil N as decomposing microorganisms use soil N to maintain their C:N ratios during the decomposition process. With time the turn-over, or breakdown, of soil organic matter reaches a new equilibrium and the pool of potentially mineralizable N increases resulting in more plant-available nitrate (NO_3)-N and ammonium (NH_4)-N. Soil P and K tend to be immobile in the soil and without tillage and soil mixing, immobile nutrients may accumulate at the soil surface (0-5 cm). An understanding of how nutrients move and react in the soil is necessary for proper fertilizer management in reduced tillage systems. However, studies on understanding nutrient dynamics in CA systems are limited, and fertilizer recommendations developed for conventionally tilled systems are generally used for crops grown under conservation agriculture practices. Kassam and Friedrich (2009) even suggested that conventional soil analysis data might not necessarily be a valid basis of fertilizer recommendations for CA, since the available soil volume and the mobility of nutrients through soil biological activities tend to be higher than in tillage-based systems against which the existing recommendations have been calibrated. The authors also suggested that the nutrients and their cycles must be managed more at the system or crop mix level in a fully established CA system so that fertilization is not strictly crop specific, rather nutrients are provided at the most convenient time during the crop rotation to maximize benefit. The importance of nutrient management in CA systems were well articulated in a recent article (Vanlauwe, 2014) where the authors argued that a fourth principle of CA– the appropriate use of fertilizer–is required to enhance both crop productivity and produce sufficient crop residues to ensure soil cover under smallholder conditions in Sub-Saharan Africa. The authors proposed fertilizer application as a separate principle for CA in contrast to other agronomic practices, including planting time, spacing, and weeding regime, because fertilizer is essential for CA to work, whilst the sub-optimal implementation of other crop management practices do not lead to the failure of CA as such. They suggested that without acknowledging this fourth principle the chance of success for CA, especially with smallholder farmers, is limited.

1. NUTRIENT MANAGEMENT IN CA SYSTEMS

The topic of nutrient management in CA systems is a complex issue and needs attention from researchers for successful adoption of conservation agriculture practices at the farm level. In general, four important chemical and biochemical processes, often working simultaneously, are involved in influencing the dynamics of a nutrient in the soil system. These are: mineralization-immobilization, sorption-desorption, dissolution-precipitation and oxidation-reduction and most of the dynamic behaviour of soil nutrients can be explained by one or a combination of these processes. Among these, the mineralization-immobilization and sorption-desorption seem to play more dominant roles in governing the source-sink interactions characterizing the nutrient dynamics. The three key elements of CA systems, minimum disturbance, residue retention and legume in crop rotation, are expected to influence the above mentioned chemical and biochemical processes considerably. The changes in physical and biological properties of the soil associated with CA practices, as discussed in the previous sections, are expected to modify the direction and kinetics of the chemical and biochemical processes leading to altered nutrient dynamics in the soil. We intend to correlate the altered bio-physical properties of soils under CA practices and their expected influence on the chemical and biochemical processes in the soil to highlight the nutrient dynamics under such systems, particularly for the macronutrients.

2. NITROGEN MANAGEMENT

Mineralization is the transformation of nutrients from organic to inorganic state while immobilization is the reverse process. Both the processes are biochemical in nature and are bound to the activities of the heterotrophic biomass. These two processes significantly influence the dynamics of several nutrients, namely nitrogen (N), phosphorus (P), sulphur (S) and the micronutrients. Both mineralization and immobilization have fundamental functions in the universal N cycle. Both the processes are linked to the heterotrophic sub-cycle (Campbell, 1978) that is characterized by mineralization, energy dissipation from organic matter, whereby the nitrogenous organic substances are converted to NH_3 or NH_4^+ ions by heterotrophic organisms. The functioning of the sub-cycle is dependent on this mineralized N where invariably a part of it is immobilized by the heterotrophic organisms involved in the sub-cycle. These two opposing processes result in net mineralization or net immobilization depending on the difference in rate with net mineralization being the normal and dominating reaction. Such continuous process of transfer of mineralized N into organic products of synthesis and of immobilized N back into inorganic decay products is defined as MIT (mineralization-immobilization turnover) (Campbell, 1978).

Whether N is mineralized or immobilized depends on the C:N ratio of the organic matter being decomposed by soil microorganisms. The progress of N mineralization and immobilization following residue addition is illustrated in Figure 1. There is rapid increase in the number of heterotrophic organisms during the initial stages of fresh organic matter decomposition as indicated by elevated CO_2 evolution. If the C:N ratio of the residue is > 20:1, net immobilization will occur as shown in the hatched area under the top curve (Fig. 1). The insufficient nitrogen in the substrate will induce the organisms to draw on the mineral nitrogen in the soil leading to immobilization of N. The residue C:N ratio will, however, decrease as the decay proceeds because of decreasing C (respiration as CO_2) and increasing N (N immobilized from soil solution) and a new equilibrium will be reached, accompanied by mineralization of N (Fig. 1). A combination of high C:N ratio plant residues and low soil nitrogen is expected to reduce nitrogen availability to plants at least at the initial phases of crop growth. Retention of cereal straws, most commonly practiced in South Asia, with reported range of C:N ratios between 60:1 to 100: 1(Havlin *et al*., 2005) and generally low available N in soils of the region is expected to prolong the stage of N immobilization. Crops planted immediately after cereal residue incorporation in such soils may become deficient in N and will require sufficient external N application to satisfy the need of the microorganisms and the growing crop.

It is well established that due to less surface evaporation (surface cover) and better infiltration of rainfall (better soil aggregation), there is usually 15-25% extra available moisture during the growing season with no-till as compared to conventional tillage. Besides the perceivable advantage of extra moisture during

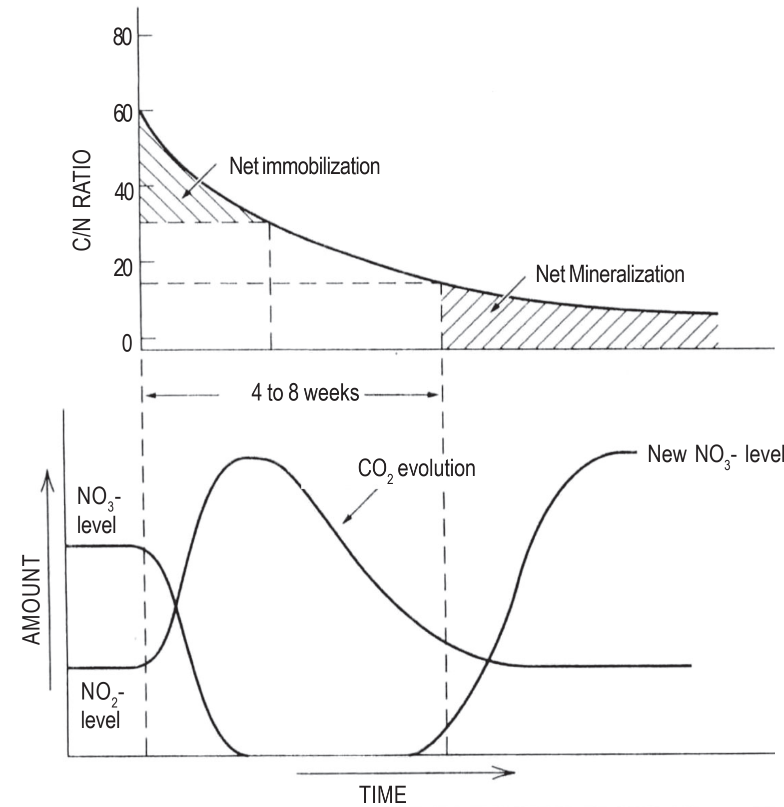

Fig. 1. General description of N mineralization and immobilization following addition of residue to soil (Havlin *et al*., 2005)

the growing season, particularly in arid and semi-arid regions, this also opens up the possibility of N losses from the system through leaching and gaseous losses. There are several reports from Kentucky, USA, (Thomas *et al*., 1973; McMahon and Thomas, 1976; Tyler and Thomas, 1977;) comparing NO_3^--N movement in no-till corn as compared to conventional tillage that showed loss of NO_3^- below 90 cm depth of the soil and attributed that to lower surface evaporation and deep penetration of water and NO_3^- through large pores, facilitated by better aggregation in the wetter no-tilled soil. This led to the researchers to speculate that more fertilizer N will be required for optimum no-till corn production than for conventionally tilled corn. The additional nitrogen is expected to compensate for high risk of leaching losses of NO_3^--N and for lower rate of mineralization of residual soil N in the Kentucky soil. Long-term yield results from one such study (Blevins *et al*., 1980) showed higher yield response in no-till corn, particularly at the first incremental N use and may reflect greater mineralization of residual soil N in conventional tillage (Table 1).

Table 1. Average annual grain yield (kg/ha) over 10 year continuous corn production on a Maury soil.

N-Rate (kg/ha)	No-till	Conventional tillage
0	4767	5958
84	7715	8028
168	8028	7840
336	8342	8216

Source: Blevins *et al*., 1980

3. NITROGEN TRANSFORMATION IN CA SYSTEM

Greater surface microbial activity in no-till soil, as compared to conventionally tilled soil, is expected due to more moisture and accumulation of organic residues in the soil surface. Greater number of both aerobic and anaerobic microorganisms has been measured in the no-till system than in conventional tillage. Even though large number of aerobes are present, the relatively larger presence of anaerobes in no-till soils increase the possibility of gaseous N loss through denitrification. Doran (1980) reported that populations of nitrifying organisms increased up to 20-fold while population of denitrifiers increased up to 44-fold in the surface layer of soil under no-till corn as compared with conventional tillage. The author suggested that this pathway of N loss, particularly of fertilizer N, may be more important than leaching losses associated with no-till systems. Nitrate reduction only takes place under conditions of low oxygen supply. Soils which appear well aerated may yet reduce nitrate, particularly if organic substrate level is high enough to create microsites where the oxygen demand by the microbial population exceeds supply from soil. The development of larger aggregates with diameters more than 9 mm are likely to have such sites within them even in soils where aeration around the aggregates appears satisfactory. Requirements for active denitrification, that is, easily available organic substrate, nitrate, suitable organisms, existence of large aggregates, high moisture content, are prevalent in no-till soils and denitrification can contribute to lesser nitrogen availability in such soils. However, lesser mineralization in no-till soils and common practices of deep placement of N at crop establishment when water content is high in soils and splitting of N to match crop demand can considerably decrease the denitrification potential in no-till systems.

Several researchers (Triplett and Van Doren, 1969; Moschler and Martens, 1975) comparing conventional tillage and no-till production systems suggested that their results indicated a more efficient utilization of fertilizer with no-till production as compared with conventional tillage. The grain yield response curve shown in Fig. 2 is typical of what is obtained in several studies. The curves showed that, although yielding less at suboptimal levels, no-till yields are higher at higher nitrogen levels. Lower grain yields and N uptake observed with no-till at suboptimal rates of fertilizer N application probably resulted from either greater immobilization of fertilizer N, losses of N from denitrification and leaching, lower mineralization of soil organic N, or some combination of these factors.

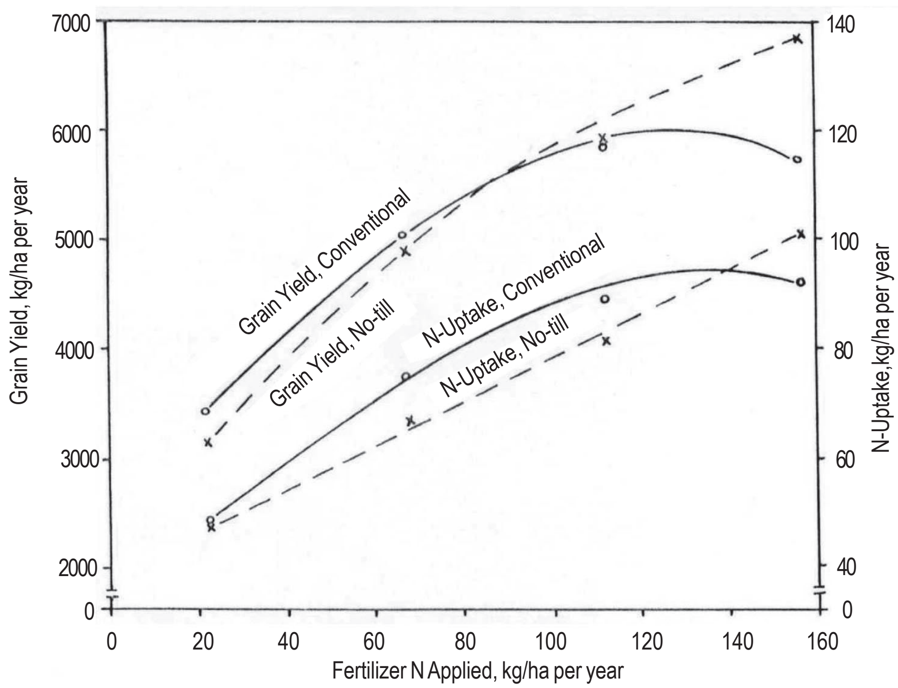

Fig. 2. Effect of conventional tillage and no-till on grain yield and N uptake by corn (Moschler and Martens, 1975)

The Fig 2. also showed that grain yields for conventional tillage peak at a lower rate of fertilizer N than no-till, which would suggest less fertilizer N is required for conventional till to reach maximum production attainable. However, grain yield from no-till at the high rate of fertilizer N exceeds that of conventional till by a greater margin than is observed with either zero N or lower rates of fertilizer N. A likely explanation is that soil moisture becomes more yield limiting in conventional tillage than in no-till, making it possible for grain yield of no-till to reach higher levels with additional fertilizer N. That higher level of fertilizer N is necessary to reach optimum grain yield levels in no-till was supported by Legg *et al*. (1979) who showed that N recovery was lower in no-till systems at suboptimal N levels but significantly higher recovery than conventional systems at higher N rate (Fig. 3).

However, Bandel *et al*. (1975) suggested that although N deficiencies were more noticeable on no-till than conventional tillage at suboptimal levels of applied fertilizer N, but there was no significant difference in fertilizer N requirement for maximum yields in the two systems. Wells *et al*. (1983) reporting from two studies in corn-silage system in Kentucky showed that although dry matter yields and the ratio of N accumulated to N applied were higher with no-till, the ratios of dry matter accumulated per unit of N accumulated were the same (Table 2).

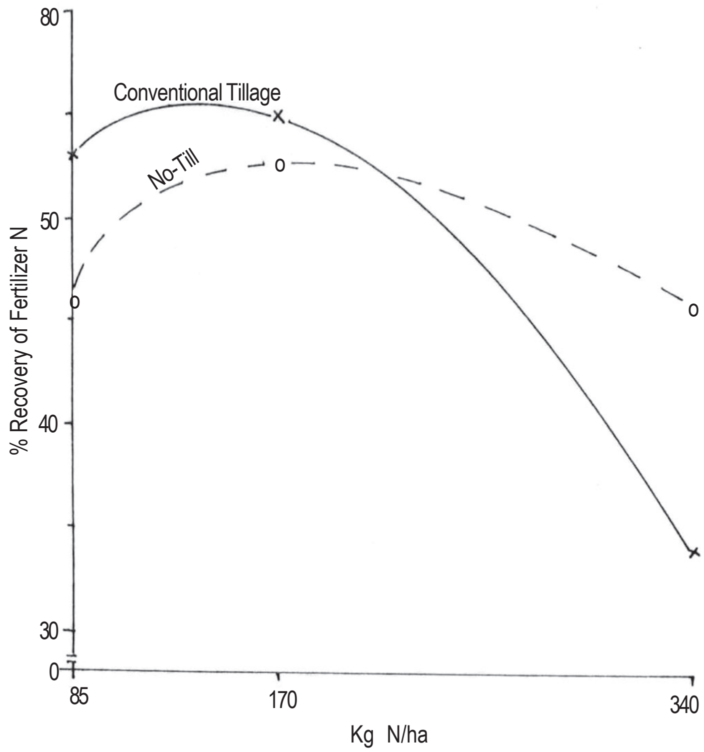

Fig. 3. Recovery of fertilizer N by no-till and conventionally grown corn (Legg *et al*., 1979)

Table 2: Dry matter production and N accumulation of corn-silage grown on two soils under no-till and conventional tillage

Parameter	*Huntington silt loam*		*Pope silt loam*	
	No-till	*Conventional till*	*No-till*	*Conventional till*
Dry matter production, kg/ha	15386	16033	16621	13406
N accumulation, kg/ha	183	190	199	162
Kg dry matter/ha per kg N/ha accumulated	84	84	83	83
Ratio of N accumulated to N applied#	0.86	0.90	0.94	0.76

Fertilizer N applied at 212 kg/ha/year

Future work comparing conventional and no-till production systems with varying fertilizer N rates is necessary to more accurately understand the above observations.

Wells (1979) summarized the response of no-till corn as influenced by fertilizer N sources and suggested that there was little basis to agronomically discriminate among N sources (ammonium nitrate (AN, urea or N solution). However, McKibben (1975) reported severe loss of N from Urea as compared to AN in no-till corn. Bandel *et al*. (1980), comparing ammonium nitrate (AN), Urea or N solutions in no-till corn, suggested that AN was superior to granular or prilled Urea or N solution and urea or N solutions should be applied beneath the surface. Several other studies also revealed better response to subsurface application of urea and N solutions in no-till systems. Surface application of urea in no-till systems should be viewed as a practice with potential but unpredictable extent of loss of applied N. This is particularly significant at the early phases of crop establishment when there is ample moisture and substantial amount of undecomposed organic substrate at the surface of the soil.

4. CONCLUSION

In summary, research results do emphasize that return of crop residues do increase soil organic matter, and additionally, the increase is greater as more fertilizer N is used. This represents a build up of a potentially larger labile pool of organic N in no-till systems. How much of that labile pool will be utilized by the subsequent crops will largely be influenced by the amount of such organic N that is mineralized during the growing season. This labile pool of organic matter is redistributed to the top 5 cm of soil in continuous no-till production systems while it is somewhat uniformly distributed throughout the profile in conventional tillage systems. Such distribution of organic matter in contrasting tillage systems influences the dynamics and efficiency of N as the rate of microbial activity increases at the soil-residue interface. There is potentially a greater likelihood of more immobilization, denitrification or leaching of applied nitrogen in no-till systems because of the increased microbial activity at the residue-soil interface in no-till systems. For this reason, poorer yield response to suboptimal N application in no-till corn (Bandel *et al*., 1975) is possibly not due as much to losses of soil N from the rooting zone as it is to a shift in N content of soil N components resulting in more total N being immobilized with no-till. The total amount of organic N mineralized in no-till systems during the growing season is less than conventional systems even though there is a potentially larger source of mineralizable N and greater microbial activity in no-till soils. This is due to less surface area of organic residues exposed to microbial action when the residue exists as undisturbed mulch as compared with plowing down the residues and mixing them in the plow layer. This probably accounts for lower no fertilizer check plot yields in no-till systems and lower no-till yields in cereals at suboptimum levels of N application. The above discussion generally suggests that N recommendations should be higher in no-till systems than conventional tillage systems, at least at the initial phases of establishment of a continuous no-till system till a new steady state equilibrium between immobilization and mineralization is reached at a later phase and supply of N from the labile organic pool increases.

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4

Nutrient Dynamics and Management under Conservation Agriculture

Mahesh C. Meena, B.S. Dwivedi, D. Mahala, Shrila Das and Abir Dey

In India nearly 94% (143 mha) of the agriculturally suitable land is under cultivation with limited scope for further horizontal expansion. Hence, the pressure on land is increasing to produce more from the constant area under cultivation through increasing the input-use efficiencies and adopt better agronomic practices. During past half century, there has been a major shift in agriculture from 'traditional animal-based subsistence' to 'intensive chemical and machinery-based' agriculture; this shift triggered the problems associated with deterioration of soil health and sustainability of natural resources. Soil organic carbon (SOC) contents less than 5 g/kg (<0.5%) in most cultivated soils compared with 15-20 g/kg (1.5–2.0%) in uncultivated virgin soils of India (Bhattacharyya *et al*., 2000), are attributed to intensive tillage, removal/burning of crop residues, mining of plant nutrients and intensive mono-cropping systems. Excessive tillage often results in serious soil problems like sub-soil compaction and loss of soil organic matter SOM (Dwivedi *et al*., 2012). The major issues of soil health are; (i) physical degradation caused by compaction, crusting *etc.,* due to excessive tillage and puddling, (ii) chemical degradation caused by wide nutrient gap between nutrient demand and supply, high nutrient turn over in soil-plant system coupled with low and unbalanced fertilizer use, emergence and spread of multi-nutrient deficiencies, low nutrient use efficiency, inadequate input of organic sources for their competitive uses, soil acidity, salinity alkalinity waterlogging, and (iii) biological degradation due to depletion of SOM, and loss of soil fauna and flora. This calls for development of efficient soil management strategies including selection of suitable crop rotations, development of novel fertilizer products, enhancing nutrient use efficiencies, balanced and integrated plant nutrient supply, recycling of crop residues and improved tillage practices. It is envisaged that development of such strategies will not only help in sustaining higher crop productivity, but also improving soil health and environmental quality.

Conservation agriculture (CA) is increasingly promoted as an alternative to address soil degradation resulting from agricultural practices that deplete the SOM and nutrient content of the soil, aiming at sustained crop productivity with lower production costs. In this context, CA principles augment the soil health by (i) minimizing mechanical soil disturbance and seeding directly into untilled soil to improve SOM content and soil health, (ii) enhancing SOM using cover crops and/or crop residues (mainly residue retention). This protects the soil surface, conserves water and nutrients, promotes soil biological activity and contributes to integrated pest management (iii) diversification of crops in associations, sequences and rotations to enhance system resilience, and (iv) controlled traffic that reduces soil compaction (FAO, 2011). Thus, CA avoids straw burning, improves SOC content (Hobbs and Gupta, 2004). The CA helps to improve biodiversity in the natural and agro-ecosystems. Complemented by other good agricultural practices, including the use of quality seeds and integrated pest, nutrient and water management *etc*., CA provides a base for sustainable agricultural production intensification. Moreover, yield levels in CA systems are comparable and even higher than convention intensive tillage systems with substantially less production costs. Conservation agriculture is thus an eco-friendly and sustainable management system for crop production with potential for all agroecological systems and farm sizes enhances input use efficiency and has the potential to reduce greenhouse gas emissions.

1. CONSERVATION AGRICULTURE AND SOIL HEALTH

Conservation agriculture improves nutrient-use efficiency (NUE) as it reduces soil erosion and prevents nutrient losses from the field. Nutrient losses may be minimized due to reduced runoff and the appropriate use of deep-rooting cover crops that recycle nutrients leached from the topsoil (FAO, 2001). This leads to the greater availability of both native and applied nutrients to crop plants which can have a significant effect on fertilizer efficiency. In a rice–wheat system, fertilizer efficiency increased by 10–15% through placement of fertilizer with the seed drill compared with broadcasting in the traditional system (Hobbs and Gupta, 2004). Nonetheless, long-term experiments have indicated an increased release of nutrients owing to microbial activity and nutrient recycling (Carpenter-Boggs *et al*., 2003). Crop residues can increase plant nutrient availability and their efficiencies in no-tillage systems (Iyamuremye and Dick, 1996). Studies indicate the permanent cover crops under different tillage systems modified N mineralization and release, as well as P sorption. Adsorption sites can be blocked by organic compounds e.g., humic acids, oxalate and malate, which decreases P sorption in the soil (Afif *et al*., 1995; Bhatti *et al*., 1998). In addition, it is not clear whether this positive effect of organic compounds on decreasing P sorption by soils exists in the field as most studies have been conducted under controlled environments (Ziadi *et al*., 2013). Legume-based crop rotations in CA significantly improve nutrient availability for crop plants (Govaerts *et al*., 2007).

Higher levels of exchangeable calcium (Ca), potassium (K), and magnesium (Mg) are found when pigeon pea (*Cajanus cajan* L.) and lablab (*Lablab purpureus* L.) are grown compared with white clover (*Trifolium repens* L.). In addition, others reported higher C, N, K, and lower sodium (Na) concentration when the crop residue left in the field compared to residue removal (Govaerts *et al*., 2007).

The distribution of nutrients in a soil under zero tillage differs from that in tilled soil as enhanced conservation increases the stratification of nutrients and their availability near the soil surface compared to conventional tillage (Duiker and Beegle, 2006). The altered nutrient availability under zero tillage is probably due to the surface placement of crop residues as opposed to the incorporation of crop residues with conventional tillage. Slower decomposition of crop residues left on the soil surface (Kushwaha *et al*., 2000; Balota *et al*., 2004) can prevent rapid leaching of nutrients through the soil profile, which is more likely when residues are incorporated into the soil. However, the possible development of continuous pores between the surface and subsurface under zero tillage may lead to more rapid passage of soluble nutrients deeper into the soil profile than when soil is tilled. Furthermore, the response of soil chemical properties to tillage practices in site-specific management depends on soil type, cropping systems, climate, fertilizer application, and management practices. The density of crop roots is usually greater near the soil surface under zero tillage compared to conventional tillage, as more nutrients are taken up from near the soil surface as illustrated by a significantly higher P uptake by corn from the 0–7.5 cm soil layer under zero tillage than under conventional tillage (Mackay *et al*., 1987).

2. NUTRIENT DYNAMICS MANAGEMENT IN SOIL UNDER CONSERVATION AGRICULTURE

Nutrient management is an important aspect of CA for sustainable crop productivity and its adoption among the farmers. Conservation agriculture has several challenges pertains to as crop residue is retained on no-tilled soil surface and a significant amount of fertilizers is remained on residue and never come in soil contact if applied through broadcast. Hence the type of fertilizer material (source), rate, time and method of application have to be evaluated in CA properly to increase the crop productivity, input-use efficiencies, farm profits and restore the nutrient supplying capacity and soil health. A very little work has been done in this aspect. However, a few studies have been done for standardization of nutrient management protocols and nutrient dynamics in CA which is summarized as below:

2.1 Nitrogen Management and its Dynamics in CA

The efficient use of N fertilizer is important for crop yield, the environment, and the adoption of CA and depends on the level of available N in the rooting zone. Applied N fertilizer rates should consider the available N in soils and other factors that affect crop response to N fertilization. Despite the importance of soil tests for N application, adjustment of fertilizer rates as a result of soil tests are rare, together with calculations for agronomic efficiency (AE) of N and the profit that can be gained by N fertilization. This is because these studies require trials on farmers' fields for several years. In addition, apart from inorganic N, organic soil N mineralized during crop growth can provide N for the crop. Nitrogen availability in CA mainly depends on composition or C/N ratio of crop residues left in the field. The C/N ratio of crop residues is used as a criterion for residue quality together with initial residue N, lignin, polyphenols, and soluble C concentrations (Moretto *et al*., 2001). Inorganic N can be immobilized during decomposition of SOM especially when organic material with a wide C/N ratio is added to the soil. There are reports of lower N fertilizer efficiency when soil microorganisms immobilized mineral N in the crop residues during the first years of implementation of CA. Total soil N mineralization has been significantly correlated with the C/N ratio of crop residues (Kumar and Goh, 2002). Raghavendra *et al*. (2017) evaluated different rates of crop residue and potassium which showed significant improvement in grain yield and economics of maize and wheat in CA over control. Studies conducted at IARI, New Delhi indicated that crop residue retention at rate of 4.0 t/ha of each crop significantly increased grain yield (4.79 t/ha in maize; 5.01 t/ha in wheat as compared to crop residue (CR) removed plots and it was on par with 6.0 t CR/ha (Fig 1). Some plant species used as cover crops have relatively high N and P contents, while their crop residues have very low N and P contents. However, these residues are more important in contributing to SOM build-up than as inorganic nutrient sources for plant growth because of their lignin and polyphenol contents.

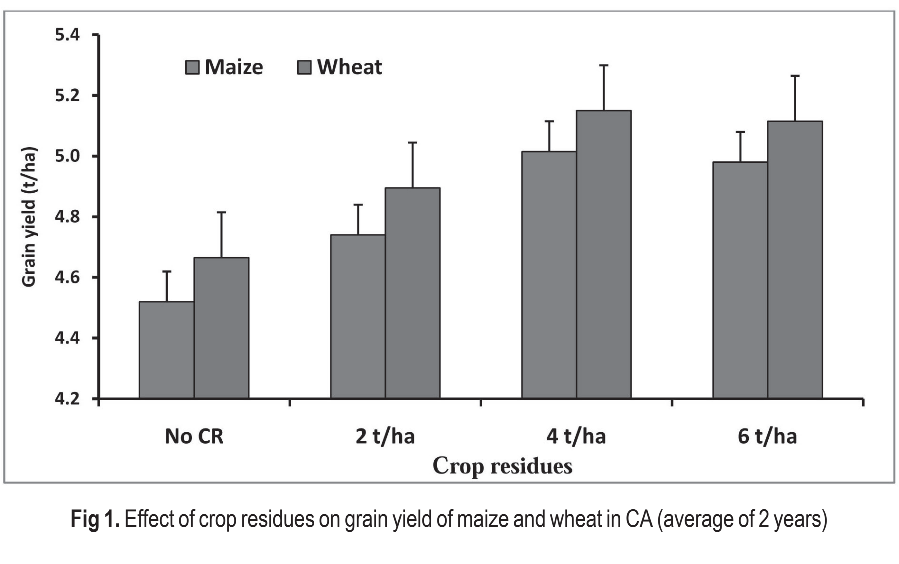

Fig 1. Effect of crop residues on grain yield of maize and wheat in CA (average of 2 years)

In several studies of CA indicated that initially first two to three years, N is immobilized in organic forms and is not available to plants because the mineralization process in the first years is quite slow and there is a need for application of sufficient N fertilizer which can speed up the mineralization process. In the later years, soil microorganisms will significantly increase and recycle essential plant nutrients leading to less fertilizers. Therefore, N needs to be managed carefully to avoid N deficiency due to slow mineralization, immobilization, and volatilization, and to avoid excess N fertilization. There are several options that allow sufficient time for SOM to decompose before sowing the crop. Application of N fertilizer (25–70 kg/ha) before sowing will increase mineralization. During sowing, N can be applied in bands to prevent immobilization and provide young seedlings with adequate N.

Tillage practices also affect N mineralization as tillage increases aggregate disruption, and the SOC is more accessible to soil microorganisms; thereby increasing mineral N released from active and physically protected N pools. In permanent raised beds, residue retention caused more stable macroaggregates and increased the protection of C and N in the microaggregates within the macroaggregates compared to conventionally till raised beds (Lichter *et al*., 2008). In addition, there is increased susceptibility to leaching or denitrification if the growing crop does not take advantage of these nutrients at the time of their release. In corn, NO_3-N losses were about 5% higher with conventional tillage compared to zero tillage (Randall and Iragavarapu, 1995). In the initial years of zero tillage, there is no effect on N availability. However, the N mineralization rate increased as tillage decreased. Govaerts *et al*. (2006) reported that after 26 cropping seasons in a high-yielding, high-input irrigated production system, the N mineralization rate was higher in permanent raised beds with residue retention than in conventionally tilled raised beds with all residues incorporated, and that it increased with increasing rate of inorganic N fertilizer application. The tillage system determines the placement of residues. In a conventional tillage system, crop residues are incorporated, while in the case of zero tillage, residues are retained on the soil surface. These placement differences contribute to the effect of tillage on N dynamics. Incorporated crop residues decomposed 1.5 times faster than surface-placed residues (Kushwaha *et al*., 2000, Balota *et al*., 2004). However, the type of residues and the interactions with N management practices may also affect C and N mineralization.

In addition to soil N status measurements, several other diagnostic tools or sensors have been developed to determine N status of plant, which are used to improve N management and decrease the risk of N loss to ground and surface waters (Fageria and Baligar, 2005). The plant-based diagnostic methods such as chlorophyll meters provide a valuable estimation of the N status of the crop. The 4R Nutrient Stewardship is an innovative approach for precise fertiliser/nutrient management practices that considers economic, social, and environmental dimensions of fertiliser management and is essential to the sustainability of agricultural systems. Precision nutrient management can be accomplished by different methods, tools and techniques like site specific nutrient management (SSNM), tools and sensor-based nutrient management, and decision support systems (DSS) for increasing crop productivity and N-use efficiency.

3. PRECISION NITROGEN MANAGEMENT

3.1 Site-specific Nutrient Management

Site-specific nutrient management (SSNM) is a set of nutrient management principles that aims to supply a crop's nutrient requirements tailored to a specific field or growing environment. It is an approach of supplying plants with nutrients to optimally match their inherent spatial and temporal needs for supplemental nutrients. The SSNM uses a nutrient balance approach in that, within season nutrient estimation is used to determine the amount of N to be applied at the time of crop establishment, and subsequent application can dynamically be varied to match the spatial and temporal needs of crop through periodic monitoring. Sensor-based, site specific application of fertiliser has been reported to improve fertiliser use efficiency and also increase grain yield of many crops around the world. The SSNM reduced N fertiliser use by 32% and increased grain yield by 5% compared with farmers' N fertilisation practices in the field experiments and demonstration trials conducted in rice (Shaobing *et al*., 2010). Mohanty *et al*. (2015) reported the growth parameters, yield attributes and yield of maize can be increased through SSNM-based nutrient-management in CA over state recommended dose of furtilizers (RDF) (Fig 2). Similarly Bijay-Singh *et al*. (2015), through their field experiments in IGP, obtained similar rice yields in SSNM as the blanket fertiliser practice but with reduced N rate thereby increasing recovery efficiency as well as agronomic efficiency of N.

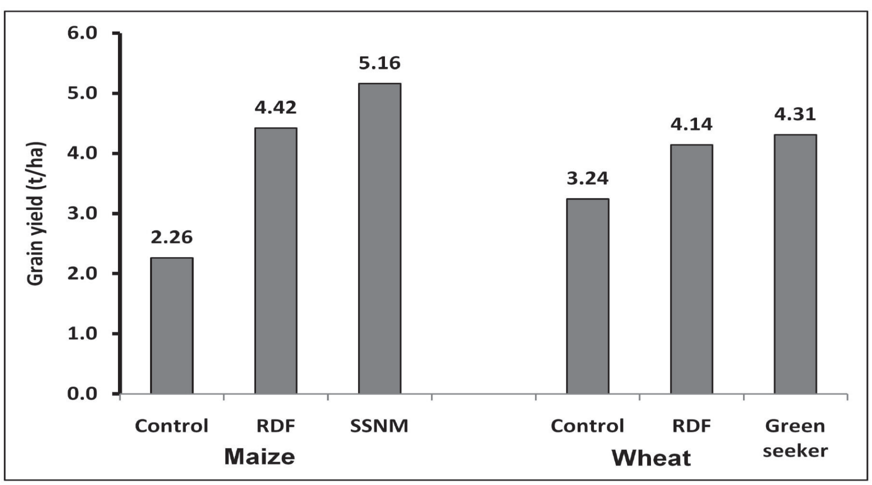

Fig. 2. Effect of nutrient-management practices on grain yield of maize and wheat under CA

3.2 SPAD Meter

Leaf chlorophyll content can be linked with leaf N content because the majority of leaf N is contained in chlorophyll molecules. Therefore, measurement of leaf greenness by chlorophyll meter such as SPAD meter throughout the growing season can signal potential N deficiency early enough to correct it without reducing yields.

3.3 Leaf Colour Chart

Leaf colour chart (LCC), alternative to SPAD, is also used to measure the relative greenness of the crop leaf. It is an innovative cost effective tool for real-time or crop need- based N management in rice, maize and wheat. The leave greenness can be used as an indicator of the plant N status to determine the in-season N demand. It is used to rapidly monitor leaf-N status at tillering to panicle initiation stage and thereby guide the application of fertiliser N accordingly. Bijay-Singh *et al*. (2002) reported that plant need based N management through use of SPAD meter or LCC can reduce N requirement from 12-25% with no loss in yield in rice-wheat system of IGP.

3.4 Green Seeker

GreenSeeker (GS) is a variable rate application and mapping equipment designed for use throughout a growing season. Here, crop vigor, measured as normalized difference vegetative index (NDVI), is used as the basis for N prescription rates. The results of GS sensor-based N management resulted into similar (in rice) to higher yield (in wheat) with reduced N rates thereby increasing NUE (Bijay-Singh *et al*., 2015). The GS-based precision nutrient management increased partial factor productivity (PDP) of N in rice by 65% over the farmers' practice in China (Yao *et al*., 2012). The GS sensor-based technology provides for a saving in N application of 10–20% in comparison to blanket state recommendations, while maintaining similar crop yields (Bijay-Singh *et al*., 2015). Mahala *et al*. (2015) revealed that the GreenSeeker based N management could be saved to the extent of 24-48% as well as enhancing N use efficiencies in maize-wheat systems (Fig. 3) by manipulating sources, rates, methods and time of application under different tillage and residue management conditions.

Mohanty *et al.* (2015) indicated that the real time N management through GreenSeeker was found effective over blanket recommended N fertilizer prescription in wheat under conservation agriculture to enhance the productivity recovery efficiency (RE) of N (Fig.3).

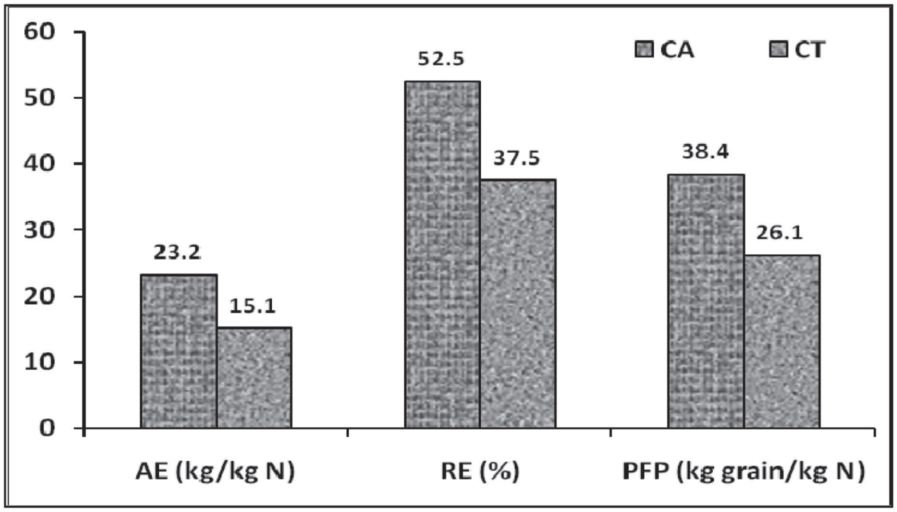

Fig. 3. Effect of different N management options on N use efficiencies in wheat (average of 2 years)

3.5 Decision Support Systems: Nutrient Expert

Nutrient Expert (NE), a Decision Support System was developed by International Plant Nutrition Institute for small holder production system of South Asia is easy-to-use, interactive computer-based decision tool that can rapidly provide nutrient recommendation for individual farmers' field in absence of soil testing data. It synthesizes the on-farm research data into a simple delivery system that enables farmers to rapidly implement SSNM for their individual fields. Satyanarayana *et al*., (2012) evaluated NE in CA-and Conventionally till (CT) maize during *kharif* (rainy season) and *rabi* (winter) season in South India. Nutrient recommendations from NE-Maize were tested against farmers' practice (FP) and blanket state recommendation (SR) during both the growing seasons. Across seasons, NE recorded higher grain yield in CA (9.3 t/ha) in comparison to CT (8.4 t/ha). Other diagnostic tools such as the nitrogen nutrition index (NNI) may be used to determine the level of plant N nutrition and is calculated by dividing the actual N concentration by the critical N concentration (Nc). Nc is defined as the minimum N concentration in shoot biomass required for maximum growth. The NNI is considered as a reference tool for assessing plant N status, but has limitations at the farm level as the actual crop biomass and its N concentration need to be determined at different growth stages which can be difficult. A more simplified method to evaluate crop N status and estimate NNI is needed.

4. PHOSPHORUS MANAGEMENT AND ITS DYNAMICS IN CONSERVATION AGRICULTURE

Conservation tillage in most cases improves the availability of surface phosphorus by converting it into organic phosphorus. Plants take up P from below, "mining" and depositing it on the surface. In conventional tillage systems, P is remixed into the soil profile, whereas in conservation tillage P accumulates at the soil surface. Therefore, conservation of P may be a potential benefit of conservation tillage, improving P availability. Study found higher extractable P levels in zero tillage compared with tilled soil (Duiker and Beegle, 2006). This is because reduced mixing of fertilizer P with the soil leads to lower P-fixation. This is an important benefit when P is limiting, but may be a threat when there is excess P due to the possibility of soluble P losses in runoff water (Duiker and Beegle, 2006). After 20 years of zero tillage, extractable P was 42% greater at 0–5 cm, but 8–18% lower at 5–30 cm depth compared with conventional tillage treatments in a silt loam soil (Ismail *et al*., 1994). Others found higher extractable P levels in zero tillage compared to tilled topsoil (Unger, 1991). Concentrations of P are higher in the surface layers of all tillage systems compared to deeper layers, but are most striking in zero tillage (Duiker and Beegle, 2006). Conservation agriculture improves labile pool of P in soil which supports in P nutrition to plants. Study revealed that among inorganic P-fraction, Ca-P fraction decreased and other fraction remains unaffected in surface soil with addition of crop residue (Kumawat *et al*., 2016). Various inorganic fractionations behaved differently with CR treatment. Soluble and loosely bound phosphorus was increased due to the CR retention while other bound P- pools *viz*. Al and Fe-bound, reductant soluble, Ca-bound pools was negatively affected by CR retention at the surface of the soil. On an average the total inorganic P pools decreased due to CR retention. It is cleared that forms of P in soil to a large extent are influenced by organic matter application.

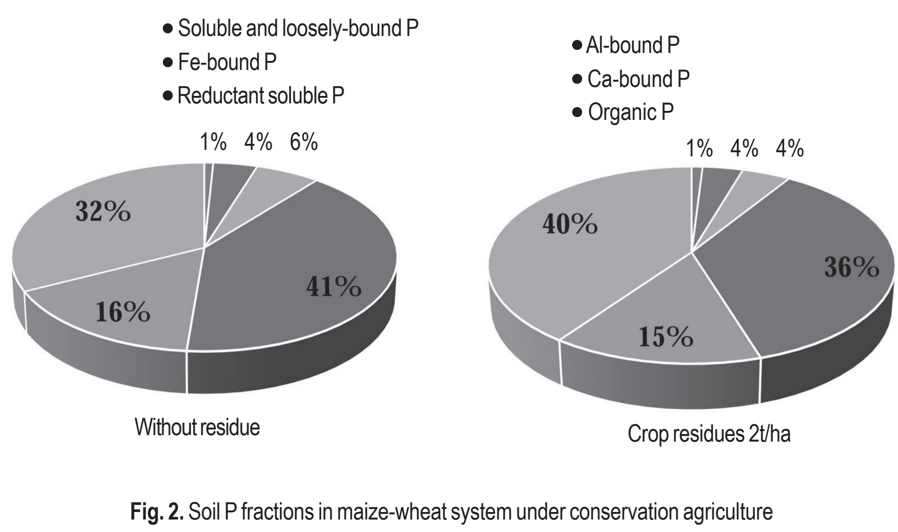

Fig. 2. Soil P fractions in maize-wheat system under conservation agriculture

When P fertilizers are used on the soil surface, a part of P will be directly fixed by soil particles making it unavailable for the crop plants. However, when P was banded as a starter application below the soil surface, there was P stratification which was taken up by the crop plants (Duiker and Beegle, 2006). This suggests that there may be less need for P starter fertilizer in long-term zero tillage because of high available P levels in the topsoil where the seed is placed (Duiker and Beegle, 2006). Placement of P in zero tillage deeper in the soil may be beneficial if the surface soil dries out frequently during the growing season. However, if mulch is present on the soil surface in zero tillage, the surface soil is likely to be moister than conventionally tilled soils and the need for deep P placement is unlikely, especially in humid areas. Extractable P is redistributed in zero tillage compared with conventional tillage which is likely a direct result of surface placement of crop residues (CR) leading to accumulation of SOM and microbial biomass near the surface (Duiker and Beegle, 2006). However, others found higher extractable P levels below the tillage zone, probably due to accumulation of P in senescent roots and the higher SOC content of the soil (Franzluebbers and Hons, 1996). In contrast, studies by (Roldan *et al.*, 2007) showed that available P was not affected by tillage system, soil depth, and crop type. A significant improvement in phosphorus use efficiency (PUE) was observed under increasing levels of crop residue retention and P fertilization (Fig. 4) (Kumawat *et al.*, 2016). Crop residue retention rates increased the PUE of maize from 17.2 (control) to 18.1% (6 t crop residues/ha). Average apparent recovery of P in maize (28.2%) was highest when 50% recommended dose of P (RDP) + phorphorus solublizing bacteria (PSB) and arbuscular mycorrhizal (AM) was

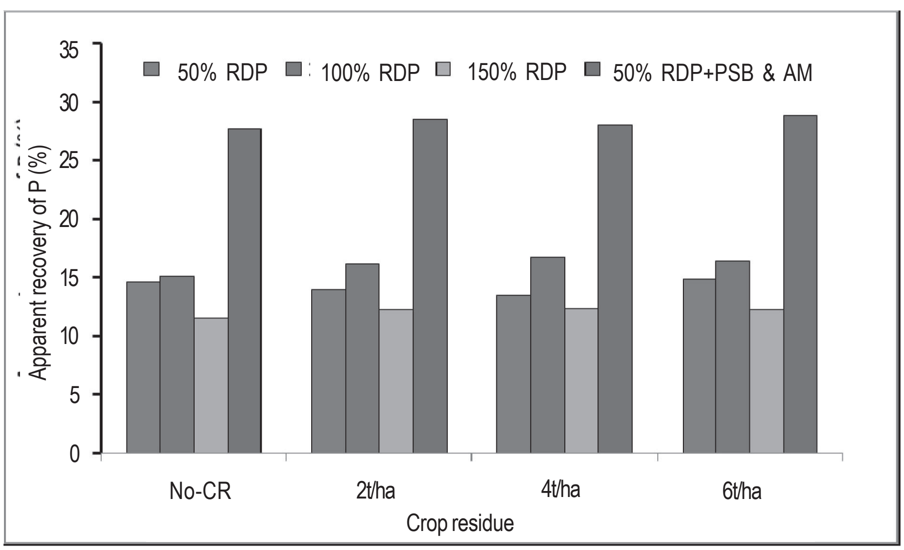

Fig. 4. Effect of phosphorus management and crop residues on apparent P recovery in maize under CA (average of 2 years)

used. These result showed a significant P fertilizer can be curtailed from RDP under conservation agriculture without compromises the yield of crops.

5. POTASSIUM MANAGEMENT AND ITS DYNAMICS IN CA

After nitrogen and phosphorus, potassium (K) is the nutrient most likely to limit plant production. In conservation tillage systems, K stays at the surface because it is not remixed by tillage. This redistribution of K can limit its availability to deep-rooted crops or increase salinity problems. Cover cropping and conservation tillage may conserve K by taking up and redistributing it to the soil surface. Zero tillage conserves and increases the availability of K and other nutrients near the soil surface where crop roots proliferate (Franzluebbers and Hons, 1996). Govaerts *et al*. (2007) reported 1.65 and 1.43 times higher K concentrations in the 0–5 cm and 5–20 cm layers, respectively, on permanent raised beds than conventionally tilled raised beds, both with crop residue retention. A higher extractable K levels at the soil surface with decreased tillage intensity has also been reported (Lal *et al*., 1990; Unger 1991). Du Preez *et al*. (2001) found higher levels of K in zero tillage compared to conventional tillage, and this effect declined with depth. However, others found surface accumulation of available K irrespective of tillage practice (Duiker and Beegle, 2006). There is no clear trend with regard to soil extractable K as some authors reported either higher or similar extractable K levels in zero tillage compared to mouldboard tillage, while others reported no effect of tillage or depth on available K concentrations (Roldan *et al*., 2007). In contrast, Standley *et al*. (1990) observed higher exchangeable K in the topsoil (0–2 cm) when sorghum stubble was retained rather than removed. The increased K concentration was more pronounced for wheat than for maize because wheat takes up large amounts of K, and most of this remains in harvest residues (Du Preez *et al*., 2001). K accumulated in the rows of the previous crop, probably because it leached from the crop residue that accumulated there (Duiker and Beegle, 2006). Studies on soil K pools under maize-wheat, cotton-wheat and pigeonpea-wheat systems revealed an improvement or maintenance in the non-exchangeable K (NEK) in CA treatments, whereas a decline in the same was noticed under conventional tillage with residue removal. Available K content varied with cropping systems, but the differences due to tillage practices were not as apparent as in case of NEK, suggesting thereby the need for inclusion of NEK (donor pool) in the K fertility evaluation.

There are some possible mitigation strategies to combat the issue of increasing potassium use efficiency under conservation agriculture through use of conventional sources of K like silicate minerals and use of bio-intervention to speed up the K release rate, especially by the microbial activity in the rhizosphere region, known as K solubilising microorganisms (KSM). They mainly include bacteria (*B. mucilaginosus, B. edaphicus etc*.) and some fungi (*Aspergillus niger, A. fumigatus etc*.) which are reported in several studies (Table 1) and explained the mode of action along with outcome (Table 2), but bacteria are the most dominant members. Apart from this, some arbuscular mycorrhizal fungi (AMF) can also release nutrient element including K from the mineral structure by releasing protons, organic acids in surrounding environments.

Table 1. Potassium solubilising microbes (KSMs) involved in solubilisation of K from minerals

Microbes	*Predominant acid produced*	*References*
Bacteria		
Bacillus mucilaginsus	Oxalic and citric	Liu *et al*. (2006)
Bacillus edaphicus	Oxalic and tartaric	Sheng and He (2006)
Fungi		
Apergillus niger	Citric, glycolic and succinic	Sperberg (1958)
Aspergillus fumigatus	Succinic and acetic	Song *et al*. (2014)
Arbuscular mycorrhizal fungi		
Glomus mosseae	Citric, malic and oxalic	Yousefi *et al*. (2011)
Glomus intraradices	Citric, malic and oxalic	Yousefi *et al*. (2011)

Table 2. Summary of experiments of mobilization of K from silicate minerals through bio-intervention

Type of experiment	*Mineral*	*Microbial strain/ bioagent*	*Outcome*	*References*
Laboratory study	Feldspar	*Bacillus cereus*	Increased K release from feldspar	Badr (2006)
Laboratory study	Mica	*Bacillus mucilaginosus*	K release increased by 66% from mica	Liu *et al*., (2006)
Composting	Waste mica	*Aspergillus awamori*	Sharp increase in water soluble K after 120 days	Nishanth and Biswas (2008)
Laboratory study	Feldspar and illite	*Aspergillus fumigatus*	Drastically increased K release from the K mineral	Lian *et al.* (2008)

6. CONCLUSION

Nutrient dynamics is a critical controller in comprehending the nutrient fluxes and budgeting under conservation agriculture based systems. Under conservation agriculture, it is characterized by soil physico-chemical properties, crops/cropping systems followed, amount and type of residue use, and fertilizer management practices adopted. Conjuctive use of crop residue cover with 4R nutrient stewardship approach considering economic, social, and environmental dimensions of fertilizer management has immense potential to enhance nutrient use efficiency and production sustainability under conservation agriculture. Future researches, therefore, must thrust upon developing cropping system specific management protocols under conservation agriculture.

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Macro and Micronutrient Availability under Conservation Agriculture

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Soils health maintenance is an essential component of sustainable agriculture for achieving food production and security. In the recent past, the soil resource has been taken granted for many uses and thus, is under tremendous pressure. Agriculture production cannot be attained on sustainable basis to meet ever growing demand with the present rate of declining resource base. Thus, converting from conventional practices to conservation agriculture will help in sustaining soil health by improving soil organic carbon (SOC), aggregation, infiltration and reducing erosion losses. Conservation agriculture (CA) practices comprise of minimum soil disturbances, providing a soil cover (at least 30%) through crop residues or other cover crops, and crop rotations for achieving higher productivity. This has emerged as a way for transition to the sustainability of intensive cropping systems (Friedrich *et al*., 2012). In the conventional systems involving intensive tillage, there is gradual decline in SOC through accelerated oxidation. Similarly, burning of crop residues causes pollution through greenhouse gases emission and loss of valuable plant nutrients. Intensive seed-bed preparation with heavy machinery leads to decline in soil fertility, biodiversity and accelerated soil erosion. When the crop residues are retained on soil surface in combination with, it initiates processes that lead to improved soil quality and overall resource enhancement. Therefore, CA practices may lead to sustainable improvements in the efficient use of water and nutrients by improving nutrient balances and their availability. The present chapter describes the changes accrued for SOC status, nutrient availability and its management strategies under CA over conventional tillage systems.

1. NUTRIENT MANAGEMENT STRATEGY IN CA

Worldwide, zero tillage (ZT) farming systems have led to many benefits such as increased soil flora and fauna biodiversity, increased SOC, improved soil structure and fertility (Thomas *et al*., 2007; Radford and Thornton, 2011). Many studies concerning ZT farming systems have also demonstrated advantages in economic, environmental and soil quality aspects over conventional tillage (CT). However, adoption of continuous ZT has also contributed to the stratification of nutrients and organic carbon near the soil surface, thus nutrient application under CA needs to be standardized.

Unlike in conventional cultivation, nutrient management under CA farming is a challenging issue, application of manures and fertilizer nutrient in the amidst of crop residues is always a challenging task. Nutrient management strategies in CA systems would need to be attended based on the following four general aspects (Kassam and Friedrich, 2009a):

(i) the biological processes of the soil are improved so that all the soil biota are microorganisms are under favourable conditions and that soil organic matter and soil porosity are built up and sustained;

(ii) there is adequate biomass production and biological nitrogen fixation for keeping soil energy and nutrient stocks sufficient to support higher levels of biological activity, and for covering the soil;

(iii) there is an adequate access to all nutrients by plant roots in the soil, from natural and synthetic sources, to meet crop demand; and

(iv) soil acidity is kept within acceptable range for all key soil chemical and biological processes to function effectively and efficiently.

2. CONSERVATION AGRICULTURE BASED NUTRIENT MANAGEMENT PRACTICES

Integrated Soil Fertility Management (ISFM) and Integrated Natural Resources Management (INRM) approaches of various types and nomenclature have been in vogue in recent years in certain sections of the scientific community. Focusing on soil fertility but without defining the tillage and cropping system, as often proposed by ISFM or INRM approaches, is only a partial answer to enhancing and maintaining soil health and productivity in support of sustainable production intensification, livelihood and the environment.

Generally, such approaches are focused more on "feeding the crop" and meeting crop nutrient needs in an input-output sense rather than managing soil health and productive capacity as is the case with CA systems. Also, most of the work that is understood under broad term of ISFM or INRM over the past 15-20 years or so has been geared towards tillage-based systems of the first paradigm which have many unsustainable elements, regardless of farm size or the level of agricultural development. Unless the concepts of soil health and function are explicitly incorporated into ISFM or INRM approaches, sustainability goals and means will remain only unconnected and sustainable production will be difficult to achieve, particularly by resource poor farmers (Kassam and Friedrich, 2009). Thus, CA systems have within them their own particular sets of ISFM or INRM processes and concepts that combine and optimize the use of organic with inorganic inputs integrating temporal and spatial dimensions with soil, nutrient, water, soil biota, biomass dimension, all geared to enhancing crop and system outputs and productivities but in environmentally responsible manner. Over the past two decades or so, empirical evidence from the field has clearly shown that healthy agricultural soils constitute biologically active soil systems within landscapes in which both the soil resource and the landscape must operate with plants in an integrated manner to support the various desired goods and services namely food, fodder, livelihood, environmental services, etc provided by agricultural land use.

Moreover, CA principles and practices offer substantial benefits to all types of farmers in most agro-ecological and socio-economic situations, CA-based IFSM and INRM approaches to nutrient management and production intensification would be more effective for farmer-based innovation systems and learning processes such as those promoted through Farmer Field School networks/ Farm Science Centre.

3. ADOPTING CONSERVATION AGRICULTURE BASED NUTRIENT MANAGEMENT FRAMEWORK

Conservation agriculture has now emerged as a major "breakthrough" systems approach to crop and agriculture production with its change in paradigm that challenges the status quo. However, as a multi-principled concept, CA translates into knowledge-intensive practices whose exact form and adoption requires that farmers become intellectually engaged in the testing, learning and fine tuning possible practices to meet their specific ecological and socio-economic conditions (Friedrich and Kassam, 2009b).

However, CA approach represents a highly biologically and bio-geophysical-integrated system of soil health and nutrient management for production that generates a high level of "internal" ecosystem services which reduces the levels of "external" subsidies and inputs needed. Conservation agriculture provides the means to work with natural ecological processes to harness greater biological productivities by combining the potentials of the endogenous biological processes with those of exogenous inputs. The evidence for the universal applicability of CA principles is now available across a range of ecologies and socio-economic situations covering large and small farm sizes worldwide, including resource poor farmers (Goddard *et al*., 2007).

There are many different ecological and socio-economic starting situations in which CA has been and is being introduced. They all impose their particular constraints as to how fast the transformation towards CA systems can occur. In the seasonally dry tropical and sub-tropical ecologies, particularly with resource poor small farmers in drought prone zones, CA systems will take longer time to establish, and step-wise approaches to the introduction of CA practices seem to show promise (Mazvimavi and Twomlow, 2006). These involve two components: the application of planting '*Zai-type*' basins which concentrate limited nutrients and water resources to the plant, and the precision application of small or micro doses of nitrogen-based fertilizer. In the case of degraded land in wet or dry ecologies, special soil amendments and nutrient management practices are required to establish the initial conditions for soil health improvement and efficient nutrient management for agricultural production (Landers, 2007). However, it is necessary to have a clear understanding about the CA system and should be followed holistically to sustain soil health and productivity. Moreover, efficient nutrient management interventions may be proposed which can contribute to the system effectiveness as a whole both in the short- and long-term.

4. CONSERVATION AGRICULTURE AND SOIL ORGANIC CARBON

Conservation agricultural systems have been successfully developed for many different regions of the world. These systems, however, have not been widely adopted by farmers for political, social and cultural reasons. Through greater adoption of conservation agricultural systems, there is enormous potential to sequester soil organic carbon, which would help to mitigate greenhouse gas emissions contributing to global warming. It also increase soil productivity and avoid further environmental damage from the unsustainable use of inversion tillage systems, which threaten water quality, reduce soil biodiversity, and erode soil around the world.

Crop residues retained on the soil surface in conservation agriculture (Plate 1), in general, serve a number of beneficial functions, including soil surface

Maize-gram system Soybean-wheat system

Plate 1. Residue retention under soybean-wheat and maize-gram system in vertisols of central India

protection from erosion, enhancing infiltration and cutting run-off rate, decreasing surface evaporation losses of water, moderating soil temperature and providing substrate for the activity of soil micro-organisms, and a source of SOC. Long-term implementation of conservation agricultural practices also increases organic matter levels in the soil. Lower soil temperatures and increased soil moisture contributes to slower rates of organic matter oxidation. An increase in organic matter is normally observed within the surface soil (0-10 cm) which helps in better soil aggregation. Carbon turnover rate slows down when soil aggregation increases and SOC is protected within stable aggregates (53-250 μm).

Zero tillage or reduced tillage have received attention due to their ability to both reduce soil erosion and increase C sequestration in agricultural surface soils (Cole *et al*., 1997) by increasing aggregate stability. Alvarez (2005) reviewed the effect of nitrogen and ZT on SOC from 137 sites, concluded that nitrogen fertilizer increased SOC but only when crop residue were retained. Furthermore, nitrogen fertilizer use in tropics resulted in no SOC sequestration while in the temperate regions, there was a trend towards increasing SOC sequestration. After 22 years of no-till, Dalal (1992) found that soil total nitrogen decreased with the period of cropping irrespective of the tillage practices in subtropical cereal cropping in Australia. Similarly, Dalal *et al*. (2011) reported that tillage effects on SOC and soil total nitrogen were small following 40 years of no-tillage in vertisols of Queensland region. Crop residue and N fertilizer interactively increased SOC and total N stocks in 0-0.1m depth and cumulative stocks at 0-0.2 m and 0-0.3 m depth. It was evident that crop residue retention increased SOC and soil total N only when N fertilisers was applied.

In contrast to CA, conventional cultivation generally results in loss of soil C and nitrogen. However, CA has proven potential of converting many soils from sources to sinks of atmospheric C, sequestering carbon in soil as organic matter. In general, soil carbon sequestration during the first decade of adoption of best conservation agricultural practices is 1.8 tons CO/ha/yr. On 5 billion hectares of agricultural land, this could represent one-third of the current annual global emission of CO from the burning of fossil fuels (FAO, 2008). Lal *et al*. (1998) estimated that widespread adoption of conservation tillage on some 400 million ha of crop land by the year 2020 may lead to total C sequestration of 1500 to 4900 Mg.

Crop residue burning is although a quick, labour-saving practice to get rid of residue that is viewed as a nuisance by farmers (Plate 2). Residue-burning, however, has several adverse environmental and ecological impacts. The burning of dead plant material adds a considerable amount of CO_2 and particulate matter to the atmosphere and can reduce the return of much needed C and other nutrients to soil (Prasad *et al*., 1999). Lack of soil surface cover due to burning or removal of the crop residues increases the loss of mineral and organic matter–rich surface layer in run-off. In comparison to burning, residue retention increases soil carbon and nitrogen stocks, provides organic matter necessary for soil macro-aggregate formation and fosters cellulose–decomposing fungi and thereby carbon cycling.

Plate 2. Pictorial view of residue burning

Crop residues returned to the soil, on the other hand, help increase SOM levels, which facilitate greater infiltration and store greater water in the soil profile. Crop residues provide substrate to soil organisms which help in recycling of the plant nutrients. Leaving crop residue on the field is another practice which could have an important impact on the global carbon cycle. The annual production of crop residue is estimated to be about 3.4 billion Mg in the world. If 15% of C contained in the residue can be converted to passive SOC fraction, this may lead to C sequestration at the rate of 0.2 x $l0^{15}$ g/yr (Lal, 1997). Similarly, restoring presently degraded soils, estimated at about 2 billion ha, and increasing SOC content by 0.01% /yr may lead C sequestration at the rate of 3.0 Pg C/yr. Systems, based on high crop residue addition and no-tillage, tends to turn the soil into a net sink of carbon (Bot and Benites, 2001).

In the USA, the total loss of carbon, from a plot of ploughed under wheat residues, was up to five times higher than from plots not ploughed, and the loss of carbon was equal to the quantity of carbon in the wheat residues which had remained in the field from the previous crop (CTIC, 1996a). Conservation tillage adoption on three-quarter of the land would half this respired CO_2 as compared to 1993, representing an accrual of almost 400 million tons (Bot and Benites, 2001). Net soil C stock changes for US agricultural soils between 1982 and 1997 due to shifts towards conservation agriculture are estimated to amount to 21.2 MMT C/year (Eve *et al*., 2002). At an average rate of 0.51 t/ha/year, Brazil is sequestering about 12 million t of carbon on 23.6 million ha of no-tillage adoption. In Canada, at a CO_2 sequestration rate of 0.74 t/ha farmers practicing no-till would be sequestering about 9 million tons of CO_2 from the atmosphere each year, while at the same time enriching the soil in carbon (Bot *et al*., 2001). It is estimated that wide dissemination of conservation agriculture (which leaves at least 30% of plant residue cover on the surface of the soil after planting) could offset as much as 16% of worldwide fossil fuel emissions (CTIC, 1996b).

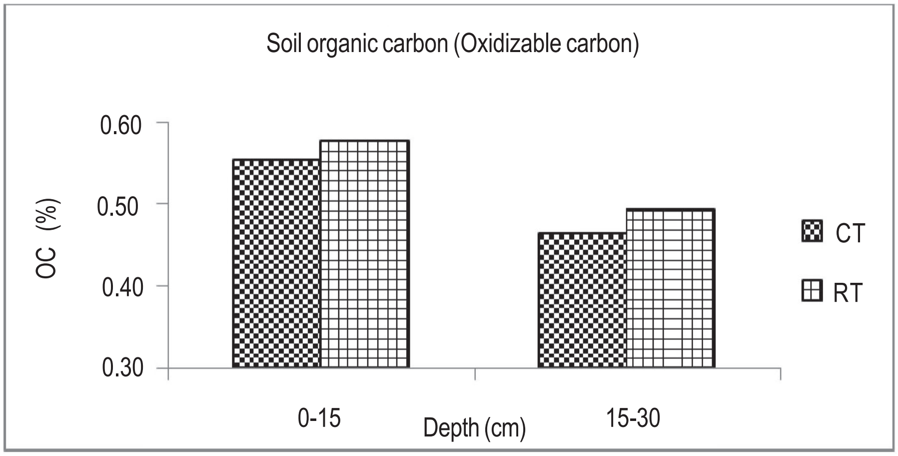

Fig. 1. Effect of different tillage on soil organic carbon

A study conducted at Bhopal also reveals effect of tillage systems on SOC was found to significant only at surface layer (0-15cm) and higher SOC value observed under reduced tillage (RT) as compared to conventional tillage (CT) after three years of crop cycles (Fig. 1). Further, reduction in tillage operation coupled with residue retention helps in maintaining the SOC (Somasundaram *et al*., 2014; Subba Rao and Somasundaram, 2013). Similarly, reports suggest that reduction in tillage intensity led to a significantly larger SOC accumulation in the surface soil layer (0–5 cm), but not in the 5- to 15-cm soil layer after 6 yr of cropping in a sandy clay loam soil (Typic Haplaquept) near Almora, India. The year-round (NT) management practice was very effective for SOC sequestration in a rainfed lentil–finger millet rotation system (net gain in SOC storage was about 0.37 Mg/ha/yr in the 0- to 15-cm soil layer)

5. CONSERVATION AGRICULTURE AND NUTRIENT AVAILABILITY

Tillage, residue management and crop rotation have a significant impact on nutrient distribution and transformation in soils, usually related to the effects of conservation agriculture on SOC contents. Similar to the findings on SOC, distribution of nutrients in a soil under zero tillage is different to that in tilled soil. Increased stratification of nutrients is generally observed, with enhanced conservation and availability (Franzluebbers and Hons, 1996). The altered nutrient availability under zero tillage compared to conventional tillage may be due to surface placement of crop residues in comparison with incorporation of crop residues with tillage (Ismail *et al*., 1994). Slower decomposition of surface placed residues (Kushwaha *et al*., 2000) may prevent rapid leaching of nutrients through the soil profile, which is more likely when residues are incorporated into the soil. However, the possible development of more continuous pores between the surface and the subsurface under zero tillage may lead to more rapid passage of soluble nutrients deeper into the soil profile than when soil is tilled (Franzluebbers and

Hons, 1996). Furthermore, the response of soil chemical fertility to tillage is site-specific and depends on soil type, cropping systems, climate, fertilizer application and management practices (Rahman *et al*., 2008).

The density of crop roots is usually greater near the soil surface under zero tillage compared to conventional tillage (Qin *et al*., 2004). This may be common under zero tillage as in the study of Mackay *et al*. (1987) a much greater proportion of nutrients was taken up from near the soil surface under zero tillage than under tilled culture, illustrated by a significantly higher P uptake from the 0–7.5 cm soil layer under zero tillage than under conventional tillage. However, research on nutrient uptake by Hulugalle and Entwistle (1997) revealed that nutrient concentrations in plant tissues were not significantly affected by tillage or crop combinations. Although there are reports of straw burning increasing nutrient availability (Du Preez *et al*., 2001), burning crop residues is not considered sustainable given the well documented negative effects on physical soil quality, especially when it is combined with reduced tillage (Limon-Ortega *et al*., 2002). Mohamed *et al*. (2007) observed only short-term effects of burning on N, P and Mg availability. As a consequence of the short-term increased nutrient availability limited nutrient uptake by plants after burning, leaching of N, Ca, K, and Mg increased significantly after burning (Mohamed *et al*., 2007).

In fact, crop residues are the main source of organic matter (C constitutes ~ 40% of the total dry biomass) as well as good sources of plant nutrients added to the soil, and are important components for the stability of agricultural ecosystems. About 40% of the N, 30-35% of the P, 80-85% of the K, and 40-50% of the S absorbed by rice remain in the vegetative parts at maturity (Dobermann and Fairhurst, 2000). According to Van Duivenbooden (1992), mean N, P and K accounts in rice straw were 6.2 kg N, 1.1 kg P and 18.9 kg K/t of straw. Potassium concentration is usually higher (up to 25 kg/t) in rice straw of North-western IGP compared to other regions of the India or other countries.

5.1 Nitrogen Availability

The presence of mineral soil N available for plant uptake is reliant on the rate of C mineralization. The literature concerning the impact of reduced tillage with residue retention on N mineralization is inconclusive. Indeed, ZT is usually associated with a lower N availability because of higher immobilization by the residues left on the soil surface (Bradford and Peterson, 2000). Some authors suggest that the net immobilization phase when zero tillage is adopted, is transitory, and that in the long run, the higher, but temporary immobilization of N in zero tillage systems reduces the opportunity for leaching and denitrification losses of mineral N (Follet and Schimel, 1989). According to Schoenau and Campbell (1996), a greater immobilization in conservation agriculture can enhance the conservation of soil and fertilizer N in the long run, with higher initial N fertilizer requirements decreasing over time because of reduced losses by erosion and the build-up of a larger pool of readily mineralizable organic N.

Tillage increases aggregate disruption, making organic matter more accessible to soil microorganisms and increasing mineral N release from active and physically protected N pools (Six *et al*., 2002). Lichter *et al*. (2008) reported that permanent raised beds with residue retention resulted in more stable macro aggregates and increased protection of C and N in the micro aggregates within the macro aggregates compared to conventionally tilled raised beds. This increases susceptibility to leaching or denitrification if no growing crop is able to take advantage of these nutrients at the time of their release. Randall and Iragavarapu (1995) reported about 5% higher NO -SN losses with conventional tillage compared to zero tillage. Jowkin and Schoenau (1998) report that N availability was not greatly affected in the initial years after switching to zero tillage in the brown soil zone in Canada. Larney *et al*. (1997) reported that, after eight years of the tillage treatments, the content of N available for mineralization was greater in zero-tilled soils than in conventionally tilled soil under continuous spring wheat. Wienhold and Halvorson (1999) found that nitrogen mineralization generally increased in the 0-5 cm soil layer, as the intensity of tillage decreased.

Govaerts *et al*. (2006) reported after 26 cropping seasons in a high-yielding, high input irrigated production system that the N mineralization rate was higher in permanent raised beds with residue retention than in conventionally tilled raised beds with all residues incorporated, and also that N mineralization rate increased with increasing rate of inorganic N fertilizer application. The tillage system determines the placement of residues. Conventional tillage implies incorporation of crop residues while residues are left on the soil surface in the case of zero tillage. These differences in the placement of residues contribute to the effect of tillage on N dynamics. Kushwaha *et al*. (2000) reported that incorporated crop residues decompose 1.5 times faster than surface placed residues. However, also the type of residues and the interactions with N management practices determine C and N mineralization.

Hati *et al*., (2015) reported that SOC content at 0–15 cm depth was significantly higher in no-tillage (NT), reduced tillage (RT) and mouldboard tillage (MB) where wheat residues were retained after harvest than that in CT system. The SOC, aggregate stability and saturated hydraulic conductivity were significantly higher in N150% compared to N50%. Similarly, Kushwa *et al*. (2016) reported from the same experiment that the highest SOC was observed in NT (8.8 g/kg) and the lowest was under CT (5.9 g/kg) in 0-5 cm depth, whereas in 5-15 cm soil layer, higher SOC was observed in MB. The stratification ratio of SOC was higher in NT (2.20) followed by RT (1.93), MB (1.68) and CT (1.51). Higher available phosphorous concentration (12.8 g/kg) was recorded in NT with N50% followed by NT with N100%. They suggested that practising and reduced tillage systems with residue retention and recommended rate of N would be a suitable practice for sustainable production of soybean–wheat cropping system in vertisols of central India.

5.2 Phosphorus Availability

Numerous studies have reported higher extractable phosphorus (P) levels in zero tillage than in tilled soil, largely due to reduced mixing of the fertilizer P with the soil, leading to lower P-fixation. This is a benefit when P is a limiting nutrient, but may be a threat when P is an environmental problem because of the possibility of soluble P losses in runoff water (Duiker and Beegle, 2006). After 20 years of zero tillage, extractable P was 42% greater at 0-5 cm, but 8-18% lower at 5-30 cm depth compared with conventional tillage in a silt loam (Ismail *et al*., 1994). Also Matowo *et al*. (1999) found higher extractable P levels in zero tillage compared to tilled soil in the topsoil. Accumulation of P at the surface of continuous zero tillage is commonly observed. Concentrations of P were higher in the surface layers of all tillage systems as compared to deeper layers, but most strikingly in zero tillage (Duiker and Beegle, 2006). When fertilizer P is applied on the soil surface, a part of P will be directly fixed by soil particles. When P is banded as a starter application below the soil surface, authors ascribed P stratification partly to recycled P by plants (Duiker and Beegle, 2006). Duiker and Beegle (2006) suggested that there may be less need for P starter fertilizer in long-term zero tillage due to higher available P levels in the surface soils. Deeper placement of P in zero tillage may be profitable if the surface soil dries out frequently during the growing season as suggested by Mackay *et al*. (1987). In that case, injected P may be more available to the crop. However, if mulch is present on the soil surface in zero tillage the surface soil is likely to be moister than conventionally tilled soils and there will probably be no need for deep P placement, especially in humid areas. Kushwah *et al*. (2016) also reported that wheat residue either incorporated or retained on the soil surface increased the availability of P and SOC content as compared to the common practices of residue burning. Residue retention or incorporation increased stratification of P and SOC over the residue burning. Irrespective of the nutrient treatments, greater stratification ratio of SOC and P were registered under wheat residue incorporation or retention compared to residue burning.

5.3 Potassium Availability

Zero tillage conserves and increases availability of nutrients, such as K, near the soil surface where crop roots proliferate (Franzluebbers and Hons, 1996). According to Govaerts *et al*. (2007), permanent raised beds had a concentration of K 1.65 times and 1.43 times higher in the 0-5 cm and 5-20 cm layer, respectively, than conventionally tilled raised beds, both with crop residue retention. In both tillage systems, K accumulated in the 0-5 cm layer, but this was more accentuated in permanent than in conventionally tilled raised beds. Other studies have found higher extractable K levels at the soil surface as tillage intensity decreases (Lal *et al*., 1990). Du Preez *et al*. (2001) observed increased levels of K in zero tillage compared to conventional tillage, but this effect declined with depth. Some authors have observed surface accumulation of available K irrespective of tillage practice (Duiker and Beegle, 2006). Follett and Peterson (1988) observed either higher or similar extractable K levels in zero tillage compared to mould board tillage, while Roldan *et al*. (2007) found no effect of tillage or depth on available K concentrations.

5.4 Micro-nutrient Availability

Indeed, nutrient management strategies in CA systems would need to be attended considering balance of soil biological, chemical processes to function effectively and efficiently (Kassam and Friedrich, 2009a). Therefore, nutrient management practices in CA systems cannot be looked to simple physical input-output model. While there is much new work that needs to be done to formulate nutrient management strategies in CA systems, it would appear to us that all such strategies would need to ensure that soil health as indicated above becomes the means of meeting crop nutrient needs in an optimum and cost-effective way within the prevailing ecological and socio-economic conditions (Kassam and Friedrich, 2009b). Similar to major-nutrients, micro-nutrient namely zinc (Zn), iron (Fe), copper (Cu) and manganese (Mn) tend to be present in higher levels under zero tillage with residue retentions as compared to conventional tillage, particularly extractable Zn and Mn near the surface layer due to surface placement of crop residues (Franzluebbers and Hons, 1996; López-Fando and Pardo, 2009). In contrast, Govaerts *et al*. (2007) reported that tillage practice had no significant effect on the concentration of extractable Fe, Mn and Cu, but the concentration of extractable Zn was significantly higher at 0-5 cm layer of permanent raised beds as compared to conventionally tilled raised beds with residue retention. Similar results were reported by Du Preez *et al*. (2001) and Franzluebbers and Hons (1996). In fact, Govaerts *et al*. (2007) reported that residue retention significantly decreased concentrations of extractable Mn in the surface layer (0-5 cm) in permanent raised beds. According to Peng *et al*. (2008), Mn concentrations are increased by higher SOM contents. From the literature, it is also apparent that even a reduction in tillage leads to enhanced chemical, microbial activity and biomass as compared to soils under conventional tillage (Feng *et al*., 2003). Similarly, López-Fando and Pardo (2009) reported that available Zn stock was higher under ZT compared to other tillage systems but with little difference. Available Cu showed similar trend with no significant differences among tillage regimes. Available Fe stocks in 0-5cm depth was higher, however it was similar between other tillage treatments such as ZT, zone-tillage subsoiling with a paraplow (ZT) and minimum tillage with chisel plow (MT) MT and conventional tillage with mouldboard plow (CT) in semi-arid region of Alfisols (Calcic Haploxealf) in Central Spain.

Santiago *et al*. (2008) reported that Mn, Cu, and Zn concentration in plants were all higher under ZT than under conventional and minimum tillage systems. This was ascribed to the increase in soil organic matter under ZT systems.

It is evident from the literature that conservation tillage practices coupled with residue retention/incorporation have favoured the nutrient availability in soils (Jat *et al*., 2011). A study conducted at RAU Research Farm, Pusa in light textured highly calcareous soil indicated that addition of crop residue significantly increased the grain and straw yields of both rice and wheat crops. Increasing levels of crop residue increased the mean grain and straw yields of rice from 2.69 to 3.38 and 6.31 to 7.55, and that of wheat from 3.1 to 3.77 and 3.90 to 4.96 t/ha, respectively. The residual effect of Zn levels was found significant where higher Zn application have increased the mean grain and straw yield of rice from 2.80 to 3.18 and 6.88 to 7.01 t/ha, respectively. In case of wheat after16th crop cycles, the increase in grain and straw yields was due to residual effect of Zn and it was in the range between 3.26 and 3.52 and 4.19 to 4.78 t/ha, respectively. Highest yield in both the crops was recorded in treatment receiving 10 kg Zn/ha to the first crop only along with 100 % of the straw produced by each crop. The residual value of 5 kg Zn/ha + 100 % of crop residue was the next promising treatment in enhancing the crops yield. Magnitude of yield increase in rice was higher than wheat. This indicates that rice is benefitted more than wheat from crop residue incorporation which may be due to fact that wheat crop is sown just after rice straw incorporation which is not properly decomposed whereas by the time rice is transplanted after wheat harvest the wheat straw might be thoroughly decomposed providing more nutrients to subsequent rice crop. Similarly, conservation tillage practices coupled with residue retention/ incorporation have favoured the micronutrient availability (Zn, Fe, Mn and Cu) in soils (Somasundaram *et al*., unpublished data).

Increasing levels of crop residue appreciably enhanced the quantity of DTPA extractable micronutrients namely Zn, Fe, Mn, and Cu in soil. Available Zn in post - harvest soils after 8 cycles of rotation increased from 0.42 to 1.64 mg/kg due to crop residue incorporation and residual Zn levels (Table 2). Increasing levels of crop residue increased the average soil available Zn from 0.47 to 1.19 mg/kg and residual Zn increased it from 0.56 to 1.02 mg/kg. In presence of residual Zn, the increasing levels of crop residue progressively increased the available Zn status of soil from deficiency to adequacy level. Moreover, the effect of Zn, crop residue and their interaction was found significant on soil available Zn status. Similar trend were followed for Fe, Mn and Cu. The available Mn content in post-harvest soil of 16th crop wheat varied from 4.23 to 4.89 mg/ kg (Table 2). The available Mn was significantly decreased due to Zn levels while it was increased due to crop residue levels. In fact, mean data of twenty years (1994-2014) indicate that varying levels of crop residue incorporation coupled with Zn application had significantly increase the build-up of micronutrient status in soils (Table 2; Fig 5).

Table 1. Effect of zinc and crop residue (CR) application on available Zinc, Iron, Manganese, and Copper (mg/kg) in post - harvest soil of rice-wheat system after 16 crop cycles in light texture (Calcareous) soils of Pusa, Bihar.

Zn levels (kg Zn/ha)	*Crop residue levels (% of straw produced)*				
	0	25	50	100	Mean
Zinc (Zn)					
0	0.42	0.43	0.59	0.78	0.56
2.5	0.44	0.58	0.82	1.06	0.73
5.0	0.48	0.74	0.89	1.27	0.85
10.0	0.52	0.82	1.10	1.64	1.02
Mean	0.47	0.64	0.85	1.19	-
Iron (Fe)					
Zn levels	0	25	50	100	Mean
0	16.1	16.5	17.1	18.4	17.0
2.5	15.67	16.0	16.9	18.5	16.8
5.0	15.67	15.9	17.0	17.5	16.5
10.0	14.6	15.6	16.6	16.9	15.9
Mean	15.5	16.0	16.9	17.8	-
Manganese (Mn)					
Zn levels	0	25	50	100	Mean
0	3.13	3.20	3.41	3.63	3.34
2.5	3.18	3.14	3.40	3.61	3.33
5.0	3.14	3.12	3.34	3.41	3.25
10.0	3.01	3.09	3.32	3.36	3.20
Mean	3.12	3.14	3.37	3.50	-
Copper (Cu)					
Zn levels	0	25	50	100	Mean
0	4.49	4.56	4.75	4.89	4.67
2.5	4.49	4.53	4.67	4.75	4.61
5.0	4.36	4.46	4.58	4.69	4.52
10.0	4.23	4.31	4.46	4.52	4.38
Mean	4.39	4.47	4.62	4.71	-
CD (P= 0.05)					
	Zinc	Iron	Manganese	Copper	
CR	0.05	0.29	0.05	0.03	
Zn	0.03	0.34	0.05	0.10	
CRX Zn	0.06	0.68	0.11	0.19	

Increasing levels of crop residue application had significantly enhanced the quantity of Zn recycled in soil. After 8 crop cycles, it was observed that Zn concentration increased from 296 to 1665 g/ha under rice crop and from 231 to 1335 g/ha under wheat crop. Increasing level of Zn progressively enhanced the quantity of Zn recycled at all the three levels of crop residues incorporation. It was found that amount of Zn recycled by rice straw was higher than wheat straw due to higher straw yield and Zn content in rice straw as compared to wheat straw. In fact after 16^{th} crop, increasing levels of crop residue addition enhanced the average Zn addition from 527 to 3000 g/ha and residual Zn increased it from 1146 to 2152 g/ha (Table 2).

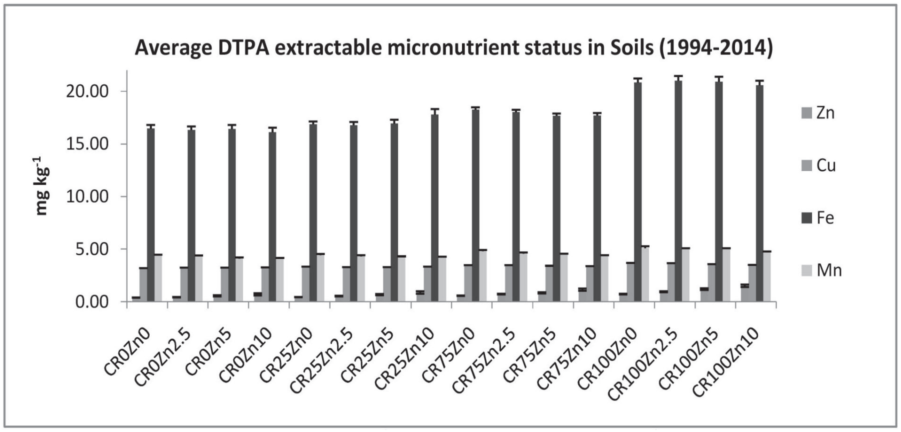

Fig. 2. Effect of long term crop residue (CR @ 0, 25, 50 and 100%) management and Zn application rate (Zn (@ 0, 2.5, 5.0 and 10 kg/ha) on DTPA extractable micronutrient at Pusa, Bihar

Table 2. Amount of Zn recycled (g/ha) at varying levels of crop residue (straw) incorporation and zinc application in rice-wheat system after completion of 8 crop cycles at Pusa, Bihar

Zn levels (kg Zn/ha^{-1})	*Crop residue levels (% of straw produced)*				
	0	*25*	*50*	*100*	*Mean*
Total zinc recycled (After 16 crops)					
0		372	937	2128	1146
2.5		478	1125	2540	1381
5.0		567	1379	3276	1741
10.0		689	1713	4055	2152
Mean		527	1289	3000	-

A study conducted at Bhopal indicated that the DTPA extractable available micro-nutrients namely Cu, Fe, Mn and Zn showed decreasing trend with increasing depth. Barring DTPA-Cu, Fe, Mn and Zn was significantly influenced ($p < 0.05$) by conservation tillage coupled with residue retention after four crop cycles, whereas cropping system had significant effect on DTPA-Cu and Fe only (Table 3).

Table 3. Effect of conservation tillage coupled with residue retention on micronutrient (mg/kg) status in vertisols of central India after four crop cycles

Depth (cm)	Conventional tillage with residue removed*				Conservation tillage with residue retention*			
	Fe	*Mn*	*Zn*	*Cu*	*Fe*	*Mn*	*Zn*	*Cu*
0-5	8.57	15.56	0.60	1.63	9.70	16.48	0.62	1.66
5-15	8.47	13.93	0.47	1.44	8.94	15.04	0.50	1.48
15-30	8.16	13.22	0.45	1.24	8.36	13.81	0.48	1.30
30-45	7.54	12.12	0.39	1.25	7.88	13.07	0.42	1.24

*indicates mean values of six cropping system (Somasundaram *et al*., unpublished data)

It is apparent that conservation tillage coupled with residue retention and crop rotations have a positive impact on micro-nutrient distribution in a vertisols of central India. Moreover, understanding the micronutrient status under conservation tillage will be helpful in strategizing nutrient recommendation and management in the region.

6. CONCLUSION

Conservation agriculture practices not only improve soil aggregation, infiltration and reducing soil erosion but also greatly influencing the nutrient availability in soils as compared to conventional agricultural practices. It is apparent that tillage, residue management and crop rotation have a significant impact on micro- and macronutrient distribution and transformation in soils. In fact, the altered nutrient availability may be due to surface placement of crop residues in comparison with incorporation of crop residues with tillage. Conservation agriculture increases availability of nutrients near the soil surface where crop roots proliferate. Slower decomposition of surface placed residues prevents rapid leaching of nutrients through the soil profile. Moreover, soils of India are potentially deficient in Zn (49%), Fe (12%), Mn (5%), Cu (3%) and B (33%). In order to overcome the micronutrient deficiencies basal application to soil and/or foliar spray of the deficient nutrient will be helpful in sustaining the crop yield. In addition to this, practicing conservation tillage coupled with residue retention/incorporation will also have a positive impact on micro-nutrient replenishment status in soils through residue recycling/decomposition.

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6

Water Management under Conservation Agriculture

Peeyush Sharma, Vikas Abrol and Neetu Sharma

Water is a vital component of agricultural production. It is expected that climate change will cause more extreme climate events including droughts and floods and shifts in plant growing zones. At present 2.8 billion people live in water-scarce areas, but by 2030, it is expected that about half of the world's population will live in water stressed areas. Recurrent droughts have often resulted in severe crop damage, decreased livestock production and widespread food shortages and the most severe impacts of droughts are felt in countries with agro-based economies.

Among all the sectors of the economy, agriculture is the most sensitive to water scarcity. Currently, agriculture accounts for 70% of global freshwater withdrawals, and more than 90% of its consumptive use. The net result is that agricultural water use is increasing the severity of water scarcity in some areas, and causing water scarcity even in areas that are relatively well endowed with water resources. India has a very formidable and challenging task of feeding 17.5% of the world's human population from a meager 2.3% of land area which is further constrained by the fact that the country has only 4% of the global water resources at its disposal. Around 40% of the world's food is produced on the 20% of land which is irrigated. About 80% of globally cultivated land is under with rainfed farming, accounting for 60% of world food production. Since under the balance between water demand and water availability has reached critical levels in many regions of the world and increased demand for water and food production is likely in the future, a sustainable approach to water resource management in agriculture is essential. 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.

1. CONSERVATION AGRICULTURE: SECTORAL SCENARIO

The three basic components of conservation agriculture (CA) are: (i) zero or minimum tillage, (ii) retention of crop residues on the soil surface and (iii) crop diversification. Minimal tillage reduces volume and velocity of surface runoff, leading to reduction in soil and water erosion and nutrient loss; incorporation of crop residues enhances soil water availability to plant. Crop diversification reduces the risk of crop failure due to biotic and abiotic stresses and is recognized as a cost-effective solution to build resilience into agricultural production system. Diversification also brings stability in soil fertility through cultivating legumes with cereals in rotation or intercropping system. The Food and Agriculture Organization of the United Nations (FAO) defines CA as application of modern agricultural technologies that collect and store rainwater to improve production, while at the same time, protecting and enhancing the land resources on which production depends. Conservation agriculture has positive effects on soil and water conservation, environmental health, and economic viability. Nowadays CA is practiced worldwide on about 125 m ha with fast growing production system (Table 1). In India, CA pratices got momentum during late 1990s mainly in cereal based systems of irrigated ecologies and presently 2.8 m ha lies under this management option.

Table 1. Global adoption of conservation agriculture worldwide

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.

2. WATER MANAGEMENT STRATEGIES

Irrigation water is a most precious input in crop production system. The technological options for improving water use efficiency varies with crop grown and cropping system followed land texture, topography, available soil moisture regimes and resource endowed with farmers. The important means for improving water use efficiency are being discussed here as under.

2.1 Improving Water Use Efficiency in Irrigated Ecosystem

2.1.1 Quantity and Time of Irrigation

Irrigation is the artificial application of water to land for the purpose of agricultural production. Effective irrigation will influence the entire growth process from seedbed preparation, germination, root growth, nutrient utilization, plant growth, yield and quality. The key to maximizing irrigation efficiency is its uniform application. The important systems and method of irrigation which regulate the quantity and time of irrigation are describe below (Table 2).

Table 2. Different systems and method of irrigations used in agricultural production system

System	*Method*	*Description*
Surface gravity irrigation in which the water is not pumped but flows and is distributed by gravity.	Flood	The application of irrigation water where the entire surface of the soil is covered by ponded water.
	Furrow	Water is applied in furrows for row crops or fruit trees
	Border	Water is applied to sloping strips of fields bordered by ridges
	Surge	In surge flooding, water is released at pre arranged intervals, which reduces unwanted runoff.
	Level basin	Slope of the land is level and area's ends are closed. Water is applied at high volumes to achieve an even, rapid ponding of the desired application depth within basins.
Sprinkler irrigation A planned irrigation system in which water is applied by means of perforated pipes or nozzles operated under pressure so as to form a spray pattern	Pivot and linear systems	High Pressure Medium Pressure Low Pressure
	Side rolls	Mobile pipelines deliver water across fields using sprinklers
	Solid set	Pipes placed on fields deliver water from raised sprinkler heads
Drip irrigation is an irrigation method that allows precisely controlled application of water and fertilizer by allowing water to drip slowly near the plant roots through a network of valves, pipes, tubing, and emitters	Surface	Emitters along pipes or hoses deliver water directly to the soil surface
	Sub-surface	Emitters along pipes or hoses deliver water below the soil surface
	Micro-sprinklers	Emitters on short risers or suspended by drop tubes sprinkle or spray water above the soil surface

2.1.2. Scheduling Irrigation

Application of water during critical crop demand is an important strategy to improve water use efficiency. Irrigation scheduling involves managing the soil reservoir so that water is available when the plants need it. Soil moisture and weather monitoring are used to determine when to irrigate, and soil capacity and crop type are used to determine how much water should be applied. Weather monitoring such as temperature, rainfall, humidity and crop evapotransporation (ET) data is also used to determine efficient irrigation scheduling. The important means for soil moisture measurement are given in Table 3.

Table 3. Various soil moisture monitoring methods used under field conditions

Plant observation	Visible changes in plant characteristics, such as leaf colour, curling of the leaves and ultimately wilting can be useful guides to indicate plant moisture stress, and hence the need for irrigation. Productivity may be lowered, particularly if moisture depletion is allowed to the point where wilting occurs. The moisture status of plants can also be measured using sap flow sensors (used mainly for research), infra-red guns (used in the cotton industry) and pressure bombs (which measure leaf water potential).
Feel and appearance of the soil	The most obvious and common method of soil moisture monitoring is to observe the soil feel and appearance at various soil depths within the crop root zone. A soil sample can be obtained by using a soil probe, auger or spade. By squeezing soil into a ball, observing the appearance of the ball and creating a ribbon of soil between the thumb and forefinger, soil moisture can be estimated
Weather based data	There are two weather - based scheduling systems used to measure the amount of water lost from a crop. These are: (i) Evaporation from an open water surface -gives some indication of crop water use (the latter is generally lower), or (ii) Historical climate data such as relative humidity, temperature, wind speed and sunshine hours.
Soil moisture monitoring	Soil moisture can be measured as a suction or volume of water. This idea is applicable to how much force a plant can exert on the soil to extract the amount of water it needs for growth. Soil moisture suction can be used as a measure of plant stress and for that reason it is a handy tool for growers to use in scheduling their irrigations.

2.1.3. Soil structure and its capacity

Soil acts as a water reservoir for irrigations and rainfall received. Soil nutrient and water together mechanically supports and stabilizes crop plants. Different soil texture governs the soil moisture holding capacity (Table 4). Therefore, irrigation water management strategies needs essential consideration of soil structure and the water holding capacity.

Table 4. Soil texture and their capability to hold moisture (based on soil depth,, soil structure and soil water tension)

Soil Texture	*Inches of water available per feet of soil depth*
Coarse Sand	0.50
Fine Sand	0.75
Loamy Sand	1.00
Sandy loam	1.25
Loam	1.50-2.00
Clay or silt loam	1.75-2.50
Clay	2.0-2.4

Source: Ag-Irrigation Management (Irrigation Training and Research Center, 2000)

3. IMPROVING WATER INFILTRATION IN RAINFED ECOSYSTEM

Rainfed agriculture represents 80% of land under cultivation, and contributes 58% of global crop production (Bruinsma, 2009). It is, therefore, rainfed production system is the primary source of food production at global level. This has prompted a broadening of the scope of agricultural water issues to include both irrigated and rainfed agriculture (Wani, Rockström and Oweis, 2008; Rockström *et al*., 2009). The rainfed agriculture in the semi-arid tropics (SAT) is typically characterized by low crop yields and high risk of crop failure. Frequent dry spells and extreme rain events are the most common characteristics of SAT, which often cause water stress situation and land degradation during rainy season. Recent studies have reported that CA improved crop productivity by 20–120% and water productivity by 10–40%. Abrol *et al*. (2016) observed that incorporation of biochar (2%) in erosion-prone soils of Israel, increased final infiltration rate (FIR) by 1.7 times, and significantly reduce soil loss by 3.6 times, compared with the control (Fig 1). The maximum soil moisture content, infiltration rate and grain yield of maize and wheat recorded higher in mulching practices over no mulch treatment in rainfed area (Sharma *et al*., 2011). Study conducted by Patil *et al*. (2016) at the International Crops Research Institute for the Semi-Arid Tropics (ICRISAT), Hyderabad revealed that maize/pigeon pea intercropping system is more sustainable and associated with less risk compared to maize + chickpea sequential cropping system and surface runoff was 28% less as compared to the conventional system, which may be attributed to residues

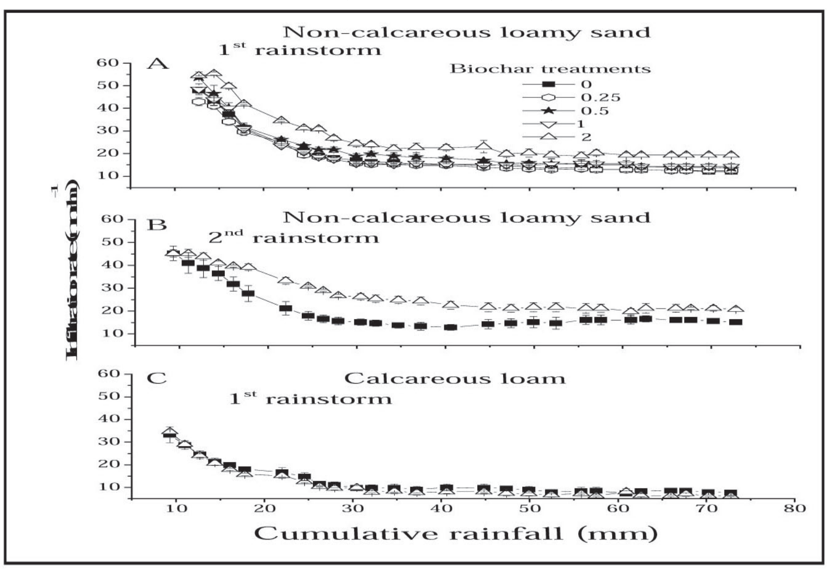

Fig. 1. Infiltration rates as functions of cumulative rainfall for various biochar treatments of 0, 0.25, 0.5, 1, and 2 wt% biochar in the first rainstorm and of 0 and 2 wt% biochar in the second rainstorm in the non-calcareous loamy sand and first rainstorm in the calcareous loam.

*Error bars represent standard error

retention. Further, simulation results indicated that CA helps in reducing water stress in dry years and reduces the risk of crop failure

3.1 Conservation Tillage

Conservation tillage is a method of soil cultivation that leaves the previous year's crop residue on fields before and after planting the next crop, to reduce soil erosion and runoff. Most definitions specify that at least 30% of the crop residue must remain on the soil surface at the time of planting. Conservation tillage methods include no-till, strip-till, ridge-till and mulch-till. Each method requires different types of specialized or modified equipment and adaptations in management. No tillage has been practiced worldwide.

Conservation tillage practices generally result increased infiltration compared to conventional tillage systems. Recent study conducted by Singh *et al*., 2016 under rice-maize system on Typic Ustocherepts sandy loam soils of Indo-Gangetic Plains reveals that zero-till direct seeded rice (ZTDSR) followed by zero-till maize (ZTM) with partial residue retention (+R) from both the crops improved the study state soil water infiltration rate significanlty compared to conventional till direct seeded rice followed by conventional till maize (CTDSR/CTM) and Conventionally till rice and maize (TPR/CTM). Conventional tillage increased bulk density (BD) and decreased infiltration rate (IR) and soil organic carbon as compare to the minimum tillage in maize-wheat rotation (Sharma *et al*., 2011).

Although different CA practices provides opportunity to reduce water use but many time it results in term of lower productivity. Sharma *et al*. (2002) showed that flooded transplanted rice and conventionally tilled wheat gave the

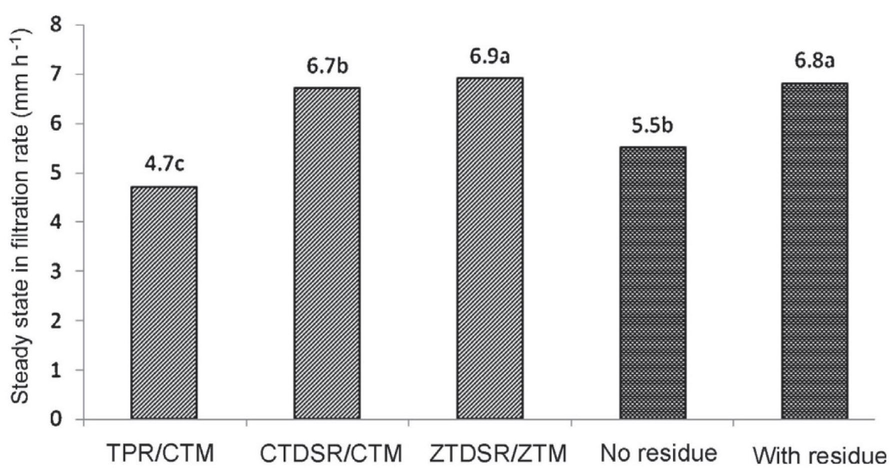

Fig. 2. Steady-state soil water infiltration rate as influenced by tillage and crop establishment (TCE) techniques and residue management (R) options at maize harvest 50 year rice-maize systom. Values of the same letter are not significantly different at $P < 0.05$ for tillage and crop establishment techniques and residue management.

highest yields. On the other hand, irrigation at 10 or 20 kPa soil water tension, bed-planted rice reduced water input by 45-51% but lowered yield by 52-53% compared with transplanted rice, whereas dry-seeded rice on flat land reduced water input by 51-57% inch reduced yield of 36-46%. The succeeding zero-tilled wheat with controlled traffic gave yields similar to those of conventional wheat and had the same water use.

3.2 Mulching

Mulching is a technique to increase soil moisture storage, decrease evaporative losses, and enhance duration of water availability to crops. Timely and satisfactory crop establishment is a serious constraint in rainfed areas due to inadequate soil moisture at the time of sowing. If through soil moisture conservation timely sowing of crop is assured, the probability of a good crop harvest is increased. Different options such as organic or inorganic materials of natural (field crop residues, waste plant biomass, wood chips, saw dust, coco-coir etc.) or of synthetic origin (plastic sheets, soil conditioners), soil (dust mulch) or pebbles (stone mulch) can be used as mulch. Alley cropping is another system of raising mulch material. Prunings from trees/shrubs provide excellent mulch material and green manure. Hedge-row trees/ shrubs also provide biologically fixed N to the companion crop, and act as a barrier to conserve soil moisture.

The study conducted in the Indo Gangatic Plains of India in irrigated maize-wheat systems (MWS) by Jat *et al*., 2015 reveals that permanent raised bed (PRB) saved 29.2% of irrigation water and improved the MWS irrigation water productivity by 24.5% over no till flat.

Other reports indicated that PRB with *ex-situ* mulching (*Jatropha* and *Sesbania*) improve yield, water productivity and system profitability. Based on meta-analysis of the effects of mulching on wheat and maize, using 1310 yield observations from 74 studies conducted in 19 countries Quin *et al*., 2015 concluded that mulching significantly increased yields, WUE (yield per unit water) and NUE (yield per unit N) by up to 60%, compared with no-mulching. Effects were larger for maize compared to wheat, and also more for plastic mulching than straw mulching.

3.3 Crop Diversification

Diversification of agriculture refers to the shift from the regional dominance of one crop to regional production of a number of crops, to meet ever increasing demand for cereals, pulses, vegetables, fruits, oilseeds, fibres, fodder and grasses, fuel, etc. It aims to improve soil health and a dynamic equilibrium of the agro-ecosystem. Diversified farms are usually more economically and ecologically resilient. Since crop diversification is an important component of conservation agriculture, the opportunity of crop diverisification in a specific location is of paramount significance. In this perspective, more remunerative and less water consuming crop rotations have been standardized at different locations of India.

Rice- mustard-green gram, rice- potato- green gram rotations were found more water efficient systems at Memari in W.B. Under high level of irrigation in tarai region of U.P, rice-lentil and rice-wheat cropping system were found better. Pre monsoon groundnut-*rabi* sorghum sequence was highly remunerative with high water use efficiency compared to sugarcane alone in Maharashtra when irrigation water is not limiting. Under limited water supply, however, rice – chickpea-green gram and rice- mustard – green gram are more remunerative with high water use efficiency. However, summer fallowing leaves land without any crops planted for one entire growing season, creating lost production opportunity. Additionally, summer fallowing has serious environmental consequences. Diversifying cropping systems with pulse crops can enhance soil water conservation, improve soil N availability, and increase system productivity. Inclusion of cowpea fodder during summer after wheat harvest under rice-wheat system not only improves system productivity but also helps in soil structural improvements like decreasing bulk density, which ultimately improves nutrient and water productivity (Dwivedi *et al*., 2003; Singh *et al*., 2006). Integration of CA based technologies further improves water productivity. Singh *et al*. (2010) observed that lower irrigation water use in wheat under permanent raised bed (PRB) compared with conventional flat bed (FB) in the Indo-Gangetic Plain region in the pigeonpea–wheat system. Parihar *et al*. (1999) observed that replacement of wheat with chickpea in rice-wheat systems not only recorded the lowest water use and maximum water use efficiency but also saved 19.3 cm of water i.e. 2 million litres.

4. CONCLUSION

The availability of water for farming is an essential condition for achieving satisfactory and profitable yields, both in terms of unit yields and quality. Managing agricultural water to enhance crop water productivity (more crops per drop) without detrimental effect on resource base is of paramount importance for both rainfed and irrigated agriculture. Conservation agriculture practices offer a new way of effectively and efficiently managing agricultural environments and the natural resource base for multifunctional services to the society. Minimal tillage reduces volume and velocity of surface runoff, leading to reduction in soil and water erosion and nutrient loss. Incorporation of crop residues enhances soil water availability, reduces evaporation loss, improves infiltration by restricting surface runoff and reduces surface sealing from raindrop impact. Crop diversification reduces the risk of crop failure and is recognized as a cost-effective solution to build resilience into agricultural production system. Conservation agriculture offers an integrated approach of above options for conserving water resource which is a most vital for agricultural production system.

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7

Enhancing Water Productivity Under Conservation Agriculture based Cropping System

B. Gangwar

Presently, focus is being given to reduce the cost of production and increase use efficiency of inputs in which cropping system investigation proved as a useful tool for studying the response in sequence. Based on area and spread of crops, 30 important cropping systems have been identified in different agro-ecological regions of the country. The cropping systems considered to be the major contributors to national food basket are; rice-wheat (10.5 m ha), rice-rice (5.9 m ha) and coarse grain based systems (10.8 m ha). Amongst systems, the share of rice and wheat together is rated as the highest about 65% to the food grain production, while rice-wheat system when grown in a sequence contributes 40%. Interestingly, most of the high-productivity systems in the country are cereal-based, having high resource demand and are grown in a monoculture fashion over the decades (e.g. rice-wheat in Indo-Gangetic plains, rice-rice in coastal and high rainfall areas, and coarse-cereals based in low rainfall areas). This has resulted in emergence of second-generation problems like, over-mining of major and micro-nutrients, decline in water table, decline in factor productivity, reduction in profitability, and appearance of the new bio-types, pests and diseases, causing concerns to sustainability. Under the present scenario, the major concerns are to write down strategies proving crucial and cost effective. These concerns have given impetus to the pursuit of alternative crops and cropping systems with new methods of cultivation, which are environment friendly and more efficient user of natural resources. Among these resources water is a crucial input for raising crops and a finite source must be utilized with care. It should be applied in such way that neither it is in excess nor in short supply. Only one per cent of water earth is considered ideal for use. It governs the growth and development of living life by diminishing the starvation. Therefore, it is pertinent to focus our programme in direction that each drop of water should be used cautiously by making right method of irrigation, right time and depth of irrigation and quality of irrigation should also be ascertained carefully. However, the water use directly relates to the use of other inputs specially nutrients and ultimately reflected in terms of productivity in relation to the management options. Therefore, the site-specific crop management practices, which ensure high productivity, profitability and resource use efficiency with a focus on water management, are considered very important and therefore, an effort has been made to discuss all the possible options in cereal-based cropping systems under the following heads.

1. SITE SPECIFIC CROP DIVERSIFICATION

Crop diversification in areas, where continuous cropping of cereal-cereal systems is in vogue, has been advocated as one of the effective tools for minimizing the second-generation problems and to make a breakthrough in productivity and profitability. The crop diversification can deliver many agronomic and ecological benefits simultaneously, while maintaining or enhancing the scale of efficiency of production. In this regards, besides adoption of proper input management technologies, diversification of the systems through introduction of crops of diverse nature may be a good preposition to break the monotony of the predominant cereal based systems and to sustain productivity over a period of time. For diversification of rice-wheat system, several options are available for different zones (Table 1). These options ensure efficient use of resources including water.

In Punjab, crops like maize, moong bean, summer groundnut, fodder sorghum/maize in *kharif* offer viable and remunerative alternatives to the nutrient and water exhaustive rice crop. While crops like potato, Indian mustard, vegetable pea, grain-pea and sunflower are the substitute crop of wheat. In rice-wheat system, it is also possible to grow an early crop of potato that is harvested in first week of January for table purpose followed by late planted wheat with a total grain yield of 5-6 t/ha and that of tuber yield of 17-25 t/ha. Onion is also proved a viable option in place of wheat. Further it was also noted that when sunflower is grown in spring season in place of late wheat, an additional yield of 2 t/ha of oilseed is obtained. Vegetables like okra and fodder crops like cowpea and sorghum can substitute rice in *kharif* season. The rice-potato-sunflower system gave highest wheat equivalent yield (22.6 t/ha), net income (Rs. 35,260/ha), land use efficiency (86-87%), production efficiency (71kg/ha/day) and cost: benefit ratio (2.26). Rice-potato-groundnut was also reported to be distinctly better than existing rice-wheat system in Punjab with wheat equivalent yield of 10.0 t/ha/year. Similarly, the yield of wheat under potato intercropping (4.2 t/ha) was higher than in rice-potato-wheat sequence (1.69 t/ha), while the yield of potato remained unaffected. In western plains of Uttar Pradesh, monetary returns and economic efficiency of land use improved considerably due to inclusion of legume/ oilseed crops in maize-wheat system. In central plain zone of Uttar Pradesh, inclusion of pulse and oilseed crops in rice-based crop sequences gives

Table 1. Efficient crop diversification options for rice-wheat farmers

Cropping system	*REY (t/ha/yr)*	*Productivity (kg/day/ha)*	*Profitability (Rs/ha/day)*	*NUP (kg grain /kg nutrient use)*	*IWUP (kg grain/ha cm)*
South Alluvial Plain zone of Bihar (Sabour)					
Rice-wheat	7.7	21.1	38.6	21.4	116.7
Rice-garlic-maize	11.2	30.6	76.4	23.7	123.9
Mid High Altitude Intermediate zone of J & K (R.S. Pura)					
Rice-wheat	9.2	25.3	87.4	26.4	53.2
Rice-cauliflower- french bean	11.0	30.1	93.8	53.2	45.1
Central Plain Zone of Punjab (Ludhiana)					
Rice-wheat	11.0	30.0	33.0	25.1	53.4
Maize-potato -onion	18.2	50.0	84.2	45.1	140.2
Central Plain Zone of U.P. (Kanpur)					
Rice-wheat	8.8	24.0	36.4	28.1	42.7
Maize-potato-sunflower	15.3	41.9	56.4	20.5	103.0
Vindhyan Plain zone of U.P. (Varanasi)					
Rice-wheat	8.5	23.2	32.3	17.7	41.4
Rice-potato-green gram	14.3	39.2	58.2	22.2	50.8
Bhabar & Tarai Zone of Uttarnchal (Pantnagar)					
Rice-wheat	11.9	32.7	91.5	23.9	101.1
Rice-rapeseed-sunflower	12.6	34.5	93.1	23.1	112.4
Plain Zone of Chattisgarh (Raipur)					
Rice-wheat	8.6	23.7	90.2	32.0	146.3
Rice-brinjal-green manure	10.7	29.4	112.4	54.0	224.8
Plateau and Satpura hill zone of M.P. (Rewa)					
Rice-wheat	6.7	18.4	53.7	16.7	44.3
Rice-berseem (f)-B. Seed	10.5	28.7	103.3	47.7	94.4

(Contd.)

Cropping system	*REY (t/ha/yr)*	*Productivity (kg/day/ha)*	*Profitability (Rs/ha/day)*	*NUP (kg grain /kg nutrient use)*	*IWUP (kg grain/ha cm)*
South Gujrat Heavy Rainfall Zone (Navsari)					
Rice-wheat	6.9	18.9	48.3	20.9	40.6
Rice-onion-veg. cowpea	8.6	23.5	52.2	22.0	42.8
Vindhyan Plateau Zone of M.P. (Jabalpur)					
Rice-wheat	5.4	14.6	33.4	14.1	35.3
Rice-berseem (f)-berseem Seed	7.2	19.6	62.4	23.8	94.1
Eastern Plain Zone of U.P.(Masodha)					
Rice-wheat	7.1	19.4	37.0	15.9	37.4
Rice-potato-green gram	15.5	42.3	97.9	11.5	29.7

K, *Kharif*; R, *rabi*; S, summer; REY, rice equivalent yield;
NUP, nutrient use productivity; IWUP, irrigation water use productivity

higher monetary gain over the rice-wheat system. Moreover, intercropping of pulses and oilseeds with recommended planting pattern after rice enhanced the net returns and improved soil health. The highest net return of Rs. 26,198 /ha/ year, was recorded in rice-chickpea+linseed, closely followed by rice-linseed+Indian mustard and rice-mustard-green gram cropping systems. Considering the production, net return and land-use efficiency and maize-Indian mustard cropping systems proved most promising and remunerative in these areas. In eastern plains of Uttar Pradesh, rice-potato-cowpea and rice-potato-okra systems were identified to be potential alternatives to existing rice-wheat system for higher productivity and profitability.

For new alluvial zone of West Bengal, cropping sequence of rice-potato-jute has been reported to be most productive, with a rice grain equivalent yield of 16.94 t/ha/year and profitability of Rs 51,465/ha/year. Rice-wheat-groundnut was equally good with highest energy production (31.45 x 10^6 k Cal/ha/ year) and system stability index of 0.91. Maximum wheat-equivalent yield could be recorded by inclusion of potato or vegetable pea in between rice and wheat crops. Similarly, rice-potato-groundnut system was identified to be most productive, profitable and efficient at Kalyani. Under declining irrigation water availability conditions of Indo-Gangetic Plain region, pigeon pea-wheat system was identified to be a potential alternate choice to rice-wheat system. In Bhilwara region of Rajasthan, maize grain equivalent yield increased by 1.44 t/ha in maize+cowpea (fodder) inter-cropping system and yield of succeeding wheat also increased by 0.84 t/ha over maize-wheat system. The highest net returns (Rs.23,292 /ha), benefit: cost ratio (3.1) and wheat equivalent yield (6.79 t/ha) were obtained from maize+cowpea (fodder)-wheat cropping system. Instead of existing rice-rice system in coastal areas, rice-potato-sesame and rice-potato-cowpea for coastal areas of Orissa, rice-rice-soybean for coastal districts of Tamil Nadu, rice-fodder sorghum-groundnut for coastal areas of Gujarat and rice-groundnut for coastal districts of Maharastra, have been identified to be more suitable with high productivity, profitability and stability. For Chattisgarh region, rice-berseem and rice-tomato have been identified to be most profitable, stable and efficient systems under assured irrigation. In this region rice crop is usually grown after winter grain legumes such as chickpea, lentil or field pea in double cropping systems. However, studies have shown the possibilities of raising a third crop of summer legume such as green gram, black gram, or cowpea. The increase in rice yields of 4.78 t/ha after cowpea, 4.50 t/ha after green gram and 4.28 t/ha after black gram could be obtained compared to 3.41 t/ha after maize fodder.

2. SITE SPECIFIC RESOURCE CONSERVATION TECHNOLOGIES

Traditionally, the crop establishment includes repeated ploughing, planking and pulverizing the topsoil. Repeated tillage operations delay planting, escalate costs, reduce profits and needs more water for crop production. Therefore, crop establishment and tillage practices are considered very crucial for resource saving. The results of experiment at Modipuram, have revealed that crop establishment and reduced tillage practices in rice-based cropping system gave higher productivity of rice-wheat, rice-chickpea and rice-mustard crop sequences over other methods of crop establishment (Table 2). The important resource saving techniques are zero tillage, furrow irrigated raised bed system and precision land levelling.

Table 2. System productivity (rice grain equivalent yield) of rice-wheat, rice-chickpea and rice-mustard cropping system as influenced by rice cop establishment and tillage

Crop establishment method	Rice-what	Rice-Chickpea	Rice-mustard
Direct seeding (dry bed)	14.7	13.9	14.0
Drum seeding (wet bed)	14.8	13.9	13.7
Mechanical transplanting (puddled)	13.8	11.1.	120.3
Mechanical transplanting (unpuddled)	13.8	12.6	12.7
Manual transplanting (puddle)	13.5	10.9	12.2
CD 5%	0.62	0.69	0.56

2.1. Zero-Tillage

This is tillage where the seed is placed into the soil by a seed drill without prior land preparation. This technology is more relevant in the higher yielding, more mechanised areas of north-western India, where most land preparation is now done with four-wheel tractors. However, in order to extend the technology in other parts, equipment for 2-wheel hand tractors and bullocks is being modified. The basis for this technology is the inverted-T openers. This coulter and seeding system places the seed into a narrow slot made by the inverted-T as it is drawn through the soil by the four-wheel tractor. The coulters can be rigid or spring-loaded depending on the design and cost of the machine. This type of seed drill works very well in situations where there is little surface residue after rice harvest. This usually occurs after manual harvesting. Where combine harvesting is becoming popular, loose straw and residue creates a problem for the inverted-T opener. Farmers presently burn residues to overcome this problem of loose stubble whether they use zero till or the traditional system. This practice needs to be discouraged because of major environmental and air pollution issues. Future strategies will look at alternative machinery and techniques to overcome this problem. Leaving the straw as mulch on the soil surface has not been given much thought. However, results suggest that this may be very beneficial to early establishment and vigour of crops planted this way and for soil moisture conservation, water infiltration and erosion. Significantly fewer weeds are found under zero-tillage compared to conventional tillage. Fields with zero tillage and those with normal tillage were sprayed with weedicide, but significantly lower weed counts were found in fields with zero tillage. This difference can be explained by the nature of the weeds found in the rice-wheat cropping system.

Most of the weeds affecting the wheat crop germinate during the crop season, and since the soil is disturbed less under zero-tillage, fewer weeds are exposed and germinate. Also before the weeds are able to grow and compete, the main crop is able to cover up the surface and significantly reduce weed biomass. Weed problems typically are more severe under conventional tillage than under zero tillage, at least in the near term. Earlier planting is the main reason for the additional yields obtained under zero-tillage. Zero-tilled plots could be planted in first week of November, the optimum date for planting wheat. The results of many trials suggest that longer the farmer delays planting, lower the yield. This finding has been confirmed in trials throughout the Indo-Gangetic Plains in the past few years. In Haryana, surveys and crop cuts have shown that zero till produces 400 to 500 kg/ha more grain than traditional systems. This is attributed to earlier, timely planting, less weeds, better plant stands and improved fertilizer efficiency because of placement with the seed drill. Some experiments are now in their 10^{th} year of continuous zero till and find no deleterious effects that would make them revert to the traditional system.

2.2 Reduced Tillage

The strip and rotary till drills have been developed that prepare the soil and sow seed in one operation. This system consists of a shallow rotovator followed by a seeding system. Soil moisture was found to be critical in reduced tillage system. The rotovator fluffs up the soil, which then dries out faster than with normal land preparation. The seeding coulter does not place the seed very deep, so soil moisture must be high during seeding to ensure germination before the soil dries appreciably. The tractor can also be used with a rotavator to quickly prepare the soil and incorporate the seed after a second pass. This speeds up the planting and results in better stands with less cost than traditional methods. However, the strip and rotary till drills do a better job because the seeds are placed at a uniform depth in the single pass.

2.3. Bed Planting

In bed planting systems, wheat or other crops are planted on raised beds. This practice has increased in the last decade. Farmers have given the following reasons for adopting the new system: management of irrigation water is improved, bed planting facilitates irrigation before seeding and thus provides an opportunity for weed control prior to planting, plant stands are better, weeds can be controlled mechanically between the beds early in the crop cycle, seed rates are lower, after wheat is harvested and straw is burned, the beds are reshaped for planting the succeeding crops, burning can be eliminated, herbicide dependence is reduced and hand weeding and rouging is easier as well as less lodging occurs. Two bed widths and two or three rows of wheat planted per bed were compared with conventional flat bed planting. Two rows on 70cm beds were best. Two of the major constraints on higher yields are weeds and lodging. Both can be reduced in bed planting. The major weed species affecting wheat, *Phalaris minor,* is normally controlled using the herbicides. Preliminary observations indicate that *P. minor* is less prolific on dry tops of raised beds than on the wetter soil found in conventional flat bed planting. Cultivating between the beds can also reduce weeds. Thus, bed planting provides farmers with additional options for controlling weeds. Lodging is also less of a problem on raised beds. Additional light enters the canopy and strengthens the straw, and the soil around the base of the plant is drier. Reduced lodging can have a significant effect on yield. An additional advantage of bed planting becomes apparent when beds are “permanent” – that is, when they are maintained over the medium term and not broken down and re-formed for every crop. In this system, wheat is harvested and straw is left or burnt. Passing a shovel down the furrows reshapes the beds. The next crop can then be planted into the stubble in the same bed.

3. EFFECT OF CONSERVATION TECHNOLOGIES ON LAND, WATER AND ENERGY PRODUCTIVITY

Studies conducted under long term CA based systems at Modipuram indicated that conservation agriculture technologies of zero, strip and rotary till drilling, and bed planting of rice and wheat saved 64 to 85% resources (time, labour, cost, fuel and energy). The bed planting also saved 39 and 34% irrigation water in rice and wheat, respectively. These technologies provided higher rice and wheat yields (2 to 8%), B: C ratio (9 to 27%) and energy efficiency (21 to 32%) compared to conventional sowing. The continuous use of these technologies has also improved soil health by increasing the soil organic carbon and mean weight diameter of the soil aggregates. Also, around 70 kg/ha/year CO_2 emissions to the environment could be reduced by the use of zero till drilling compared to conventional sowing which is vital to our environmental sustainability.

Farmers are adopting these technologies quickly. The adoption could be even faster if it were possible to have sufficient machinery available from small-scale manufacturers. Farmer feedback on water savings with these technologies essentially says that they save water. For zero-tillage, farmers report about 25-30% savings. This comes in several ways. First, zero tillage is possible just after rice harvest and any residual moisture is available for wheat germination. In many instances where wheat planting is delayed after rice harvest farmers have to pre-irrigate their fields before planting. Zero-till saves this irrigation. Savings in water also comes from the fact that an untilled soil has less infiltration than a tilled soil and so water flows faster over the field. That means farmers can apply irrigation much faster. Because zero tillage takes immediate advantage of residual moisture from the previous rice crop, as well as cutting down on subsequent irrigation, water use is reduced by about 10 cm-hectares, or approximately 1 million litres/ha. One additional benefit is less water logging and yellowing of the wheat plants after the first irrigation that is a common occurrence on normal ploughed land. In zero till, less water is applied in the first irrigation and this yellowing is not seen.

3.1 Cropping System Management and Land Configuration

At Modipuram, experiments conducted to upscale water productivity through cropping systems management and land configuration. Revealed that bio-intensive system of raising maize for cobs + vegetable cowpea in 1:1 ratio on broad beds (BB) and *Sesbania* in furrows during *kharif* and mustard in furrows and 3 rows of lentil on broad beds in *rabi* while 3 rows of zero till sown green gram on beds in summer was found remarkably better than others which produced highest rice equivalent yield (REY) of 19.52 t/ha with productively of 53.5 kg grain/ha/day and profitability of Rs.190 ha/day. The complimentary effects could be reflected in the system as in broad bed and furrow (BBF) system, the furrows served as drainage channels during heavy rains in *kharif* which were utilized for in-*situ* green manuring with 38 t/ha green foliage incorporated after 45 days of sowing and timely sown mustard crop in these furrows resulted a good harvest 1.99 /ha and a bonus yield of lentil (1.28 t/ha) could be harvested on one hand and 33% of irrigation water could be saved as applied only in furrows.

Another long at Modipuram showed that during kharif, maize (cob) (broad bed, BB) + vegetable cowpea (BB) + sesbania (furrow, F) system produced maximum REY (3.71 t/ha) followed by maize (cob) (raised bed, RB) + vegetable cowpea (RB) + sesbania (furrow, F) system (3.31 t/ha) while rice (flat bed, FB) produced lowest REY (1.05 t/ha). During *rabi*, vegetable pea (broad bed, BB) + wheat (furrow, F) system produced maximum wheat equivalent yield, WEY (9.0 t/ha) followed by vegetable pea (bed, B) + wheat (F) system (8.9 t/ha), wheat (BB) + mustard (F) system (8.8 t/ha), wheat + mustard (5:1) system (8.1 t/ha) while mustard (Flat) produced lowest WEY (1.0 t/ha). Also, vegetable pea (broad bed, BB) + wheat (furrow, F) system produced maximum wheat equivalent productivity (0.075 t/ha/day) followed by vegetable pea (bed, B) + wheat (F) system (0.074 t/ha/day), wheat (BB) + mustard (F) system (0.074 t/ha/day), wheat + mustard (5:1) system (0.068 t/ha/day) while mustard (Flat) produced lowest WEY (0.008 t/ha/day).

The results of the experiment on evaluation of different cropping systems under limited water availability situation revealed that no irrigation was needed during *kharif* season in any of the crops evaluated under the system. Based on irrigations applied to *rabi* crops, the highest system productivity (16.96 kg/ha/day) and profitability (Rs.142 /ha/day) of pearl millet-wheat and pigeon pea-barley (25.78 kg/ha/day & Rs. 230/ha/day) was recorded when three irrigations were applied. Under the two irrigation application conditions the systems involving maize-mustard with production of 14.95 kg/ha/day and productivity of Rs. 109 /ha/day performed best while under only one irrigation condition sorghum-lentil with production of 14.71 kg/ha/day and productivity of Rs. 100 /ha/day was the best.

3.2 Site-specific Water Management

In rainfed areas, water harvesting and recycling is the only option to provide either life saving or supplementary irrigation ensuring the stability in the productivity. Likewise, where under ground water is of poor quality, crops require less water like cotton, pigeon pea and cluster bean during *kharif* season and gram, wheat rapeseed and mustard in winter season is most preferable. High water requiring crops such as sugarcane, rice, berseem, turmeric, mentha, should categorically be discouraged. In addition, emphasis should be given on conjunctive use of water, crop establishment technique for high yield realization. The timing of first irrigation in wheat is very crucial on realizing high yield level. The missing of irrigation at crown root initiation caused yield reduction up to 26% because the moisture content in the zone where fertilizer was applied by drilling at sowing has become depleted and hence availability of the nutrients is reduced. The application of irrigation also helps to ensure the balanced supply of nutrients. The subsequent irrigation schedules of 0.6, 0.9 and 1.2 IW/CPE had significant effect on wheat yield and the significantly higher yield was recorded at the water irrigation schedule of IW/CPE of 1.2 and the interaction effect was not significant (Table 3). Among field crops, rice is the major user of water. Irrigation scheduling in rice is, therefore, crucial to save the irrigation water. Moreover, scheduling of irrigation in other crops, on most critical stages depending upon the availability of water is also important for ensuring good yield of crops in cropping systems (Table 4). The studies conducted under All India Coordinated Project on Water Management have clearly shown that irrigation at 3 day after disappearance of ponded water in rice was better at most of the locations (Table 5). Similarly, scheduling of irrigation in wheat at critical stages is desirable. Similarly, in a study at Kanpur, irrigation in rice at hairline cracking stage in soil proved better for saving irrigation water (20.5%) and realizing almost same productivity of 4.57 under disappearance of water and 4.73 t/ha under hairline cracking stage in soil.

4. FUTURE THRUST

- Water will be scarce resource in future. Therefore, most efficient cropping systems for quantified water availability conditions need to be identified.
- Inputs becoming more costly every year resulting increase in cost of crop production. Therefore, *in situ* supplementation of inputs would be helpful. As such, bio-intensive complementary cropping systems need to be identified for partial *in situ* management of nutrient and pests on one hand and saving of precious resource water on the other.
- Both short and long-term strategies need to be worked out considering the present trends and future perspectives of globalization of economy with new trade opportunities.

Table 3. Grain yield, irrigation water requirement, and water-use in wheat at optimum schedule of irrigations (based on IW/ CPE ratio) at different locations

Location	*Soil type*	*No. of irrigation (depth, cm)*	*Optimum IW/ CPE ratio*	*Grain yield (t/ha)*	*Irrigation water requirement (cm)*	*Total water use (cm)*
Belvatagi (Karnataka)	Clay	6-7 (6)	0.90	3.81	39	39
Bikramganj (Bihar)	Sandy loam	3 (6)	0.90	2.64	18	23.8
Bilaspur (M.P.)	Sandy loam to clay	3 (6)	0.90	4.01	18	24.5*
Chiplima (Orissa)	Sandy loam	4-5 (6)	1.05	2.70	24-30	24-30
Faizabad (U.P.)	Silt loam	4 (6)	1.05	4.01	24	24
Hisar (Haryana)	Sandy loam	6 (6)	1.05	3.85	36	37
Kharagpur (W.B.)	Silt loam	5 (6)	0.75	2.82	30	33.6
Kota (Rajasthan)	Clay loam	4 (6)	0.80	3.98	24	24
Madhipura (Bihar)	Loamy sand to sandy loam	2 (6)	0.60	2.40	12	12
Navsari (Gujarat)	Clay	7 (6)	1.05	4.60	42	42
Pantnagar (U.P.)	Silty clay loam	2 (6)**	1.05	4.22	12	12
Rahuri (M.S.)	Clay	5 (6)	1.05	4.10	30	30
Parbhani (M.S.)	Clay loam to clay	6 (6)	0.75	2.41	36	41.2
Srigangangar (Raj.)	Sandy loam	4 (6)	1.05	5.40	24	24

* Includes one irrigation at CRI, **Shallow water table condition

Table 4. Effect of irrigation, applied at variable critical growth stages, on the grain yield wheat

Growth stage	*Grain yield (t/ha) at different growth stages*						*Irrigation water requirement* (cm)*	*Total water use (cm)*
	No. of irrigations (depth, cm)	*Hisar (Sandy loam)*	*Faizabad (Silt loam)*	*Morena (Sandy loam)*	*Delhi (Sandy loam)*	*Jhargram (Laterite sandy loam)*		
CRI	1 (6)	2.68	-	-	-	-	6	-
CRI+F	2 (6)	2.89	-	-	-	-	12	-
CRI+M	2 (6)	-	3.00	-	-	-	12	-
CRI+F+M	3 (6)	3.75	-	-	-	-	18	-
CRI+LJ+M	3 (6)	-	3.39	-	-	-	18	-
CRI+B+M	3 (6)	-	-	-	3.57	-	18	20.9
CRI+F+GF	3 (6)	-	-	-	-	1.29	18	19.3
CRI+LJ+M+D	4 (6)	-	3.70	-	-	-	24	-
CRI+F+M+D	4 (6)	4.42	-	-	-	-	24	-
CRI+T+J+F+M	5 (6)	-	-	3.30	-	-	30	-

* The irrigation requirement is exclusive of pre-sowing irrigation

CRI= Crown root initiation, F= Flowering, M= Milking, LJ= Late jointing, D= Dough, T= Tillering, B= Boot, GF= Grain filling, J= Jointing

Table 5. Effect of intermittent irrigation regimes on rice yield and requirement of irrigation water at various locations

Location		*Yield (t/ha)*				
		Continuous submergence	*Irrigation after desaturation period*			*Saving in irrigation water with 3-day de-saturation vs continuous submergence (%)*
			1-day	*3-day*	*5-day*	
Pusa (Bihar)	Sandy loam	3.59 (81)	3.47 (60)	3.25 (46)	2.85 (35)	43
Madhepura (Bihar)	Sandy loam	4.03 (35)	-	3.97 (16)	3.99 (11)	54
Chiplima (Orissa)	Sandy loam	7.21 (99)	6.66 (90)	6.47 (76)	5.85 (68)	23
Kharagpur (W.B.)	Sandy loam	3.11 (197)	5.98 (150)	5.89 (129)	4.99 (108)	34
Bilaspur (M.P.)	Clay loam	5.86 (98)	5.59 (77)	5.13 (70)	4.62 (56)	29
Faizabad (U.P.)	Silt loam	3.77 (65)	2.94 (42)	-	-	-
Pantnagar (U.P.)	Sandy clay loam	8.09 (121)	7.57 (112)	7.38 (90)	6.92 (60)	44
Ludhiana (Punjab)	Sandy loam	5.52 (190)	5.44 (145)	5.12 (113)	5.20 (96)	40
Hisar (Haryana)	Sandy loam	5.66 (220)	5.15 (196)	4.69 (126)	-	43

Figures in parenthesis shows water requirement in cm

- Location specific resource management strategies need to be worked out for different crops and cropping systems so as to achieve quantum jumps in crop production.

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8

Weed Management Strategies under Conservation Agriculture based Rice-Wheat System

N.K. Jat, R.S. Yadav, S. Kumar and M. Shamim

Rice-wheat (RW) cropping system is the world's largest agricultural production system occupying around 12.3 million ha in India, and around 85% of this area falls in Indo-Gangetic Plains (IGP) (Ladha *et al*., 2003). Both rice and wheat have been the staple food for a large population in Asia and their assured supply is essential for ensuring food security in future. In India, the two-crop system contributes nearly 26% of total cereal production and 60% of the national caloric intake (Singh and Paroda, 1994). By 2020, India's population is projected to reach 1.5 billion and the annual food demand will reach 343 million tonnes. To meet this demand, India has to increase the rice and wheat production by 33 and 35%, respectively (Malik *et al*., 2003).

This cropping system so far has maintained the balance between food supply and population growth but now the sustainability of this cropping system is at risk because of stagnant or declining productivity of both rice and wheat and declining total factor productivity (Ladha *et al*., 2009). This could be attributed to multiple factors, including (1) degradation in the natural resource base, especially soil and water; (2) rising scarcity of labour and water; (3) increasing costs of cultivation; and (4) higher weed abundance (Ladha *et al*., 2009).

In the RW system in India, rice is grown during the rainy season and wheat during the winter. Rice is primarily grown by conventional tillage-puddled transplanted rice (CT-TPR) method, in which approximately one month old rice seedlings are transplanted manually into puddled soil and fields are kept flooded thereafter. This practice of rice production is effective in (1) achieving good weed control and crop establishment, (2) reducing percolation losses of water and nutrients, and (3) enhancing nutrient availability (Johnson and Mortimer, 2005). However, CT-TPR is labour intensive, involves large amounts of water and is detrimental to soil health. Of late, alternative practices including dry direct-seeding rice (DSR) with reduced or zero-tillage (ZT) are being advocated. ZT-DSR can reduce water and labour requirements and overcome the adverse effects of puddling on soil health and productivity of the succeeding wheat crop (Ladha *et al*., 2009). Additionally, ZT in wheat reduces the time required for field preparation, resulting in timely sowing and higher yields. As it is estimated that each one day delay of wheat sowing after the optimal date results in a yield loss of 26.8 kg/ha/day (Tripathi *et al*., 2005). In wheat, ZT has been widely adopted, especially in the North-western IGP in the RW systems, and has positive impact on wheat productivity, profitability, and resource use efficiency (Ladha *et al.,* 2009).

Despite multiple benefits of DSR and ZT in RW systems, weed control remains a major obstacle to its adoption. Weed control is particularly challenging in ZT in RW systems because of the diversity and severity of weeds and as it is typically associated with a shift away from flooding and tillage, both of which play an important role in suppressing weeds under conventional cultivation.

1. WEED MANAGEMENT IN RICE-WHEAT SYSTEM

Weeds in RW system are generally controlled manuallyl and with cultural manipulations. Now-a-days, herbicide use for weed control in rice and wheat is becoming increasingly popular. Herbicide use has increased in both conventional and ZT systems because it provides effective and economical weed control and saves on labour, which has become more scarce and expensive. Although herbicides play an important role in facilitating adoption of ZT practices; however, over reliance has aggravated problems of herbicide resistance in weeds. Additionally, public concerns about the potential adverse effect of herbicides on neighbouring water resources and human health have increased.

Hence, to expand the adoption of ZT in RW systems while minimizing the risks associated with herbicide use, it is important to adopt integrated weed management packages. Since, non-chemical management of weeds under ZT is challenging because both tillage and herbicides, two major weed control methods, are removed from the systems. However, integration of multiple strategies, including the use of stale seedbed, crop residue as mulch, competitive cultivars, crop rotation; adjustment of sowing time and plant density etc. have been reported effective in suppressing weeds and can be included as part of an alternative weed management programme.

2. WEED FLORA DYNAMICS IN RICE-WHEAT SYSTEM OF INDIA

The seasonal and regional variations in weed flora composition of a crop field are always a reality. An account of some weed species in RW system of IGP is presented in Table 1.

Table 1. Weed spectrum of rice-wheat cropping system in IGPs

Weed	*Rice*		*Wheat*	
	NW-IGP	*E-IGP*	*NW-IGP*	*E-IGP*
Grassy weeds				
Avena ludoviciana			√	
Brachiaris reptans		√		√
Cynodon dactylon				√
Dactyloctenium aegyptium	√			
Digitaria ciliaris	√			
Echinochloa crusgalli	√			
Echinochloa colonum	√	√		
Elusine indica	√			
Eragrostis tenella		√		
Panicum repens		√		
Phalaris minor			√	√
Paspalum distichum	√			
Poa annua			√	
Polypogon monspeliensis				√
Broad leaves weeds				
Alternanthera sessilis		√		
Anagallis arvensis			√	√
Cannabis sativa				√
Celosia argentea		√		
Cirsium arvense				√
Caesulia axillaris	√	√		
Chenopodium album				√
Convolvulus arvensis			√	
Commelina benghalensis		√		
Cucumis spp		√		
Digera arvensis		√		
Eclipta alba	√	√		
Lindernia crustacea	√			
Medicago indica				√
Phyllanthus riruri	√			
Physalis minima		√		
Parthenium hysterophorus				√
Rumex dentatus			√	√
Sedges				
Cyperus iria	√			
Cyperus compressus	√			
Cyperus difformis	√	√		
Cyperus rotundus	√		√	
Fimbristylis quinquangularis	√			
Fimbrisstylis milicea		√		

Source: Gopal *et al*., 2010

NW-IGP- North Western Indo-Gangetic Plains; E-IGP- Eastern Indo-Gangetic Plains

The shift from CT-TPR to ZT-DSR, typically results in changes in tillage, crop establishment method, irrigation practices, and weed management that influence weed diversity and abundance. Under ZT-DSR, weed flora often shifts towards competitive grasses and sedges (Kumar and Ladha, 2011). Experiences with ZT-DSR in India and other Asian countries reveals that the shift from CT-TPR to ZT-DSR favour grassy weeds.

The shift from CT to ZT in wheat also results in shift in weed flora. Emergence of littleseed canary grass is lower under ZT than CT in wheat but higher for some of the broad leaved weeds (Chhokar *et al*., 2007). If ZT is adopted in both rice and wheat, then there are chances of a shift in weed flora toward perennial weeds like Burmuda grass. In the Eastern IGP, problems of some perennial grassy weeds like purple nutsedge and Bermuda grass are serious under ZT as tillage is not used to disrupt perennation and because of poor crop canopy to out-compete these weeds as a result of lower N use and late planting of the crop in the region (Kumar *et al*., 2013).

3. YIELD LOSSES CAUSED BY WEEDS

Yield losses because of weeds have been reported to be much higher in ZT-DSR compared with CT-TPR. Yield reductions in rice has been recorded high as 46% due to weeds in weedy plots (Chin and Sadohara, 1994). Similarly, in wheat losses because of weeds are reported higher in ZT compared with CT. Normally weeds offer severe competition to wheat and cause up to 40 to 50% reduction in grain yield if not managed at critical time. Among others, littleseed canary grass is the single most important grassy weed of wheat which is highly competitive, causing significant yield reductions in the range of 25 to 80% depending on the severity of infestation.

4. WEED MANAGEMENT IN DIRECT SEEDED RICE UNDER ZERO TILLAGE

4.1 Cultural Practices

4.1.1. Tillage Practices

Tillage practices like ZT seeding systems can reduce the weed problems, if managed properly. If weeds are controlled effectively for initial 2-3 years, ZT helps in reducing the effective weed seed bank as soil is not being disturbed and therefore, weed seeds from lower depths are not being brought back towards the soil surface where they can more readily germinate.

4.1.2 Stale Seedbed

The stale seedbed technique is recommended as part of an integrated weed management strategy in ZT-DSR. In this technique, weed seed germination is encouraged by applying light irrigation and then emerged seedlings are killed using a non-selective herbicide (paraquat, glyphosate etc.) before crop sowing. This method has great potential for suppressing weeds and is feasible under ZT-DSR because there is about a 45 to 60 days fallow period between wheat harvest and sowing of rice. This technique is effective not only in reducing weed emergence during the crop season but also in reducing the weed seed bank. In farmer field trials, 53% lower weed population was observed after stale seedbed practices in DSR (Singh *et al*., 2009).

4.1.3 Crop Establishment

Spatially uniform establishment of healthy and vigorous rice seedlings increases crop competitiveness and suppresses weed growth. Zero-till rice can be established either by ZT-DSR or by ZT-TPR method by transplanting the seedlings manually or mechanically (using a paddy transplanter). Under DSR, weeds are more diverse and difficult to control compared with TPR. Many researchers found substantially lower weed biomass in ZT-TPR compared with ZT-DSR. Hence, where DSR is preferred for saving labour and water resources, ZT-DSR can be rotated with ZT-TPR every few years to keep weed pressure under check.

4.1.4 Seed Rate

Weed competition in ZT-DSR can also be reduced by optimizing seed rate and the crop geometry, as weed density and biomass declined linearly with an increase in seed rate (Chauhan *et al*., 2011). However, most seed rate studies reported increase in rice grain yields with increase in seed rate under weedy conditions only, and not in weed-free conditions (Chauhan *et al*., 2011). Under weed-free conditions, yields were not affected by seed rates while, under weedy conditions, weed biomass decreased linearly and yields increased quadratically with increased seed rates (Chauhan *et al*., 2011). In the absence of weeds, optimal seeding rates are often lower because high seeding rates can cause N deficiency, higher spikelet sterility, fewer grains per panicle, higher incidence of insects and diseases, and crop lodging (Kumar and Ladha, 2011). In the IGP a seed rate of 20 to 25 kg/ha has been recommended for DSR (Kumar and Ladha, 2011) under optimum weed control. However, Chauhan *et al*. (2011) suggested a seed rate of 95 to 125 kg/ha for inbred varieties and 83 to 92 kg/ha for hybrid varieties to achieve maximum yields in competition with weeds.

4.1.5 Crop Geometry

Crop geometry, including row spacing and planting pattern, can also be employed to influence crop-weed competition. Narrow row spacing can shift the competitive balance in favour of rice by achieving faster canopy closure and reducing light availability to weeds (Chauhan and Johnson, 2011). Reductions in row spacing from 45 to 15 cm had no effect on yields under weed-free conditions but increased yields where weeds were present (Chauhan and Johnson, 2011). Weed competition can also be reduced for some cultivars by sowing rice in a paired-row pattern. Weed biomass was found 25% lower under paired-row sowing (15-30-15 cm) of rice compared with uniform row spacing of 23 cm (Mahajan and Chauhan, 2011). These results suggest that weed competition in

ZT-DSR can be reduced by growing rice with narrow spacing or in a paired-row planting pattern. However, narrow row spacing could make other weed control operations like hand/mechanical weeding more difficult compared to wide row spacing.

4.1.6 Residue Mulching

ZT rice systems create opportunities for exploitation of surface residues for weed suppression that are not available when puddling and flooding are used. Because, most rice weed species are sensitive to mulching, it can be an effective weed management strategy in ZT-DSR. Residue mulching ensures weed suppression by imposing a physical barrier to emerging weeds and through release of allelo-chemicals in the soil. A few studies on residue mulches in rice have demonstrated substantial reduction in emergence and growth of weeds. In ZT-DSR in the IGP, Singh *et al*. (2007) reported that application of 4 t/ha wheat residue as mulch reduced emergence of grasses and broad leaves weeds in the range of 44 to 47% and 56 to 72%, respectively.

Despite the significant positive effects of mulches on weed suppression, the limited availability of residue for mulch during the rice season is a constraint. In the IGP, previous wheat crop residue is used as animal feed and hence removed from the field. Therefore, there is a need to identify alternative ways to generate residue mulch. One way is to grow short duration additional crops such as mungbean during the fallow period between wheat harvest and rice planting and to retain the entire residue of this crop as mulch.

4.1.7 Sesbania Co-culture (Brown manuring)

"Brown Manuring" practice involves seeding of rice and *Sesbania* crops together and killing the *Sesbania* crop at 25-30 days after sowing with 2, 4-D ester at 0.40- 0.50 kg a.i./ha. Initially *Sesbania* grows rapidly and suppress weeds and this technology can reduce weed population substantially without any adverse effect on rice yield. Singh *et al*. (2007) reported 76 to 83% lower broad leave weed densities and 20 to 33% less densities of grassy weeds with this practice compared with rice sole crop.

4.1.8 Competitive Cultivars

Cultivars with with seedling vigour and spreading nature, which cover the ground quickly during the early vegetative stage, result in weed suppression (Kumar and Ladha, 2011). In general, it has been observed that early maturing (short duration) cultivars are more effective in smothering weeds than medium and long duration cultivars because of their early faster growth and ground cover. Besides, basmati varieties suppress weed growth more than short-statured, high-yielding, coarse-grain cultivars (Singh *et al*., 2009).

4.1.9 Water Management

Water management has been an important component of weed control in flooded CT-TPR, where flooding is employed from the first day of transplanting. Emergence and growth of many rice weeds are influenced by timing, duration, and depth of flooding. The emergence and growth of most weed species is inhibited only when fields are submerged shortly after seeding. In ZT-DSR, flooding cannot be applied immediately after sowing because rice seeds cannot germinate and survive under completely submerged conditions. Moreover, the duration of flooding is limited under ZT because water infiltration is faster in absence of puddling. Therefore, in DSR, many weeds can emerge before flooding is possible, making weed management difficult. Hence, development of rice cultivars capable of germinate under anaerobic conditions would greatly facilitate weed management through flooding in DSR (Chauhan, 2012). This trait would not only help in weed control but also in enhancing the adoption of DSR in both rainfed and irrigated areas as crop establishment can be improved with this trait.

4.1.10 Strategies to Reduce Weed Seed Bank

One way to deplete seed bank is to minimize weed seed production. Even after practicing weed control, some weeds escape and can produce large number of seeds, which further reduce yields or increase weed management costs in subsequent seasons. Attention should also be given to preventing seed production from weeds growing during the fallow period and on bunds and channels because they can contribute significantly to the soil seed bank. Weed seeds could also gain entry into rice fields via contaminated owner-saved seeds; manures or compost; and irrigation water. These sources should be prevented by using certified seeds and well-decomposed manures/compost free from weed seeds.

4.1.11 Strategies to Maximize Weed Seed Exhaustion

Another approach to diminishing weed seed banks involves enhancing weed seed predation and decay. ZT with crop residues could enhance weed seed predation and seed decay because in ZT a greater proportion of weed seeds remain on the soil surface where they are more prone to seed predation. Besides, residues might provide a desirable habitat for seed predators and decay agents. Improved soil characteristics under ZT could also facilitate seed predators and decay agents.

Chauhan *et al*. (2010) reported a high rate (78 to 91%) of rice for seed predation of grassy weed species, including *Eleucine indica* and *Digitaria* spp. from the soil surface in rice fields under ZT than under CT. Similarly, ZT with residue could play an important role in enhancing weed seed decay. Under ZT, the surface soil layer has a higher proportion of weed seeds, higher soil moisture and higher microbial diversity all of which favour microbial seed decay (Gallandt *et al*., 2004). Therefore, crop management practices such as ZT and residue retention, which could enhance weed seed decay agents (microbes/fungal pathogen), might contribute to reductions in the weed seed bank in the long run.

4.1.12 Crop Rotation

Crop rotation is the effective way to control weeds. Every crop imposes a distinct set of biotic and abiotic stresses on the weeds and this will promote the growth of some weeds while inhibiting others. Rotating crops will rotate selection pressures, preventing one weed from being repeatedly successful, and thus preventing its further perpetuation and infestation. Rotations alter selection pressures through three main mechanisms including (i) altering managements (e.g., timing of field activities, herbicides), (ii) varying patterns of resource competition, and (iii) allelopathy. Some farmers in IGPs rotate rice with some pulse crops like pigeon pea, mungbean etc. that is very effective for weed management since volunteer rice seedlings failed to survive in pulse because of insufficient soil moisture. Inclusion of perennial forages such as alfalfa in a rotation has been shown to contribute in weed control for up to three years, and can be particularly effective in ZT systems (Ominski and Entz, 2001).

4.2 Chemical Weed Control

Herbicidal weed control is the most adopted and perhaps the most versatile approach throughout the world. The herbicides act to kill the weed plants by blocking different physiological functions which are essential for plant growth. A variety of herbicides are available depending upon their mode of action, chemical composition, formulation, selectiveness and efficacy. Individual herbicides have strength and weakness but the right herbicide for use in DSR depends on the weed flora composition of a field. However, rotational use of herbicides with different modes of actions is desirable to check the development of herbicide tolerant or resistant weed biotypes. Some herbicides recommended for weed management in ZT-DSR are given in Table 2.

Table 2. Herbicide molecules recommended for weed management in rice.

Herbicide	*Application time*	*Dose (a.i./ha) (spray vol. L water/ha)*	*Application DAS/DBS*	*Weed control*		
				Grass	*BLW*	*Sedge*
Sole application						
Glyphosate	PP	1.0-1.5 (500)	1-7 DBS	***	***	**
Paraquat	PP	0.5 (500)	0 DBS	**	***	*
Pendimethalin	PE	0.8-1.2 (500)	2-3 DAS	***	*	*
Pyrazosulfuron	PE	0.02 (500)	12-20 DAS	**	*	
2,4-D	PoE	0.5 (500)	30-35 DAS		**	*
Azimsulfuron	PoE	17 g (400)	12-25 DAS	*	***	***
Bispyribac	PoE	25 g (500)	15-25 DAS	***	*	**
Ethoxysulfuron	PoE	18 g (500)	12-20 DAS		**	**
Fenoxaprop	PoE	60 g (500)	14-21 DAS	**		

(Contd.)

Herbicide	*Applicationtime*	*Dose (a.i./ha) (spray vol. L water/ha)*	*Application DAS/DBS*	*Weed control*		
				Grass	*BLW*	*Sedge*
Penoxulam	PoE	22.5 g (500)	12-25 DAS	***	**	**
Tank mixtures						
Glyphosate+ 2,4-D-EE	PP	1.0+0.25 kg (300)	1-7 DBS	**	**	***
Azimsulfuron+ bispyribac	PoE	17+12.5 g (500)	12-20 DAS	***	***	***
Propanil+ Triclopyr	PoE	3.0+0.5 kg (500)	12-25 DAS	**	**	*

PP- Pre-plant; PE- Pre-emergence; PoE- Post-emergence; DAS- Days of per sowing; DBS - Days before sowing. *, ** and *** indicates level of significance at 0.05, 0.01 and 0.001 respectively

Source: Gopal *et al.,* 2010

4.3 Bio-herbicidal control

Weed control through living organisms is an effective way to manage weeds. A large number of predators, pathogens and other plant competitors are being exploited to kill or suppress the weeds. To minimize the dependency on herbicides, some fungal pathogenic agents are also now being explored as mycoherbicides. To date, the most promising fungi for inundative biological control of *Echinochloa crusgalli* are *Exserohilum monoceras* and *Cocholiobolus lunatus* (Thi *et al*., 1999). Rice varieties IR50404 and CR203 were not affected by these fungi. *Setosphaeria* spp. cf. *rostrata* was also found to effectively control *Leptochloa chinensis* and not damaging to IR64. Besides, *Colletotrichum gleosporioides* for jointvetch (*Aeschynomene virginica*) and *Puccinia canaliculata* against yellow nutsedge (*Cyperus iria*) were found effective in rice. However, the use of bioherbicides at the farm level and the methods of delivery remain serious constraints to adoption so far.

5. WEED MANAGEMENT IN WHEAT UNDER ZERO TILLAGE

5.1 Cultural Practices

5.1.1 Use of Weed-free Certified Seed

Sowing seeds contaminated with weed seeds has been a major source for their spread. In contrast to rice, the majority of wheat farmers use their own seeds for sowing which contains weed seeds, particularly of the littleseed canary grass. Hence, the use of either certified seeds or proper cleaning of owner-saved seeds for planting is important in reducing littleseed canary grass populations.

5.1.2 Zero-Tillage and Residue Management

Zero tillage, even without residues, has been found helpful in reducing the population of littleseed canary grass (Malik *et al*., 2002). Moreover, ZT when combined with residue retention on the surface and early sowing, results in weeds suppression in wheat. When early seeding and rice mulch were combined, littleseed canary grass emergence was 83 to 98% lower compared with normal or delayed seeding without residue (Kumar *et al*., 2013). ZT wheat with rice residue mulch (6.0 t/ha) recorded the higher grain yield (6.14 t/ha) and lesser weed density (43.5%) over ZT wheat without residue management (Jat *et al*., 2014).

In rice-wheat systems of North-western IGP, most of the farmer's burn residues of previous rice crop for its rapid disposal before wheat sowing because it can interfere with drilling. Such burning of rice straw increases the germination of littleseed canary grass and reduces the efficacy of soil-active herbicides like isoproturon and pendimethalin (Chhokar *et al*., 2009). However, with recent planting technology particularly, the rotary disc drill and turbo happy seeder sowing of wheat can be done in heavy residue mulch of up to 8 to 10 t/ha without any adverse effect on crop establishment (Sharma *et al*., 2008).

5.1.3 Crop Planting Date

Due to dormancy, many weeds germinate during specific seasons. If the approximate date of emergence is known for some weeds, crop planting dates can be adjusted so that either the crop emerges before the weeds for a competitive advantage or weeds are allowed to germinate and are controlled before or during crop planting. Planting earlier by even a few days can give the crop a significant competitive advantage over weeds. The potential weed suppression offered by early crop planting is proven in case of *Phalaris minor* in rice-wheat systems of the IGPs. As the ZT sown wheat can be sown 1–2 weeks earlier, allowing the crop to establish before emergence of *Phalaris minor* (Chhokar and Malik, 1999).

5.1.4 Sowing Methods and Seed Rate

Seed rate and sowing methods can also influence crop–weed competition in ZT wheat. Narrow-row planting with increased crop density can shift the competitive balance in favour of the crop. Narrow row spacing (15 cm) reduced littleseed canary grass biomass by16.5% compared with normal spacing of 22.5 cm (Mahajan and Brar, 2002).

5.1.5 Competitive Cultivars

Crop cultivars vary in their growing habit, which can influence markedly the crop–weed competition. Wheat varieties with faster growth, faster canopy formation, spreading habits and greater height are less susceptible to weed competition (Balyan and Malik, 1989). Although, the competitive ability of wheat is often negatively associated with yield potential under weed-free environments, the magnitude of yield loss under weedy conditions is greater in high-yielding, less competitive dwarf wheat cultivars than in tall competitive cultivars (Challaiah *et al*., 1986). Even among high-yielding cultivars, there is a large difference in weed competitiveness. Wheat cultivars 'WH-147' and'HD-2285' with medium height were more competitive with wild oats and other weeds compared with other cultivars, such as 'HD-2009', 'WH-291', and 'S-308' (Singh *et al*., 1990).

5.1.5 Crop Rotation

Rotating crops that have different cultivation practices is a very effective cultural practice for disrupting life cycles and improving control of problematic weeds like littleseed canary grass (Chhokar *et al*., 2008). The incidence of littleseed canary grass was greatly reduced in RW systems by growing clovers or oats for fodder once in 3 years instead of wheat after rice. Intensification of the RW system by including short-duration vegetables (pea or potato) followed by late wheat can also improves weed control without herbicide applications (Chhokar *et al*., 2008).

5.1.6 Water and Nutrient Management

Nutrients and water management practices can be manipulated to favour crops against weeds. High moisture in rice-wheat systems favours moisture-loving weeds like littleseed canary grass, Indian sorrel and foxtail grass (Singh *et al*., 1995). Because wheat can germinate under drier conditions than many weeds (Chhokar *et al*., 1999), sowing under dry conditions can facilitate reduced weed emergence and competition. Similarly, placement of fertilizer in the crop root zone can shift weed–crop competition in favour of the crop. Under ZT, seed drills can place basal applications of fertilizer below the seeds, thereby suppressing weeds as compared with normal practice of broadcasting of fertilizers.

5.2 Chemical Weed Control

In areas with high soil moisture, perennial weeds and some annual weeds germinate and start growing before wheat crop and offer a tough competition to wheat. These weeds can be controlled by application of herbicides (Table 3).

Table 3: Recommendations of herbicide molecules for weed management in wheat

Herbicide	*Application time*	*Dose (a.i./ha) (spray vol. L water/ha)*	*Application (DAS)*	*Weed control*		
				Grass	*BLW*	*Sedge*
Carfentrazone	PoE	20 g (500)	25-30		***	*
Clodina Fop	PoE	60 g (400)	30-45	***		
Isoproturon	PoE	1.0 kg (500)	25-30	**	*	
Mesosul Furon+ Iodosulfuron	PoE	12+2.4 g (400)	30-35	***	**	**
Metsulfuron	PoE	4 g (400)	30-35		**	**

PoE- Post-emergence; DAS = Days after sowing

*, ** and *** indicates level of significance at 0.05, 0.01 and 0.001, respectively.

Source: Gopal *et al*., 2010

6. CONCLUSIONS

Sustainability of rice-wheat cropping system can be augmented with some conservation agriculture based resource conservation technologies such as zero-tillage, residue management and direct seeding of rice to overcome the problems associated with the conventional rice-wheat cultivation involving puddling and repeated tillage. In rice, the farmers are considering switching to ZT-DSR instead of CT-TPR which is labour intensive, requires large amounts of water, and is detrimental to soil health. Zero tillage technology has been widely adopted in wheat in the rice-wheat cropping systems in Indo-Gangetic Plains. Despite multiple benefits of ZT in RW systems, weed control remains a major obstacle to its adoption. To expand the adoption of ZT in RW systems while minimizing the risks associated with herbicide use, it is important to develop integrated weed management packages.

It is challenging to manage weeds under ZT without herbicides. However, when multiple tactics for weed control are integrated, dependence on herbicides can be reduced. In ZT rice, integration of stale seedbed, residue mulching, *Sesbania* co-culture, competitive cultivars, and appropriate cultural practices, including quality seed, seeding rate, crop geometry, crop establishment methods, water management, and strategies to reduce weed seed bank by minimizing seed input and enhancing seed mortality can reduce weed infestations and hence herbicide use. In ZT wheat, an integrated approach comprising rice residue retention, earlier sowing of certified/clean seeds, higher seed rates and narrow row spacing of competitive cultivars, crop rotation can drastically reduce weed problems. Further research is needed concerning interactions between conservation agriculture practices with regard to weed control, particularly tillage and residue retention. Besides, location-specific synergistic combinations of technology options have to be identified and used to maximize economic returns to farmers and environmental benefits to the community.

7. FUTURE RESEARCH NEEDS

Additional research on the following aspects will help in further developing and strengthening weed management strategies of ZT RW systems:

- For maximizing effectiveness of weed control approaches, emergence periodicity of key weed species of rice and wheat under ZT should be determined.
- To achieve optimum weed suppression without affecting crop establishment, effects and amount of different crop residue mulches (rice, wheat, *Sesbania*, mungbean, etc.) should be quantified.
- Identification of vulnerable stages of weed species in ZT rice and wheat by studying weed population dynamics.
- Quantifying short and long-term effects of summer legume on weed suppression during cover cropping and after its termination in ZT rice crop.
- Estimating the role of irrigation water and manure/compost in seed dissemination and developing strategies to minimize it.

- Efforts are needed to integrate multiple tactics and to evaluate long-term effects of nonchemical weed management practices on sustainability of RW cropping system.
- Effect of different weed control measures should be quantified on population dynamics and long-term shifts in weed populations.
- Developing weed-competitive cultivars with anaerobic germination traits so that early flooding can be used in ZT-DSR for weed suppression.
- To study the effects of rotating crops and crop management practices on the evolution of weeds and the stability of grain yields over time.

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9

Conservation Agriculture–Farm Machinery and Implements

K.K. Singh

The conventional mode of agriculture through intensive agricultural practices was successful in achieving goals of production, but simultaneously led to degradation of natural resources. The growing concerns for sustainable agriculture have been seen as a positive response to limits of both low-input, traditional agriculture and intensive modern agriculture relying on high levels of inputs for crop production. Sustainable agriculture relies on practices that help to maintain ecological equilibrium and encourage natural regenerative processes, such as nitrogen fixation, nutrient cycling, soil regeneration, and protection of natural enemies of pest and diseases as well as the targeted use of inputs. Agricultural systems relying on such approaches are not only able to support high productivity, but also preserve biodiversity and safeguard the environment. Conservation agriculture has come up as a new paradigm to achieve goal of sustained agricultural production. It is a major step toward transition to sustainable agriculture.

This chapter describes various cost effective and energy efficient resource conservation technologies for shaping future agriculture by attaining the goal of increasing productivity and meeting food security needs while at the same time efficiently using natural resources, including water, providing environmental benefits and improving the rural livelihoods of farmers. The resource conservation technologies (RCTs) are rapidly gaining popularity among farmers as they result in higher production at less cost with significant benefits to the environment and more efficient use of natural resources. This ultimately results in higher profits, cheaper food, and improved farmer livelihoods. Crop diversification is also easier as less land is needed to produce staple cereals, freeing up land for other crops.

1. THE THREAT TO AGRICULTURE

Climate change has emerged as a major challenge in achieving goals of sustainable agriculture. Agriculture impacts climate change causing green house gas emissions, and is at the same time impacted by effects of climate change as well. Amongst elements of climate change, the most important relate to increasing uncertainty in availability of water due to increasing frequency of draught and/ or excess water events resulting in uneven water availability over time and space. The rise in temperature and its implication for the whole range of agricultural practice is yet another critical element of climate change. Developing and promoting strategies that minimize contribution of agriculture to GHG emissions and that impart greater resilience to production systems constitute a major challenge to all; researchers, farmers, and policy makers. Conservation agriculture (CA) practices hold the promise of providing both a strategy for mitigating climate change and also working as an adaptive mechanism to cope with climate change. CA practices can contribute to sequester significant quantities of atmospheric CO_2 in the form of soil organic matter, as well as significant reduction in GHG emissions through improved use efficiency of the production system.

Agriculture is also being affected by the problem of soil degradation including decline in soil and water quality, water availability, biodiversity, etc. Various other socio-economic factors, namely migration of youth to urban areas, lowering yields, persistent incidence of pests, and rising cost of inputs are also impacting agriculture adversely. While large farmers are also affected, it is the small land holder farmer who is reaching a point of criticality with no option left to try. Roughly 60% of the area is rainfed, substantially involving small farmers, and while 40-45% of the land is cultivated by small and marginal farmers, they constitute 80% of the farming community.

2. CONSERVATION AGRICULTURE AND RESOURCE CONSERVATION TECHNOLOGIES

Generally, the terms "conservation agriculture" (CA) and "resource conservation technologies" (RCTs) are used as if their meanings are similar but in this note, a sharper distinction has been made. "Resource conservation technologies" will refer to those practices that enhance resource- or input-use efficiency. This covers a lot of ground. New varieties that use nitrogen more efficiently may be considered RCTs. Zero or reduced tillage practices that save fuel and improve plot-level water productivity may also be considered RCTs, as may land levelling practices that help save water. There are many, many more. In contrast, "conservation agriculture" practices will only refer to the RCTs with the following key features:

- Minimum soil disturbance by adopting no-tillage and minimum traffic for agricultural operations,
- Leave and manage the crop residues on the soil surface, and
- Adopt spatial and temporal crop sequencing/crop rotation to derive maximum benefits from inputs and minimize adverse environmental impacts.

The distinction is important because some RCTs, while attractive in the near-term, may be unsustainable in the longer-term. An example of this is the use of zero tillage without residue retention and without suitable rotations which, under some circumstances, can be more harmful to agro ecosystem productivity and resource quality than a continuation of conventional practices (Sayre, 2000).

The principles listed above are defined as common to CA systems. However, the specific components of a CA system (establishment methods, farm implement selection, crops in the rotation, soil fertility management, crop residue and mulch management, germplasm selection, etc.) tend to be different across environments. Local investments in adaptive research typically are needed to tailor CA principles to local conditions.

3. CONSERVATION AGRICULTURE – THE NEW PARADIGM

Over the past 2-3 decades globally, conservation agriculture has emerged as a way for transition to the sustainability of intensive production systems. The term 'Conservation Agriculture' (CA) refers to the system of raising crops without tilling the soil while retaining crop residues on the soil surface. Land preparation through precision land levelling and bed and furrow configuration for planting crops further enables improved resource management.

Conservation agriculture permits management of soils for agricultural production without excessively disturbing the soil, while protecting it from the processes that contribute to degradation e.g. erosion, compaction, aggregate breakdown, loss in organic matter, leaching of nutrients etc. Conservation agriculture is a way to achieve goals of enhanced productivity and profitability while protecting natural resources and environment, an example of a win-win situation. In the conventional systems, while soil tillage is a necessary requirement to produce a crop, tillage does not form a part of this strategy in CA. In the conventional system involving intensive tillage, there is a gradual decline in soil organic matter through accelerated oxidation and burning of crop residues causing pollution, green house gases emission and loss of valuable plant nutrients. When the crop residues are retained on soil surface in combination with no tillage, it initiates processes that lead to improved soil quality and overall resource enhancement.

4. 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 agricultural productivity. More than 90% farmers have adopted semi-dwarf wheat by 1997 (Pingali, 1999). 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 fertilizers and expansion of irrigation, there has been a consistent increase in the use of external inputs including pesticides. Thanks to green revolution, the higher food availability without using the extra land represents a success story in agriculture.

There were not the varieties alone which transformed the food production scenario, but the response of these varieties to external inputs brought about a major change in the food production. The gross consumption of fertilizers increased 25-fold in developing countries to reach 91 million tons 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 because of ever deeper tube wells, micronutrient depletion, mono-culture, reducing bio-diversity and build up of insect, diseases and weeds, development of resistance against pesticides and high concentration of pesticides or fertilizer derived nitrates and nitrites in water courses. The amelioration of above factors adds to the cost of cultivation and, therefore, a decline in the total factor productivity. With the rise in input cost, the net profit of farmers has decreased even if the productivity is increasing slightly. Each farmer, therefore, needs to maximize earnings through alternate technologies. Seen from profitability point of view, it will be important to maintain natural resources. Resource Conservation Technologies (RCT), therefore, have become a critical component to growth in agriculture. These technologies require complementary innovations through multi-disciplinary, multi-institutional and farmers' participatory approach. This is important because the livelihood of more than a billion agriculture population in developing countries will depend on technologies that raise outputs per labour-hour and per unit area at less cost (Lipton, 2004).

5. DESCRIPTION OF VARIOUS RESOURCE CONSERVATION TECHNOLOGIES

A basket of technologies has been developed and made available to farmers. Some are based on reduced tillage for wheat including zero-tillage. Bed planting systems increase water productivity and when combined with reduced tillage in a permanent bed system provide even more savings. Laser levelling combined with these tillage systems provides additional benefits. Many of the benefits of the tillage options for wheat are lost when rice soils are traditionally puddled. System based technologies do away with puddling so that total system productivity is increased. The various technologies are described briefly below:

5.1 Laser Land Leveller

Laser controlled land levelling equipment grades fields to contour the land for different irrigation practices. Laser levelling can reduce water use by 20-30%

and increase crop yields by 10-20%. The quality of land levelling in zero slope fields can be estimated through the standard deviation (SD) of the soil surface elevation. A field levelled with conventional equipment can attain a SD of 20-30 mm, while using laser levelling the technical limit extends up to 10 mm. The laser levelling can result in more than 10% increase in water application efficiency, while the cost of the levelling operation is two to three times that of a standard tillage operation.

One of the measures to improve irrigation efficiency is zero grade levelling for crop production. Zero slope fields can be flushed or drained more quickly. Level fields allow for a more uniform flood depth, using less water and reducing pumping costs. Benefits of laser land levelling extend for many years, although some minor land smoothing may be required from time to time due to field operations and weather conditions. Laser land levelling helps save irrigation water, increase cultivable area by 3 to 5% approximately, improve crop establishment, improve uniformity of crop maturity, increase water application efficiency up to 50%, increase cropping intensity by about 40%, increase crop yields (wheat 15%, sugarcane 42%, rice 61% and cotton 66%), facilitate management of saline environments, and reduce weed problems and improve weed control efficiency.

The laser leveller involves the use of laser (transmitter) that emits a rapidly rotating beam parallel to the required field plane, which is picked up by a sensor (receiving unit) fitted to a tractor towards the scrapper unit. The signal received is converted into cut and fill level adjustment and the corresponding changes in the scrapper level are carried out automatically by a hydraulic control system. The scrapper guidance is fully automatic; the elements of operator error are removed allowing consistently accurate land levelling. The set up consists of two units. The laser transmitter is mounted on a high platform. It rapidly rotates, sending the laser light in a circle like a light house except that the light is a laser, so it remains in a very narrow beam. The mounting has an automatic leveller built into it, so when it is set to all zeros, the laser's circle of light is perfectly level.

The benefits of laser land levelling over other land levelling methods include (i) increase in cultivable area, (ii) saving in irrigation water, (iii) improvement in irrigation efficiency, (iv) enhancement of water productivity, (v) enhancement of nutrient use efficiency, (vi) increase in crop yield, and (vii) weed control efficiency. Some of the limitations include (i) high cost of the equipment/ laser instrument, (ii) need for skilled operator to set/ adjust laser settings and operate the tractor, and (iii) less efficient in irregular and small sized fields.

5.2 Machinery for Surface Managed Crop Residue

The importance of maintaining trash cover has long been recognized. However, this often interferes with the placement of seed in firm and moist soil, therefore, farmers frequently burn in the fields which are not an eco-friendly practice. Seed could be placed in the soil in anchored stubble condition after partial burning for removal of loose straw. Uniform spreading of straw during harvesting itself by mounting a device at the rear of combine and then using drills under loose straw condition or chopping loose as well as anchored stubbles with a rotary shredder followed by residue drills are some of the viable options. The seeding machinery needed for such varied conditions and their limitations are discussed below.

5.2.1 Zero-Tillage

This is RCT where the seed is placed into the soil by a seed drill without prior land preparation. This technology is more relevant in the higher yielding, more mechanised areas of north-western India, where most land preparation is now done with four-wheel tractors. However, in order to extend the technology in other parts, equipment for 2-wheel hand tractors and bullocks is being modified. The basis for this technology is the inverted-T openers. This coulter and seeding system places the seed into a narrow slot made by the inverted-T as it is drawn through the soil by the four-wheel tractor. The coulters can be rigid or spring-loaded depending on the design and cost of the machine. This type of seed drill works very well in situations where there is little surface residue after rice harvest. This usually occurs after manual harvesting. Leaving the straw as mulch on the soil surface may be very beneficial to early establishment and vigour of crops planted this way and for soil moisture conservation, water infiltration and erosion. Earlier planting is the main reason for the additional yields obtained under zero-tillage. Zero-tilled plots could be planted in first week of November, the optimum date for planting wheat. The results of many trials suggest that the longer the farmer delays planting, the lower the yield. This finding has been confirmed in trials throughout the Indo-Gangetic plains in the past few years. In Haryana, surveys and crop cuts have shown that zero till produces 400-500 kg/ha more grain than traditional systems. This is attributed to earlier, timely planting, less weeds, better plant stands and improved fertilizer efficiency because of placement with the seed drill. Experiments at Indian Institute of Farming Systems Research, Modipuram after 16th year of continuous zero till and find no deleterious effects that would make them revert to the traditional system.

5.2.2 Reduced Tillage

The strip and rotary till drills have been developed that prepare the soil and plant the seed in one operation. This system consists of a shallow rotovator followed by a seeding system. Soil moisture was found to be critical in reduced tillage system. The rotovator fluffs up the soil, which then dries out faster than with normal land preparation. The seeding coulter does not place the seed very deep, so soil moisture must be high during seeding to ensure germination before the soil dries appreciably. The tractor can also be used with a rotavator to quickly prepare the soil and incorporate the seed after a second pass. This speeds up the planting and results in better stands with less cost than traditional methods. However, the strip and rotary till drills do a better job because the seeds are placed at a uniform depth in the single pass.

5.2.3. Bed Planting

In bed planting systems, wheat or other crops are planted on raised beds. This practice has increased in the last decade. Farmers have given the following reasons for adopting the new system: management of irrigation water is improved, bed planting facilitates irrigation before seeding and thus provides an opportunity for weed control prior to planting, plant stands are better, weeds can be controlled mechanically between the beds early in the crop cycle, seed rates are lower, after wheat is harvested and straw is burned, the beds are reshaped for planting the succeeding crops, burning can be eliminated, herbicide dependence is reduced and hand weeding and roguing is easier as well as less lodging occurs. Two bed widths and two or three rows of wheat planted per bed were compared with conventional flat bed planting. Two rows on 70cm beds were best. Two of the major constraints on higher yields are weeds and lodging. Both can be reduced in bed planting. The major weed species affecting wheat, *Phalaris minor,* is normally controlled using the herbicides. An additional advantage of bed planting becomes apparent when beds are "permanent" – that is, when they are maintained over the medium term and not broken down and re-formed for every crop. In this system, wheat is harvested and straw is left or burnt. Passing a shovel down the furrows reshapes the beds. The next crop can then be planted into the stubble in the same bed.

5.2.4 Zero Till Drill for Loose Straw Condition

Loose straw as well as anchored stubbles are left on the surface of the field after combining of crops. The ZT seeding of crop requires drills capable of cutting through loose straw, penetration into soil and placing seed at proper depth. Generally, four types of furrow openers i.e. single disc opener, double disc opener, triple disc opener i.e. double disc opener equipped with either powered or unpowered rotary disc coulter and star wheel punch planter are being introduced in rice-wheat cropping systems.

5.2.5 Single Disc Opener

The single disc type furrow opener cuts a furrow slice in the soil and pushes it to the side, thereby causing disturbance to the top layer soil. The boot for seed tube is placed at backside of disc. Generally, a single disc of 34 cm diameter sharpened at an angle of 9-100 and with concavity of about 2-2.5 cm is used. The openers are mounted at disc angle of 60 (with horizontal) and tilt angle of 3° (with vertical) to move the soil laterally. These furrow openers are recommended for tilled but trashy field conditions.

5.2.6 Double Disc opener

These openers are provided with two flat and sharpened discs opposed to each other and set at a small angle to the direction of travel as well as to vertical with included angle of about 100. Discs are positioned in such a way that they form a V-groove in the soil by pushing the soil downward and sideways. The penetration of discs is obtained by applying downward force. The seed boot is located between the two discs. The openers are used in various soil conditions, especially tilled and trashy fields.

5.2.7 Happy and Turbo Seeders

The Happy and Turbo Seeder technology provides an alternative to burning for managing rice residues and allows direct drilling of wheat in standing as well as loose residues. Both on-farm and on-station trials were conducted to evaluate the feasibility of direct-drilling of wheat in the presence of heavy loads of rice residue using the Happy and Turbo Seeders and the effects of tillage and residue management methods on crop productivity and soil physical properties.

5.2.8 Bed Planter-cum-Zero Till Drill

Presently zero- till drills are available in two-in-one version also, as raised bed planter-cum-ZT drill. The loose straw after combining could be collected with field balers, the drill can be used directly without any surface manipulation of residue and a system for combining, field baling and zero-tillage could be a viable option. To manage the straw from combine harvested wheat fields, the straw (bhusa) combine is also used extensively. The straw combine harvests the uncut straw as well as pick up the combine ejected loose straw from the field, chops the straw into fine pieces (bhusa) and blows it into an enclosed trolley trailed behind the tractor. The field could be drilled directly with rigid tines mounted inverted-T openers. Another option of using ZT drill in combination with flail type residue chopper is known as Happy Seeder and Turbo Seeder.

6. CONSERVATION AGRICULTURE IN INDIA

India is heavily dependent on wheat as a source of food. Wheat covers about 10 million ha. At present RCTs or CA practices are not widely used. However, in the wheat area of IGP, a dynamic is unfolding that may lead to the development and widespread adoption of zero tillage practices. The major objective of fostering CA practices at farmer field are here as under (Singh, 2011).

- ***Residue retention***. Problems of environmental degradation due to large scale crop residue burning and land degradation, fueling interest in residue retention for soil cover.
- ***Direct sowing with zero tillage***. Local drills were converted for use with zero tillage using locally made inverted “T” type furrow openers. Direct sowing with zero tillage was found to reduce costs and improve yields – especially during relatively dry seasons, when retained stubble is more effective for moisture conservation than bare soil.

- ***Diversification.*** Changing wheat mono cropping into other crops such as mustard, chickpea, sunflower and barley; and ***intensification*** with the introduction of legumes, pulses, vegetables and fodder crops.
- ***Chemical weed control to replace mechanical weed control.*** The cultivation of continuous wheat has led to problems of disease, soil fertility loss – and build-up of problem weeds. Mechanical weed control methods were unable to solve the problem. Weed control practices based on residue retention, new crop rotations and the application of glyphosat, in contrast, have proven effective, with herbicide use requiring diminishing over time.

As a consequence of these and related activities, conservation agriculture has become important farmers are converting their drills to zero tillage at their own expenses. Early adopters observe a clear and immediate cost savings through chemical fallow and zero tillage – savings that are likely to increase as the cost of herbicide continues to decline.

7. Effect of resource conservation technologies on land, water and energy productivity

The comparative performance of zero till drill (ZT), strip till drill (ST), bed planter (BP), rotary till drill (RT) and conventional drill (CS) for rice and wheat sowing based on long term experiments at this directorate are presented in this section. The conservation agriculture technologies of zero, strip and rotary till drilling, and bed planting of rice and wheat saved 61 to 87 % resources (time, labour, cost, fuel and energy). The bed planting also saved 37 and 35 % irrigation water in rice and wheat, respectively (Table 1). These technologies provided higher rice and wheat yields (2 to 8 %), B: C ratio (9 to 27 %) and energy efficiency (21 to 32 %) compared to conventional sowing (Singh *et al*., 2004; Gangwar *et al*., 2004 & 2005). The continuous use of these technologies has also improved soil health by increasing the soil organic carbon and mean weight diameter of the soil aggregates. Also, around 70 kg/ha/year CO_2 emissions to the environment could be reduced by the use of zero till drilling compared to conventional sowing which is vital to our environmental sustainability.

Table 1. Percent saving of resources under different RCTs compared to conventional sowing in rice - wheat cropping system during 15th year (*BP – Bed planting, ZT – Zero till drilling, ST – Strip till drilling, RT – Rotary till drilling)*

Parameter	*Rice*				*Wheat*				*Average*
	BP	*ZT*	*ST*	*RT*	*BP*	*ZT*	*ST*	*RT*	
Time	85	87	86	84	74	81	76	78	81
Labour	81	85	85	83	68	77	71	74	78
Diesel	83	86	83	60	85	85	82	63	78
Operational cost	79	81	77	63	67	76	71	74	74
Operational energy	82	86	83	61	84	85	82	63	78
Irrigation water	37	11	10	8	35	10	10	10	16

Farmers are adopting these technologies quickly. The adoption could be even faster if it were possible to have sufficient machinery available from small-scale manufacturers. Farmer feedback on water savings with these technologies essentially says that they save water. For zero-tillage, farmers report about 25-30% savings. This comes in several ways. First, zero tillage is possible just after rice harvest and any residual moisture is available for wheat germination. In many instances where wheat planting is delayed after rice harvest farmers have to pre-irrigate their fields before planting. Zero-till saves this irrigation. Savings in water also comes from the fact that an untilled soil has less infiltration than a tilled soil and so water flows faster over the field. That means farmers can apply irrigation much faster. Because zero tillage takes immediate advantage of residual moisture from the previous rice crop, as well as cutting down on subsequent irrigation, water use is reduced by about 10 cm-hectares, or approximately 1 million liters per hectare. One additional benefit is less water logging and yellowing of the wheat plants after the first irrigation that is a common occurrence on normal ploughed land. In zero till, less water is applied in the first irrigation and this yellowing is not seen.

8. EVALUATION OF DIFFERENT RESOURCE CONSERVATION TECHNOLOGIES FOR PLANTING OF RICE

The comparative performance of different methods of rice planting, namely; hand transplanting (HT), transplanting by self-propelled transplanter (MT), transplanting by manual transplanter (MaT), bed planting (BP), zero till drilling (ZT), strip till drilling (ST), rotary till drilling (RT), drum seeding (DS) and sprouted broadcasting (BS), with respect to rice yield (Y), benefit: cost ratio (B: C), energy output: input ratio (EE), water use (WU), infiltration rate (IR) and weed infestation (We) were evaluated. The effect of planting methods on rice yield, benefit: cost ratio and energy efficiency is depicted in Table 2 and Figure 1. The effect of planting methods on rice yield over the years is depicted in Figure 2. We noted that the rice (Saket – 4) yield was higher in MT (7.2%), MaT (9%), ZT (6%), ST (2.1%), RT (0.8%) and BP (0.4%); but lower in DS (3%), CS (7%) and BS (10%), respectively, compared to traditional HT (5.13 t/ha). The net return was 39 higher in ZT, 32 to 35% higher in MT and MaT; 19 to 25% higher in BP, RT and ST; 17% higher in DS; but 1 and 8% lower in CS and BS, respectively, compared to HT (Rs 22280/ha). The B: C ratio was 27% higher in ZT; 16 to 20% higher in ST, MaT, MT, BP and RT; 0.5 to 8% higher in BS, CS and DS, respectively, compared to HT (1.82). Energy output: input ratio was 24% higher in ZT, 15 to 4% higher in all the methods except DS, CS and BS, where it was 3 to 10% lower, compared to HT (4.73). The water use was 35% lower in BP; 3 to 95 lower in all other methods except CS, DS and BS, where it was 3 to 5% higher, compared to HT (214 ha-cm). The infiltration rate was maximum in BP (87 mm/day) and lowest (39 to 43 mm/day) in the three transplanting methods because of puddling. The weed dry matter was 64 to

206% higher in all the methods but 34 and 39% lower in MaT and MT, compared to HT (67 kg/ha) (Table 2).

Table 2. Effect of planting methods on rice yield, benefit: cost ratio, energy output: input ratio, water use and weed dry weight in rice – wheat cropping system during 15th year

Planting method	*Rice Yield (t /ha)*	*Benefit: cost ratio*	*Energy output: input ratio*	*Water use (ha-cm)*	*Weed dry weight (kg/ha)*
Conventional sowing	4.76	1.91	4.36	221	142
Bed planting	5.15	2.14	5.32	138	110
Zero till drilling	5.45	2.32	5.88	198	150
Strip till drilling	5.24	2.19	5.34	193	148
Rotary till drilling	5.17	2.12	4.94	201	146
Drum seeding	4.97	1.96	4.56	223	169
Sprouted broadcasting	4.61	1.83	4.23	226	212
Hand transplanting	5.13	1.82	4.73	214	67
Mechanical transplanting	5.50	2.19	5.06	207	41
Transplanting by manual transplanter	5.59	2.18	5.43	207	44
CD (5 %)	0.23	0.16	0.21	7.5	24

9. EVALUATION OF DIFFERENT MACHINES FOR DIRECT DRY SEEDING OF RICE

Five machines for direct dry seeding of rice, namely; conventional drill (CS), zero-till drill (ZT), strip-till drill (ST), rotary-till drill (RT) and bed planter (BP) were evaluated using uniform seed (Saket - 4) rate of 30 kg/ha. Under ZT, ST, RT and BP sowing was done directly without any field preparation but sowing under CS was done after preparing the field with two harrowing, 2 cultivator passes and one planking operations. The row spacing was kept at 180 mm in CS, ZT, ST and RT, and 120 mm in BP.

The performance parameters of different rice seeding machines showed that ZT, ST, RT and BP of rice saved time (87 to 84%), labour (85 to 83%), diesel (86 to 60%), cost (81 to 63%), energy (86 to 61%) and also irrigation water (8 to 37%) as compared to conventional sowing. The rice yield, economics and energy use affected by different methods is presented in Table 2 and Fig. 1. The zero till drilling produced higher rice (14 %), net returns (40 %), B: C ratio (21 %) and energy output: input ratio (35 %), compared to conventional sowing. The rotary till drilling produced higher rice (8%), net returns (22%), B: C ratio (11%) and energy output: input ratio (13 %), compared to conventional sowing. The strip till drilling produced higher rice (10 %), net returns (26 %), B: C ratio (14 %) and energy output: input ratio (22 %), compared to conventional sowing. The bed planting produced higher rice (8 %), net returns (20 %), B: C ratio (12 %) and energy output: input ratio (22 %), compared to conventional sowing.

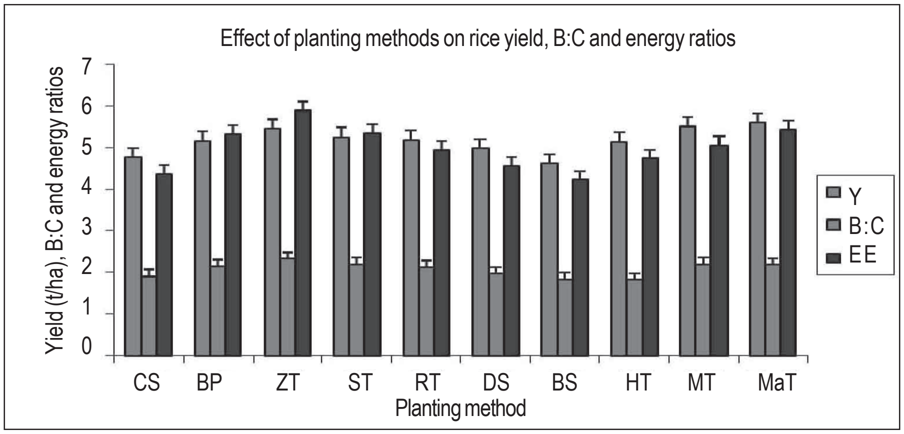

Fig. 1. Effect of planting methods on rice yield (Y), benefit: cost (B:C) and energy ratios (EE) (CS – Conventional sowing, BP – Bed planting, ZT – Zero till drilling, ST – Strip till drilling, RT – Rotary till drilling, DS – Drum seeding, BS – Sprouted broadcasting, HT – Hand transplanting, MT – Mechanical transplanting, MaT _ Transplanting by manual transplanter)

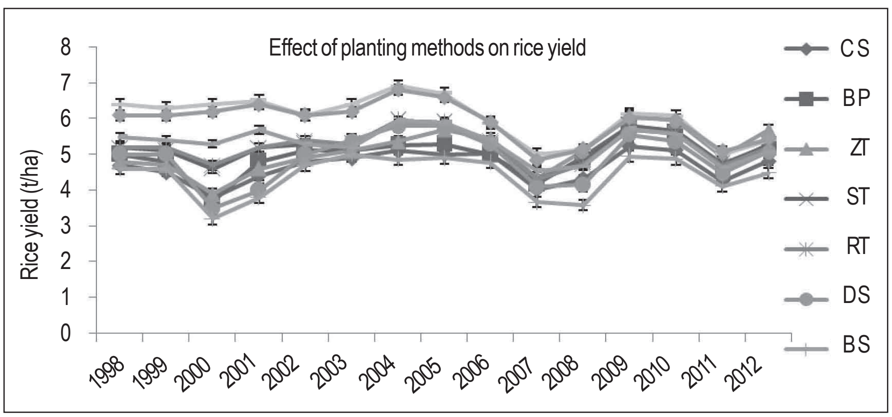

Fig. 2. Effect of planting methods on rice yield over the years (CS – Conventional sowing, BP – Bed planting, ZT – Zero till drilling, ST – Strip till drilling, RT – Rotary till drilling, DS – Drum seeding, BS – Sprouted broadcasting, HT – Hand transplanting, MT – Mechanical transplanting, MaT– Transplanting by manual transplanter)

10. EVALUATION OF DIFFERENT DRILL MACHINES FOR PLANTING WHEAT SUCCEEDING RICE

The comparative performance of different machines namely; bed planter (BP), zero-till drill (ZT), strip-till drill (ST), rotary-till drill (RT), and conventional drill (CS), in terms of wheat yield (Y), benefit: cost ratio (B: C), energy output: input ratio (EE), water use (WU), infiltration rate (IR), *Phalaris minor* (PM) and other weeds (OWE) were assessed. The effective field capacities of RT, ST, ZT, BP and CS were 0.42, 0.39, 0.52, 0.35 and 0.45 ha/h respectively. The rotary, strip and zero till drilling and bed planting were time saving (74 to 81%), labour saving (68 to 77%), diesel saving (63 to 85%), cost saving (67 to 76%), energy saving (63 to 85%) and also irrigation water saving (10 to 35%) compared to conventional sowing of wheat. Also, there was saving of about 20-25% in seed and fertilizer inputs in bed planting compared to conventional sowing. Zero, strip and rotary till drills and bed planter provided higher wheat yields (8-12%), net returns (8-19%), cost effectiveness (8-13%) and energy efficiency (19-26%); and reduced *Phalaris minor* (57-82%), other weeds (65-82%), compared to conventional sowing of wheat (Table 3 and Fig. 3). The effect of planting methods on wheat yield over the years is depicted in Figure 4.

The effect of different resource conservation technologies on soil organic carbon (OC), mean weight diameter of aggregates (MWD) and percent change in OC and MWD revealed that there was an improvement in soil properties by the use of these drills. Zero till drilling resulted in maximum moisture content at all the growth stages of crop, minimum cone index and bulk density, and maximum OC and MWD than any other method. Bed planting, and zero and strip till drilling improved soil organic carbon (15-39%) whereas rotary till drilling and conventional sowing reduced OC (2-13%) after fifteen crop cycles. Bed planting, and zero and strip till drilling also improved MWD (18-72%), whereas rotary till drilling and conventional sowing reduced MWD (13-20%) after fifteen crop cycles.

Table 4. Effect of planting methods on soil organic carbon, mean weight diameter of aggregates, moisture content, bulk density and cone index in rice – wheat cropping system after 15 years.

Planting method	*Organic carbon (%)*	*Mean weight diameter of aggregates (mm)*	*Moisture content (%)*	*Bulk density (t m^{-3})*	*Cone index (MPa)*
Conventional sowing	0.46	0.28	12.4	1.65	3.00
Bed planting	0.61	0.41	12.6	1.60	2.65
Zero till drilling	0.74	0.60	13.3	1.50	2.25
Strip till drilling	0.65	0.49	13.0	1.56	2.50
Rotary till drilling	0.52	0.30	13.3	1.56	2.60
Initial value	0.53	0.35	—	1.53	2.30
CD (5 %)	0.04	0.05	0.4	0.04	0.05

11. EVALUATION OF DIFFERENT CROP RESIDUES MANAGEMENT PRACTICES IN RICE-WHEAT CROPPING SYSTEM

A field experiment is in progress since 1998 to study the energy requirement and cost of recycling of rice-wheat straw after combine harvesting and to evaluate the performance of subsequent crops in straw recycled fields. The recycling was done by rotavator and achieved in shallow layer only (20-50 mm). The action of rotavator was to impart rotation to successive bites of soil so that chopped/ broken straw falls between these bites for uniform mixing with the

Table 3. Effect of planting methods on wheat yield, B:C ratio, energy output: input ratio, water use, and dry weight of *Phalaris minor* and other weeds in wheat under rice – wheat cropping system during 15th year.

Planting method	*Wheat yield (t/ha)*	*Benefit: cost ratio*	*Energy output: input ratio*	*Water use (ha-cm)*	*Phalaris minor (kg/ha)*	*Other weeds (kg/ha)*
Conventional sowing	5.65	2.63	5.26	47.6	691	122
Bed planting	5.76	2.86	6.27	33.3	194	28
Zero till drilling	6.32	2.98	6.65	43.2	123	22
Strip till drilling	6.10	2.98	6.53	43.4	208	35
Rotary till drilling	6.12	2.96	6.48	43.7	294	42
CD (5 %)	0.14	0.13	0.18	2.4	47	12

soil. After harvesting of rice and wheat, three straw management practices (recycling, retrieval and burning) were practiced before the planting of next crop. Self-propelled transplanter was used for transplanting of rice after wheat straw recycling. Zero, strip and conventional drills were used for wheat sowing after rice straw recycling. It was observed that for recycling of rice (5 to 6 t/ha), as well as wheat straw (8 to 9 t/ha), the degree of recycling was 75-80% and cost and energy of recycling of Rs 4250/ha and 2425 MJ/ha, respectively. There was appearance of yellowing in seedlings at the initial stage but subsequent establishment and growth of crops was found similar to non-straw recycled fields. The recycled wheat straw got decomposed after about 50 to 55 days in rice fields.

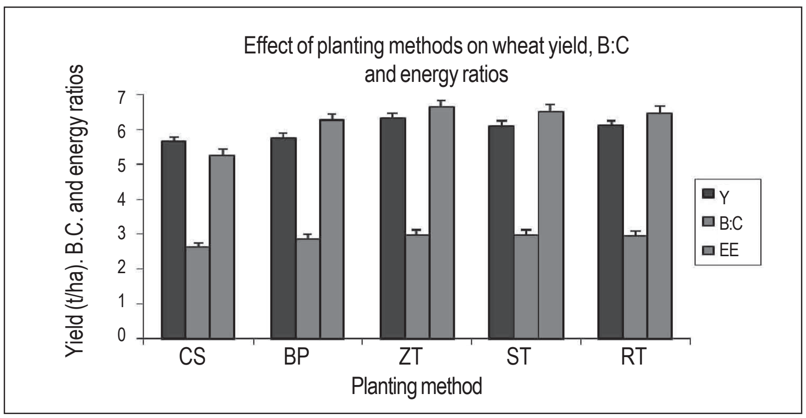

Fig. 3. Effect of planting methods on wheat yield (Y), benefit: cost (B:C) and energy ratios (EE) (CS – Conventional sowing, BP – Bed planting, ZT – Zero till drilling, ST – Strip till drilling, RT – Rotary till drilling)

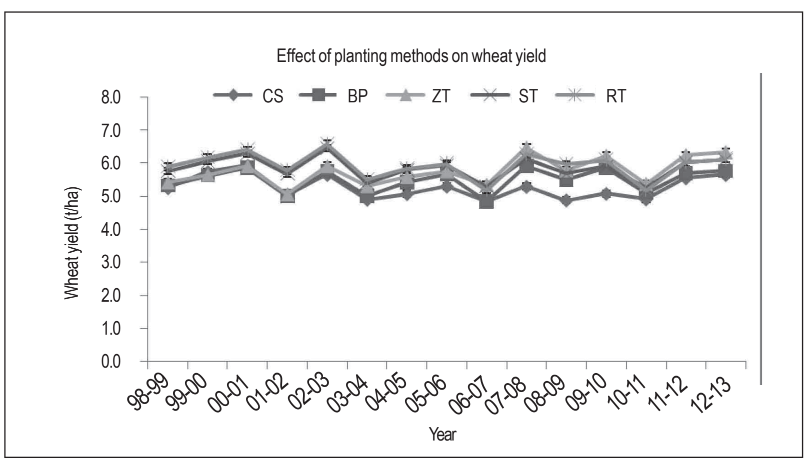

Fig. 4. Effect of planting methods on wheat yield over the years (CS – Conventional sowing, BP – Bed planting, ZT – Zero till drilling, ST – Strip till drilling, RT – Rotary till drilling)

The effect of different crop residue management practices on yield, benefit: cost ratio (B: C) and energy efficiency (EE) of rice and wheat are given in Figure 5. The effect of crop residue management practices on the yield of rice and wheat over the years is depicted in Fig. 6 and 7. The *in-situ* recycling of wheat straw produced 14 and 10% higher rice yield than straw retrieval and burning treatments, respectively. The net returns under straw recycling were 22 and 14% higher; B: C ratio and energy output: input ratio were 7 and 4% higher, and 0.5 and 0.2% higher, respectively. The recycling of rice straw increased the wheat yield (9%), net returns (11%) and B: C ratio (4%), but decreased energy output: input ratio (3%) compared to straw retrieval treatment. Crop residue recycling and burning improved soil organic carbon, SOC (43 and 11%) whereas retrieval decreased SOC (11%) compared to initial values after fifteen crop cycles. The recycling also improved SOC (22 and 15%) compared to retrieval and burning treatments. Crop residue recycling improved, MWD (15%), whereas retrieval decreased MWD (5%) compared to initial values after fifteen crop cycles.

12. IMPACT OF CONSERVATION AGRICULTURE PRACTICES

The rapid adoption and spread of CA technologies particularly zero-tillage for wheat is attributed to multiplicity of benefits. These include:

12.1 Reduction in Cost of Production

This is a key factor contributing to rapid adoption of zero-till technology. Most studies show that the cost of wheat production is reduced by Rs.1500 to 2000 per hectare. Cost reduction is attributed to savings on account of diesel, labour and input costs, particularly weedicides.

12.2 Reduced Incidence of Weeds

Most studies tend to indicate reduced incidence of *Phalaris minor*, a major weed in wheat, when zero-tillage is adopted resulting in reduced use of weedicides.

12.3 Saving in Water and Nutrients

Limited experimental results and farmers experience indicate that considerable saving in water (up to 20-30%) and nutrients are achieved with zero-till planting and particularly in laser leveled and bed planted crop.

12.4 Increased Yields

In properly managed zero-till planted wheat yields were invariably higher by 4 to 6% compared to traditionally prepared fields for comparable planting date.

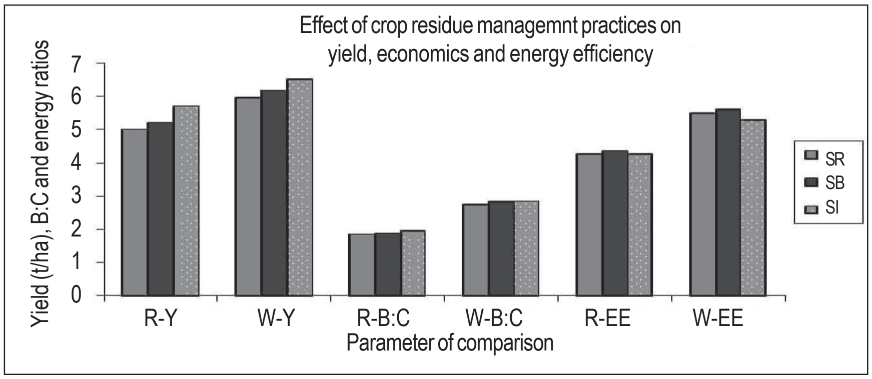

Fig. 5. Effect of crop residue management practices on yield (Y), economics (B:C) and energy efficiency (EE) of rice (R) and wheat (W) (SR – Straw removed, SB – Straw burnt, SI – Straw incorporated)

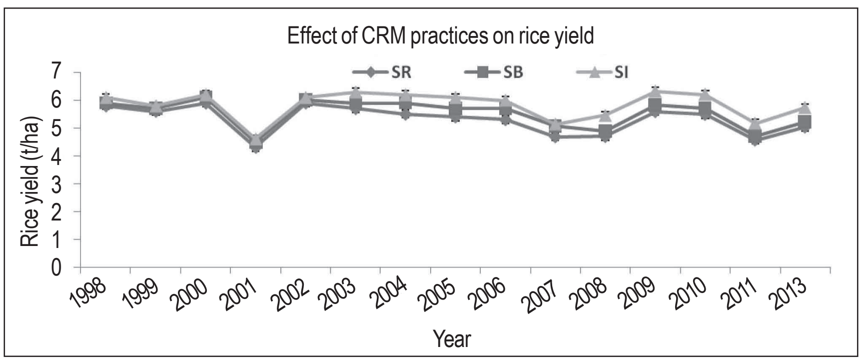

Fig. 6. Effect of crop residue management practices on rice yield over the years (SR – Straw removed, SB – Straw burnt, SI – Straw incorporated)

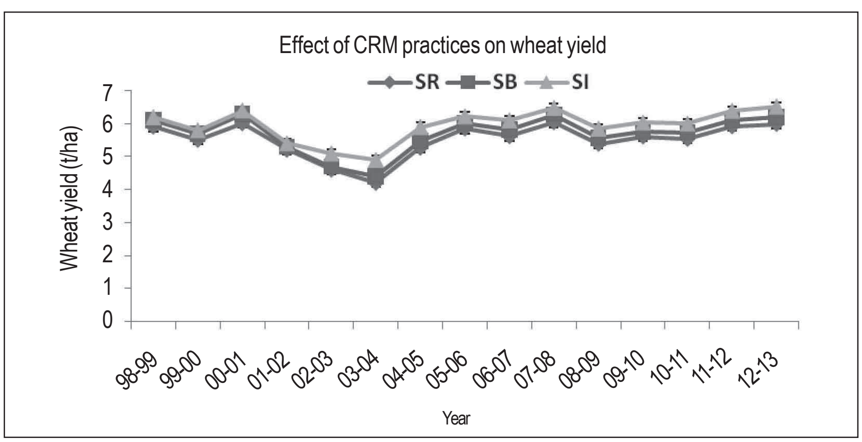

Fig. 7. Effect of crop residue management practices on wheat yield over the years (SR – Straw removed, SB – Straw burnt, SI – Straw incorporated)

12.5 Environmental Benefits

Conservation agriculture involving zero-till and surface managed crop residue systems are an excellent opportunity to eliminate burning of crop residues which contribute to large amount of green house gases like CO_2, CO, NO_2, SO_2 and large amount of particulate matter. Burning of crop residues, also contributes to considerable loss of plant nutrients, which could be recycled when properly managed. Large scale burning of crop residues is also a serious health hazard.

12.6 Crop Diversification Opportunities

Adopting CA system (includes planting on raised beds) offers opportunities for crop diversification. Cropping sequences/rotations and agro-forestry systems when adopted in appropriate spatial and temporal patterns can further enhance natural ecological processes which contribute to system resilience and reduced vulnerability to yield reducing disease/pest problems. Limited studies indicate that a variety of crops like mustard, chickpea, pigeon pea, sugarcane, etc., could be well adapted to the new systems with advantage.

12.7 Resource Improvement

No tillage when combined with surface managed crop residues sets in the processes whereby slow decomposition of residues results in soil structural improvement and increased recycling and availability of plant nutrients. Surface residues acting as mulch, moderate soil temperatures, reduce evaporation, improve biological activities and provide more favorable environment for root growth, the benefits which are traditionally sought from tillage operations.

13. MAKING THE SHIFT TO RCTS

A major bottleneck in large scale adoption of RCTs is due to mind set of the stake holders and the age-old practice of excessive tillage for establishment of rice and wheat. The shift to resource conserving technology will require a reorientation and retraining of farmers, development workers, scientists, policy makers, educators and other interested stakeholders and overcoming the ‘Not Invented Here’ (NIH) syndrome on the part of technocrats. The technologies are more management sensitive; they work when done properly. Farmers will need training in proper use and calibration of machinery, good after sales service and available spare parts, trained mechanics and more. Resource conserving curriculum will need to be introduced into places of learning so that extension workers, scientists and farmers can be taught the benefits and needs of this technology. Public awareness of the benefits of RCT at the farm, village, country and global level is needed. New innovative ways to upscale the technology and make it available to farmers are needed that rely on more participatory approaches of all stakeholders.

14. POLICIES NEEDED

To enhance efficiencies of inputs (agro-chemicals, water and fossil energy) and the development and use of resource conserving technologies, certain policies concerning pricing, incentives, research, agricultural education, funding etc have to be made. Efficient use of water will not occur if farmers are given it free. Subsidies have to be more production oriented and linked to improving the water use efficiency. There is a need for the new implements to experiment with the resource conserving technologies; more funds are needed for refinement and development of farm equipments to promote precision agriculture. Farmers should save sufficient funds in the first year to pay for the cost of these new drills and other equipments. A better policy would make credit more easily available although repayment schedules must be met. Subsidies on equipments are seen as a step forward in deteriorating the quality of farm implements manufactured in small-scale sectors, where quality control is difficult, and quality standards are generally missing. This whole issue of policy is complex, since there is a need to balance the needed encouragement of farmers to produce more food at lower prices without unduly degrading the environment and the resource base while still providing cheap food for the urban and rural poor.

With the rapid expansion of wheat zero tillage in the Indo-Gangetic plains, there has been, within that region a surge of interest in resource conservation technologies. In the 2009-2010 wheat season, zero tillage is estimated to have been used on nearly 2 million ha of sown area. And wheat zero tillage is seen by many as merely the first step in a broad movement towards the development and adoption of an ever richer collection of resource conserving, conservation agriculture technologies.

15. FACTORS TO IMPROVING EFFICIENCIES OF RCTS

Following factors need to be taken into account for improving efficiencies of RCTs in Integrated Farming Systems:

1. Ideally, farmers should cut spending rather than investing more on inputs like fertilizers or pesticides.
2. We must look for extra revenues to plug the gap in net profits. The best way to increase revenue is increase yields without increase in input use.
3. It remains true that yield is primarily a time phenomenon i.e. it is a function of time for which the crop remains in the field. That means longer the crop remains in the field for its growth and development, higher the grain yield. Most parts of Indo-Gangetic Plains (IGP) have the big difference in the base line when crop is sown. For instance, in the eastern region of IGP, sowings are delayed beyond December. This is where maximum gains in productivity will come especially from North-East plane zones where sowing of wheat is delayed beyond December.
4. Many farmers especially small farmers spend their income as soon as they receive it, in fact, they have no seed money to invest in the next season. Whatever little money they save, farmers channel most part of saving into

tillage operations. Technologies like zero tillage can help scrapping such spending and provide room for diverting the spending towards input that improve yield.

5. Increase in the soil organic matter by retaining more residues on the soil is important. Promoting existing biological cycle and soil biological activity, maintaining environmental resources and using them more carefully and efficiently and reusing residues as much as possible can help sustaining the rice-wheat cropping system. Thus, minimizing only pollution both on-site and off-site is an important feature of reducing soil degradation.
6. Rice-wheat cropping system requires enormous expenditure of energy to frequently till the land and to pump the groundwater for irrigation. To sustain the energy based activities, diesel consumption will increase in future decades. Saving of diesel consuming operations can help sustaining the import of oil for other purposes.
7. The water resources are under great stress. The real water saving will come by obtaining more crop production from same amount of water. Bed planting and laser leveling can help to reduce this stress.
8. Puddling of alkali soils further degrades the soil structure, and can facilitate formation of subsurface plough pan further restricting the percolation of water through soil profile. Reduced infiltration slows down the process of reclamation, therefore, puddling should be avoided (Gupta and Zia, 2003).
9. The existing practices like straw burning lead to pollution, which is spread of, from smoke of burnt straw. Farmers do not bear the cost of such pollution, which is publicly unacceptable. Zero tillage can effectively serve as an opportunity to evolve residue management technologies because management of surface residue is easier than incorporation.

Retention and management of adequate amount of crop residues (at least 30%) under conservation agriculture is the key to realize long-term benefits and also to reverse the process of soil degradation. In a soil that is not tilled for many years, the crop residues remain on the soil surface and produce a layer of mulch. Retention of crop residues improves organic carbon content, water stable aggregates, bulk density, and hydraulic conductivity and reduces runoff. But most of the farmers in Haryana and Punjab burn the crop residues to get their fields well cleaned before sowing. Therefore, to replace residue burning, and to realize benefits of residue cover under conservation agriculture, its efficient management through machinery modification is the need of time.

16. CONCLUSION

With proper integration of various cost effective and energy efficient resource conservation technologies, the future agriculture may be shaped to bring out the desired level of agricultural production to fulfil food security needs. At the same time higher water productivity with restoration of environment for improving the rural livelihoods and nutritional security of farmers may be achieved. These technologies are rapidly gaining popularity among farmers due to higher energy efficiency at lower cost of production.

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10

Role of Pulses in Conservation Agriculture

N. Nadarajan and Narendra Kumar

Land, water, air and biodiversity are the core natural resources of our planted earth, which need to be conserved and utilized most efficiently for survival and development of mankind. However, the conventional agricultural practices which exploited natural resourses to a great extent for short time benefits without concern of soil erosion and various kinds of degradation. Degradation of natural resources is a serious environmental problem that threatens ecosystem health and water resources lead to reduction in use efficiency of inputs (eg. fertilizer, irrigation, tillage etc.). According to an estimate, the global loss of fertile top soil from cropland varies from 0-5 to 400 tonnes/ha/year and the loss of nutrients is 19 kg N, 5 kg P and 39 kg K /ha/year (Tan *et al*., 2005). Excessive tillage and open soil surface accelerate the process of soil C loss. Since advent of agriculture about 10,000 years back, 16-20% of present day global carbon stock is estimated to be lost to atmosphere as CO_2 (Haider, 1999). Lal (2004) projected that since mechanization few hundred years ago, about 78 billion metric tons of carbon trapped in soil is lost to atmosphere. Conversion of forest land to agriculture led to an average loss of about 22% of soil carbon (Murty *et al*., 2002).

Endowed with unique ability for biological nitrogen fixation, deep root system, low water requirements, capacity to withstand drought, pulses constitute an important component of crop diversification. Pulses in general fix 40-150 kg of atmospheric nitrogen through microbial association. Inclusion of pulses in cropping system also enhances the microbial activities in soil thus improving the population of soil bacteria, actinomycetes and fungi.

1. PULSE STATISTICS

Pulses are the second most important group of crops after cereals. Developing countries contribute about 74% to the global pulses production and the remaining comes from developed countries. India, China, Brazil, Canada, Myanmar and

Australia are the major pulse producing countries with relative share of 25%, 10%, 5%, 5% and 4%, respectively. In 2009, the global pulses production was 61.5 million tonnes from an area of 70.6 million hectares with an average yield of 871 kg/ha. Dry beans contributed about 32% to global pulses production followed by dry peas (17%), chickpea (15.9%), broad bean (7.5%), lentil (5.7%), cowpea (6%) and pigeonpea (4.0%). About 90% of the global pigeonpea, 75% of chickpea and 37% of lentil area falls in India (FAOSTAT, 2009). India is the largest producer and consumer of pulses in the world contributing around 25-28% of the total global production.

Being an inseparable ingredient in the diet of the vast majority of population and mainstay of sustainable crop production, pulses continue to be an important component of the rainfed agriculture since time immemorial. Over a dozen pulse crops including chickpea (*Cicer arietinum*), pigeonpea (*Cajanus cajan*), mungbean (*Vigna radiata*), urdbean (*Vigna mungo*), cowpea (*V. unguiculata*), lentil (*Lens culinaris* ssp. *Culinaris*), lathyrus (*Lathyrus sativus*), frenchbean (*Phaseolus vulgaris*), horsegram (*Macrotyloma uniflorum*), field pea (*Pisum sativum*), moth bean (*V. aconitifolium*), *etc* are grown in one or the other part of the country. The latest data (2010-11) indicate that the present production of pulses is 18.09 million tonnes from an area of 26.28 million hectare with productivity of 637 kg/ha (Fig. 1). The stagnant growth of pulse production (approx. 14 mt) and continuous increasing human population in the country led to decline in per capita consumption of pulses from 61 g/day/person during 1950 to 30 g/day/person during 2011 (Indian Council of Medical Research recommends 65 g/day/person) (Amrender Reddy, 2009).

Chickpea continues to be the largest consumed in this complex comprising of 51% of the total pulses production from 35% pulses area with average productivity of 883 kg/ha. Pigeonpea is the second pulse crop with total production of 2.89 million tonnes from 3.47 million hectare area and productivity of 711 kg/ha. The other important pulses grown in India are urdbean (8%), lentil (7%), mungbean (5%) and fieldpea (4%) (Fig. 2). About 85% pulses are grown under rainfed condition which encounter with many types of biotic and abiotic stress. Pulses are grown in almost all types of soil available across the country with minimal inputs. The major pulses producing states in the country are Madhya Pradesh (29.36%), Maharashtra (16.16%), Uttar Pradesh (12.97%), Andhra Pradesh (9.75%), Karnataka (7.63%) and Rajasthan (6%) which together share about 80.7% of total pulse production while remaining 19.3% is contributed mainly by Gujarat, Chhattisgarh, Bihar, Orissa, Jharkhand and Tamil Nadu (Table 1).

There has been an interesting shift in the area of pulses within different parts of India (Fig. 3). The area has reduced drastically in North India from 10.83 m ha in 1971-75 to 8.16 m ha in 2006-2010, while it gone up in central and South India from 11.34 m ha to 15.01 m ha. This was more conspicuous in case of chickpea with regional shift from North India (5.1 m ha to 2.06 m ha) to central and South India (2.39 m ha to 5.2 m ha). The area under chickpea has increased from 6.4 m ha in 1993-94 to 9.21 m ha in 2010-11. Similarly, in pigeonpea the area increased from 3.53 m ha to 4.42 m ha and production from 2.69 m t in 1993-94 to 2.89 m t in 2010-11.

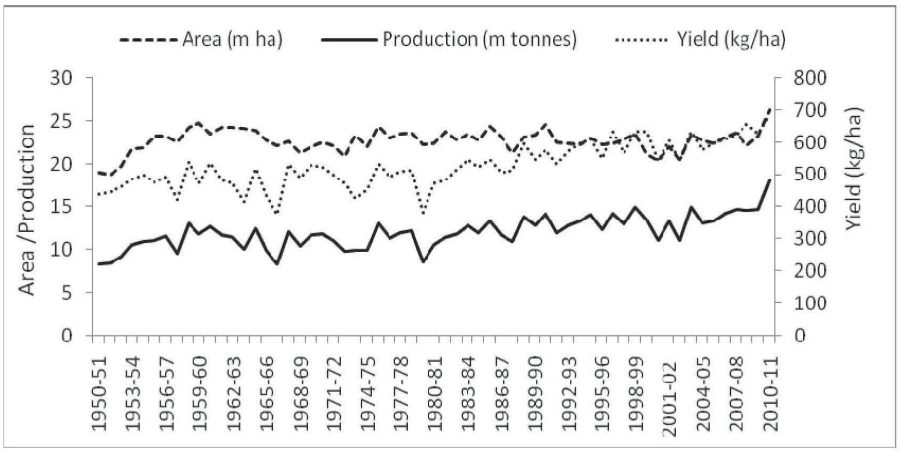

Fig. 1. Area, production and yield trend of total pulses in India

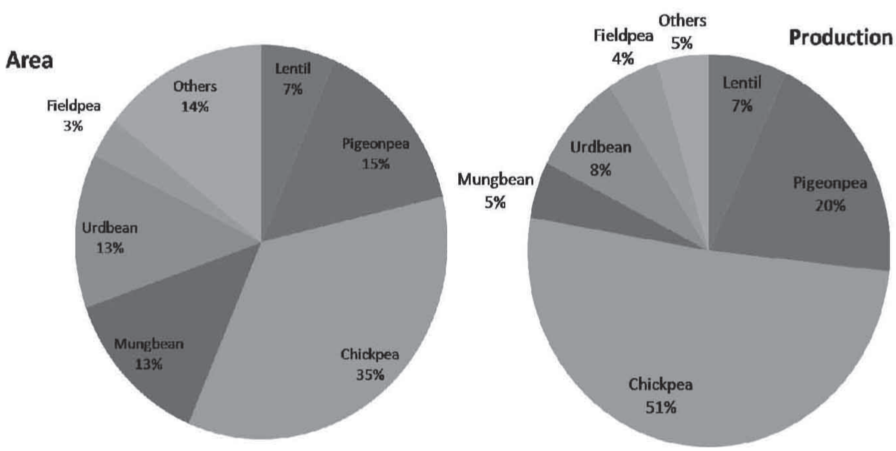

Fig. 2. Area (%) and production (%) of different pulse crops in India

Table 1. Percent share of major states in area and production of pulses in India

State	*Percent share*	
	Area	*Production*
Madhya Pradesh	21.22	29.36
Maharashtra	14.50	16.16
Uttar Pradesh	10.91	12.97
Andhra Pradesh	8.30	9.75
Karnataka	10.65	7.63
Rajasthan	15.04	4.87
Gujarat	3.15	3.53
Chhattisgarh	3.47	3.33
Bihar	2.43	3.22
Orissa	3.72	2.72
Jharkhand	1.36	1.53
Tamil Nadu	2.30	1.39
West Bengal	0.78	1.03
Haryana	0.57	0.68
Others	1.61	1.84
All India	100.00	100.00

Source: (Directorate of Economics and Statistics, GOI)

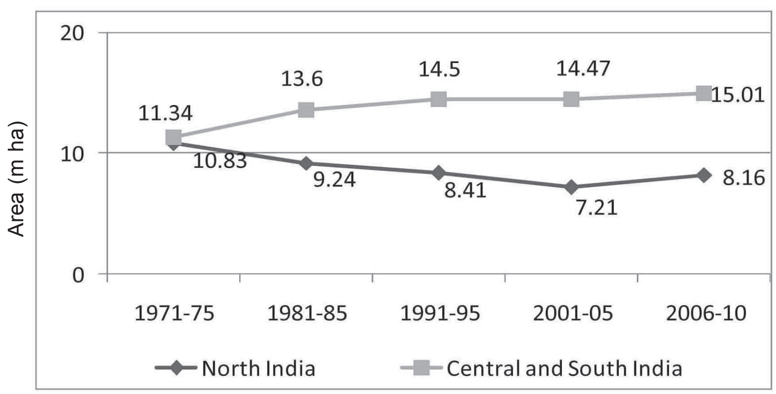

Fig. 3. Shift in area under pulses in north and south India

2. CONSTRAINT IN PULSE PRODUCTION

Pulses are mostly cultivated on marginal land under rainfed condition with minimum inputs and care subject which leads to severe yield losses not only due to edaphic, abiotic and socio-economic factors but also due to confounding effects of various biotic stresses (Kumar *et al.*, 2011). High influence of environmental factors and their interactions with genotype (G×E interaction) are the major production constraint in pulses which leads to a limited gain in terms of productivity in most of the pulses.Yield losses caused by various kinds of biotic and abiotic factors at different growth stages are discussed below.

3. BIOTIC STRESSES

Among the major biotic stresses, diseases and insect-pests are the most important. In case of chickpea, the important biotic stresses affecting its production are, fusarium wilt (FW) caused by *Fusarium oxysporum* f.sp. *ciceri* and Ascochyta blight (AB). Other biotic stresses include bortrytis grey mold (BGM) caused by *Botrytis cinerea*, leaf spot by *Alternaria* sp, black root rot by *Fusarium solani*, phytophthora root rot by *Phytophthora megasperma* and *Pythium* damping-off by *Pythium ultimum* and rust by *Uromyces* and beet western yellow virus (BWYV) causing narrow leaf. In case of pigeonpea, Fusarium *wilt,* sterility mosaic and *Phytopthora* blight (*Phytophthora drechsleri*) are economically the most important diseases. In short duration pigeonpea (120-150 days maturity) varieties *Phytopthora* blight is more common as compared to medium and long duration varieties of pigeonpea. However, in *Vigna* species, yellow mosaic disease cause by Mungbean Yellow Mosaic Virus (MYMV) and Mungbean Yellow Mosaic India Virus (MYMIV), powdery mildew, C*erscospora* leaf spot, root disease caused by *Pythium* and *Fusarium spp*. cause significant losses. Lentil also suffers from many diseases, the most importat being rust (*Uromyces vicia fabae*), *fusarium* wilt (*Fusarium oxysporum f.sp.lentis*), a*scochyta* blight (*Ascochyta lentis),* stemphylium blight (*Stemphylium botryosum*) while pea suffers from powdery mildew (*Erysiphe pisi),* downy mildew (*Peronospora viciae)* and rust (*Uromyces vicia fabae*).

In pulses (pigeonpea and chickpea) pod borer, *Helicoverpa armigera* (Hubner) is the most damaging pest worldwide and its frequent occurrence often results in complete crop failure. Besides *Helicoverpa*, other pests like maruca (*Maruca vitrata* Geyer), pod sucking bugs (*Clavigralla horrida* Germar) and podfly (*Melanagromyza chalcosoma* Spencer) pose a big threat to pigeonpea production. Mungbean and urdbean most suffer by spotted pod borer (*Maruca vitrata),* whitefly (*Bemisia tabaci*), aphids (*Aphis craccivora*) and thrips (*Caliothrips indicus, Megalurothrips distalis*).

4. ABIOTIC STRESSES

The most common abiotic stresses affecting pulses production are drought accompanied by heat and cold. Other abiotic stresses specific to some regions of the country are soil moisture stress, salinity, water logging, soil alkalinity and acidity, nutrient deficiency and toxicity. In *kharif* season water logging conditions in early stage of growth, especially in areas receiving good rains, highly affect the yield potential. Contrary to this, moisture stress is responsible for yield loss in low rainfall areas. In case of *Vigna* crops, during rainy season, the crops invariably witness rains at the time of pod maturity, leading to deterioration of seed quality and pre-harvest sprouting (Singh *et al*., 2011). This has a direct negative impact on both, productivity and marketability of the crop. During *rabi* season, low temperature and terminal drought cause considerable yield losses while in spring/summer grown pulses, terminal heat and drought stress are the major causes of concern.

5. PULSES IN CONSERVATION AGRICULTURE (CA)

Pulses are endowed with unique gift of nature to trap atmospheric N_2 in their root nodules in association with *Rhizobium* bacteria besides adding huge amount of organic matter to soil and protect from erosion. Pulses crops fix 1.0-1.5 million tonnes N and thus help in cutting industrial production of GHGs. Pulses have immense value in conservation agriculture (CA) and fitted well in all three principles of CA to achieve objectives of CA. Therefore, inclusion of pulses in cereal based crop rotation is considered as one of the RCTs which will reverse the negative effect of cereal- cereal rotation system. Some of the CA related issues and values of pulses are as follows:

5.1 Crop Diversification

5.1.1 Pulses in Rice-wheat

After the green revolution, area under the rice-wheat system in north-west parts and rice-rice in east-south parts has increased considerably due to high productivity and profitability with less risk. Rice occupies an area of 44 million ha, wheat 26 million ha and rice-wheat system 10.5 million hectare in India. About 90% of rice-wheat area is concentrated in the Indo- Gangetic Plains (IGP) comprising the states of Punjab, Haryana, Uttar Pradesh, Himachal Pradesh, Bihar, parts of Rajasthan, Madhya Pradesh and West Bengal. Rice consumes more than 40% of all the irrigation water resources available for agriculture. Many problems have been arising due to continuous following of rice-wheat system such as deterioration of soil structure and health, build-up of obnoxious weeds including resistance to herbicides, multi-nutrient deficiency (S, Zn, B, Mo, Fe), buildup of insect pests and diseases, environmental pollution due to burning of crop residues and escape of N to sub-surface water (Malik and Singh, 1995; Malik, 1996; Pingali and Heisey, 1996; Pingali and Gerpacio, 1997; Yadav *et al*., 1998; Gulati, 1999; Malik *et al*., 1998; Nayyar *et al*., 2001). Thus, to overcome these problems diversification of rice-wheat cropping system with pulses is being advocated since long.

In a long-term study at IIPR, Kanpur revealed that inclusion of pulses in the cereal based system increased the system productivity as well as yield component of crops. Highest system productivity of 5,140 kg/ha in terms of chickpea equivalent yield was recorded in rice-wheat-mungbean followed by rice- chickpea and lowest under rice- wheat (Fig. 4). In another set of long-term study in which maize- wheat system was compared with pigeonpea- wheat, maize- wheat, maize- chickpea, and maize- wheat- mungbean. Highest system productivity in terms of pigeonpea equivalent yield (3, 411 kg/ha) was recorded in maize- wheat-mungbean followed by pigeonpea- wheat and least under maize- wheat (Fig. 5). However, trials on resource conservation revealed that rice-chickpea- mungbean and rice- chickpea performed better than rice-wheat system in terms of productivity and sustainability (Annual report 2012-13). Similar results were also reported by Ghosh *et al*. (2012) and Ali and Kumar (2006).

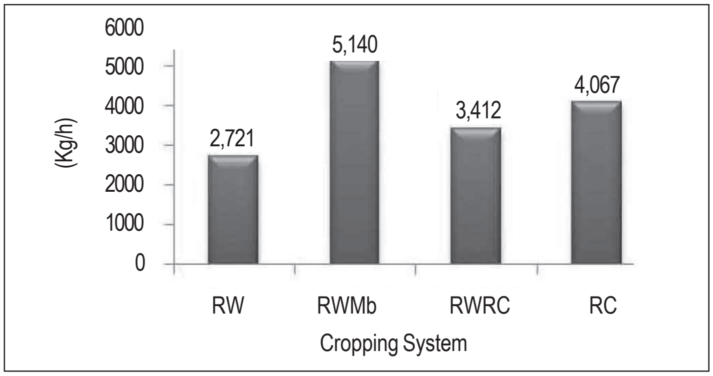

Fig. 4. Long-term effect of rice based cropping system on system productivity *(Source: Annual Report 2012-13) RW2 rice-wheat; RWMb= rice-wheat-mungbean; RWRC= rice-wheat followed by rice-checkpea; RC= rice-chickpea;*

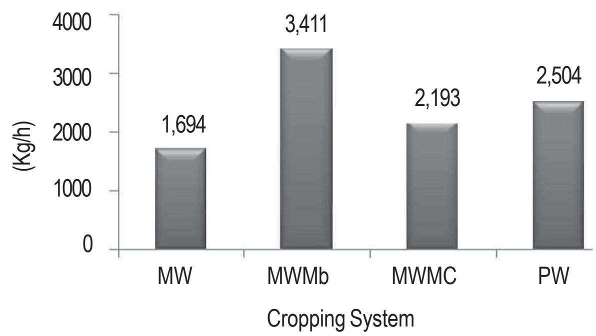

Fig. 5. Long-term effect of maize based cropping system on system productivity *(Source: Annual Report 2012-13) MWMb= Maize-Wheat-mungbean; MWMC= maize-wheat followed by maize-chickpea; PW= pigeonpea-wheat.*

5.1.2 Pulses in Inter-cropping

The major considerations for intercropping are the contrasting maturities, growth rhythm, height and rooting pattern and variable insect pest and disease associated with component crops so that these complement each other rather than compete for the resources and guard against weather adversities. Growing of crops in intercropping systems is found more productive particularly under rainfed conditions. Pulses can easily intercropped with oilseeds, cereals, coarse grains and commercial crops.

Among pulses, pigeonpea is planted in wider rows and its initial growth is slow which provides an opportunity for intercropping with crops like mungbean, urdbean, sorghum etc. Being a deep-rooted crop it extracts nutrients and water from deeper soil layer and thereby minimizes the competition for these inputs with cereals. Pigeonpea intercropped with short duration pulses (mungbean and urdbean) is the most popular combination in north India. The special feature of this system is that the productivity of the base crop i.e pigeonpea remains unaffected and an additional 400-500 kg/ha of mungbean or urdbean or 6-8q/ha of sorghum can be obtained without any additional inputs. Intercropping of mungbean and urdbean in pigeonpea, sorghum or maize smother the weed growth. Intercropping of winter pulses like chickpea and lentil with oilseeds is common in rainfed areas. Literatures reveal that high productivity and monetary returns can be obtained from chickpea + mustard, lentil + linseed and wheat + lentil intercropping systems (Ali and Mishra, 1992; Singh and Rathi, 2003). Similarly, horsegram can also intercropped with early pigeonpea in mid hills of Himalaya (Kumar *et al*., 2010).

Chickpea and mustard intercropping systems have been tried in 1:1 to 1:8 row ratios by different workers in the country. Varietal differences in chickpea in intercropping with mustard in 4:1 row ratio was also observed (Ali, 1992). Semi erect *desi* genotype BG 256 proved better under sole cropping but erect tall type BG 261 proved better under intercropping with mustard var. Varuna. Out of five *desi* chickpea genotypes, KPG 59 and Pant G 114 were found most compatible for intercropping with mustard (cv. Vardan) under irrigated condition. Among three *kabuli* chickpea genotypes (L 550, BG 1003 and KAK 2) and two mustard genotypes (Vardan and Varuna), KAK 2 + Vardan was found most compatible for intercropping system. In chickpea + mustard intercropping system, planting geometry of 6:2 row ratio was found ideal especially when Varuna variety of mustard was intercropped.

Under rainfed wheat+ chickpea was found more remunerative than wheat + mustard, but in irrigated conditions wheat+ mustard proved more profitable over wheat + chickpea. Lentil and linseed make a perfect combination for intercropping as compared to other *rabi* crops in rainfed conditions. Many other intercropping systems were also reported by several workers Ahlawat *et al*. (2005), Kumar *et al*. (2006), Kumar *et al*. (2008) and Kumar *et al*. (2010). It has been observed that growing one row of mungbean gave about half tonne/ha additional yield of mungbean without affecting the sugarcane yield. Further, increase in mungbean rows to 2-3 makes the systems non-profitable. It has been also found that mungbean is more suitable than urdbean (Yadav *et al*., 1987 and Panwar *et al*., 1990). Studies conducted at IISR, Lucknow established that urdbean and mungbean had synergistic effects on cane yield in spring planted crop and provided 0.4-0.5 tonnes/ha additional yield of pulses grains (Lal *et al*., 1999). Similarly, lentil is a suitable for intercropping with autumn planted sugarcane.

5.1.3 Pulses in Rice Fallow

A considerable area (about 11.7 m ha) remains fallow after rice harvest in India. Pulses like lentil, chickpea, mungbean and blackgram can be successfully grown under this situation following RCTs practices. Under this system a number of abiotic factors related to soil and water lead to poor productivity. Low moisture content in the soil after rice harvest followed by fast decline in water table with the advancement of *rabi* season results in mid- and -terminal drought at flowering and pod filling stages that adversely affects the productivity of pulses.

Besides the inherent constraints, rice fallows also affect seed germination, seedling emergence and crop establishment due to disruption of soil structure, soil water deficit, poor aeration and mechanical impedance of the seed zone. Under such hostile situation, pulses can be successfully grown on residual soil moisture after rice harvest following resource conservation practices for soil moisture conservation. The improvement in soil structure, microbial population and organic matter build-up was recorded with growing pulses after rice harvest (Rahmiaanna *et al*., 2000; Diaz-Ambrona and Minguez, 2001; Ghuman and Sur, 2001; Ishaq *et al*., 2001; Gangwar *et al*., 2006). Therefore, productivity and profitability from second crops in rice fallow can be improved with suitable crop management technique (Pratibha *et al*., 1996; Kar *et al*., 2004).

6. CONSERVATION TILLAGE

Excessive tillage of soils practiced in conventional agriculture results in short term increase in fertility, but degrades soil in long run. Structural degradation, loss of organic matter, erosion and falling microbial biodiversity are expected outcome of excessive tillage practices. Soil degradation due to tillage has forced us to look for alternatives to reverse the process. Conservation tillage with suitable cropping systems is helpful to maintain soil health, increase water use efficiency and check erosion (Fuzisaka, 1990; So *et al*., 2001). In fact higher yield of pulses after wet season (rainy season) rice with reduced tillage was also reported by Pratibha *et al*. (1996) and Mahata *et al*. (1992) from the rainfed areas of eastern India. Minimum tillage with crop residue management is found to reduce soil water evaporation, soil sealing and crusting (Verma and Bhagat, 1992; Meelu *et al*., 1994; Gangwar *et al*., 2006) which prevent growth and development of pulse crops.

In a study on soil moisture conservation effect on rainfed chickpea after rice harvest at IIPR, Kanpur revealed that chickpea can be successfully grown on residual soil moisture after rice harvest under zero tillage + rice straw mulch. The improvement in chickpea yield was 23-28% due to zero tillage and mulching over conventional method. The highest relative water content at flowering stage was also recorded in zero tillage + dibbling sowing + mulching (72.4%) followed by zero tillage + no till drill sowing + mulching (69%) and lowest under conventional practice (61.2%) (Fig. 6). This was mainly due to more soil moisture under zero tillage + mulching at flowering stage which finally resulted in higher yield of chickpea under these practices. Similarly, in other set of studies, highest chickpea yield and system productivity was recorded in rice-chickpea-mungbean under conservation tillage.

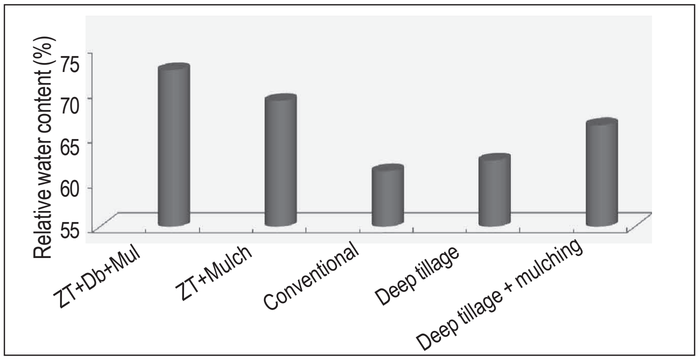

Fig. 6. Relative water content (%) of chickpea leaves at flowering stage
(ZT: Zero tillage; Db: Dibbling; Mul: Mulch)

6.1 FIRB Planting System

Furrow Irrigated Raised Bed (FIRB) system of planting is an agronomic intervention where crops are sown on raised beds. The concept of raised bed planting is very advantageous in both water logged and limited water area. The system of planting crops on raised bed alters crop geometry and land configuration, imposes effective control over irrigation and drainage. Water logged situation is common features of rainy season pulses, however rabi pulses are normally grown under limited water condition. 40-50% saving in irrigation water was recorded when irrigation was applied through furrows. The problem of over irrigation or ponding at some points in field can also be avoided. In a various studies at IIPR, Kanpur revealed that planting of 2 lines on raised beds size 75 cm enhances seed yield by 33.6% in urdbean, 15% in chickpea and 16% in lentil over conventional system of planting (Fig. 7). In addition, 40-45% saving of irrigation water and 25% saving of fertilizers and seeds were also recorded under FIRB planting.

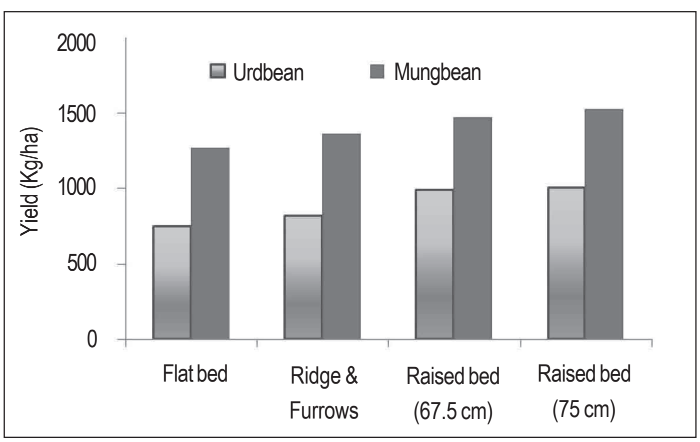

Fig. 7. Effect of sowing methods on urdbean and chickpea yield (mean of 2 years)

6.2 Residues Management

Crop residues are good sources of plant nutrients and are important components for the stability of agricultural ecosystems. Green revolution during 1960s not only drastically enhanced the food grain production but also crop residue production. About 511 Mt of crop residues are produced in India alone. In areas where mechanical harvesting is practiced, a large quantity of crop residues are left in the field, which can be recycled for nutrient supply. About 25% of nitrogen and phosphorus, 50% of sulfur, and 75% of potassium uptake by cereal crops are retained in crop residues, making them valuable nutrient sources.

Study conducted at IIPR, Kanpur revealed that incorporation of urdbean and mungbean residue was beneficial to the succeeding mustard crop in terms of higher yield (6-7%). In rice-chickpea sequence, yield of chickpea was significantly influenced by rice-residue incorporation and highest seed yield was obtained with incorporation of chopped straw + irrigation, while lowest yield was obtained in rice residue removal treatment (Fig. 8). Incorporation of chopped residue of mungbean + irrigation resulted in maximum wheat yield (4, 495 kg/ ha) which was significantly higher (38%) than control. In rice (upland) - lentil and rice-wheat – mungbean systems, incorporation of crop residues increased yield of all crops. Incorporation of both crop residues had shown an improvement of 17.6% in lentil yield over no residue in rice-lentil cropping system. Similarly, higher yields of all three crops in rice – wheat – mungbean were recorded due to incorporation of crop residues of either one crop or all crops in the system (Annual Report 2010-11 and Kumar *et al.*, 2012).

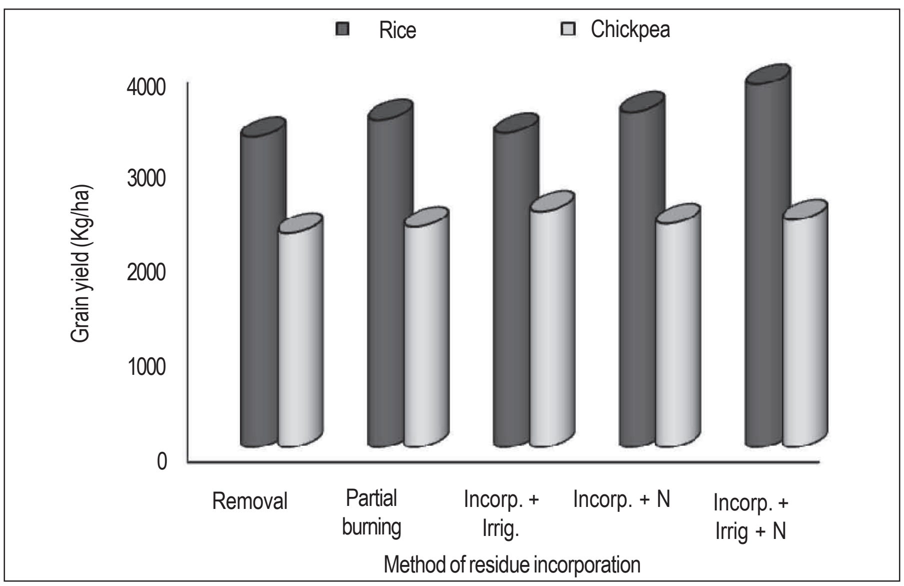

Fig. 8. Effect of residue incorporation on grain yield (kg/ha) of rice and chickpea in system (*Source*: IIPR, 2009)

Further, incorporation of urdbean and mungbean residue raised the organic carbon level by 35.48% over control. Residue incorporation also resulted in higher soil available N (24.6%), P (11.5%), and K (18.5%) over the initial fertility levels (Singh *et al*., 2012). Aggarwal *et al*., (1997) also reported increase in soil organic carbon, nitrogen, phosphorus, phosphatase and dehydrogenase activity in the soil after incorporation of pulse crops residues. Soil physical parameters *viz*., bulk density, particle density, percent pore space and WHC also improved under residue incorporation plots over residue removal plots (Table 2). In same set of study, periodic changes in soil microbial biomass carbon (SMBC) were also recorded. The results revealed that increase in SMBC up to 56 days after incorporation of urdbean and mungbean under chopping + incorporation + irrigation. Similar trend was also observed after harvest of wheat crop (Table 2).

The ratio of microbial carbon to soil organic carbon was also higher under chopping + incorporation+irrigation (Singh *et al*., 2012). Similarly, other studies at IIPR revealed that incorporation of all crop residues in rice (upland)-lentil and rice–wheat–mungbean systems enhanced yields of all crops in the system, besides, improvement in soil physico-chemical properties including infiltration rate (Fig. 9), nodulation and earthworm population were also observed.

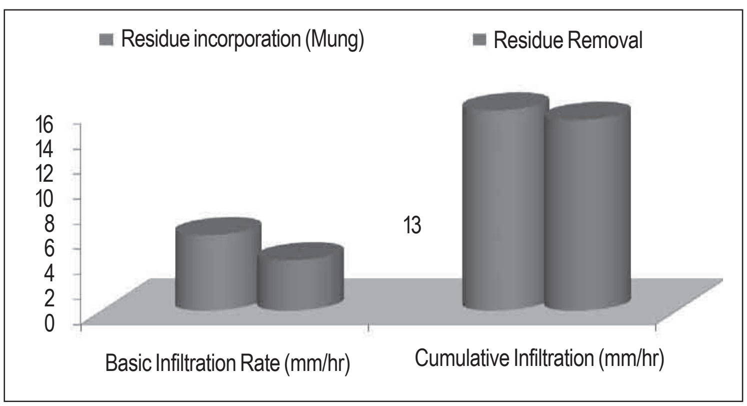

Fig. 9. Infiltration rate after rice harvest in rice-wheat-mungbean system

6.3 Improvement in Soil Quality

In rice-wheat and other cereal- cereal systems, major concern for sustainability is decline in soil physico-chemical properties. The process of decline in soil quality can be reversed by inclusion of pulses in the cereal based system. The improvement in bulk density, porosity, infiltration and other physical parameters were recorded under rice-lentil, pigeonpea-wheat and rice-wheat-mungbean. The improvement in soil structure is attributed to increase in more stable soil aggregates. The protein, glomalin, symbiotically along the root of legumes and

Table 2. Effect of crop residue incorporation on soil physical properties

Residue management	*Bulk Density (g/cc)*	*Particle Density (g/cc)*	*Pore space(%)*	*WHC (%)*	*MBC (µg /100 g)*	*SOC (g/kg)*	*Ratio of MBC to SOC (%)*
Mungbean [1]	1.38	2.42	45.5	37.3	262	3.9	6.71
Urdbean [1]	1.39	2.39	44.65	38.3	222	4.2	5.28
Mungbean [2]	1.38	2.38	46.80	38.3	322	3.9	8.25
Urdbean [2]	1.38	2.40	47.00	41.60	312	4.1	7.60
Mungbean [3]	1.34	2.38	47.32	42.50	327	3.6	9.08
Urdbean [3]	1.35	2.39	48.23	45.10	337	3.7	9.10
Mungbean [4]	1.32	2.36	49.63	46.40	320	3.5	9.14
Urdbean [4]	1.33	2.35	48.20	45.90	347	3.7	9.37
Control	1.44	2.50	38.15	33.40	132	3.1	4.25
CD (p=0.05)	0.05	0.10	3.51	3.8	39.8	0.29	N S

1- Incorporation; 2- Incorporation + irrigation; 3- Chopping + incorporation; 4 - Chopping + incorporation + irrigation; MBC: Microbial biomass carbon; SOC: Soil organic carbon; WHC: Water Holding Capacity

Source: Singh *et al.*, 2012

other plants serves as glue that binds the soil together into stable aggregates. This aggregate stability increases pore space and tilth reducing both soil erodibility and crusting. Similar observations were also recorded in two long-term trials at IIPR in which SOC improvement was recorded in rice-chickpea, rice-wheat-mungbean in lowland situation and maize-chickpea, pigeonpea-wheat and maize-wheat-mungbean system in comparison to rice-wheat and maize-wheat, respectively. Inclusion of pulses in rice-wheat and maize-wheat cropping systems also increased different fractions of soil organic carbon. Inclusion of a single pulse crop like summer mungbean in rice-wheat and maize-wheat systems improved the total organic carbon content, being greater in surface soil (0-0.2 m) depth. In both the production system crop rotation had significant effect on labile fraction of the TOC (Table 3). Pulses also contribute to an increased diversity of soil flora and fauna leading a greater stability to the total life of soil. They foster production of a greater total biomass in soil by providing additional N. Soil microbes use the increased N to break down carbon rich residues of crops. Pulses improve physical (soil aggregates, pore space, bulk density), chemical (OC, pH) and biological properties (soil biota population, efficiency and synergy, SMBC) of soil (Ali and Venkatesh, 2009). Similarly, improvement in nutrients availability in soil was also observed with inclusion of pulses in cereal-cereal systems (Table 4).

6.4 Nitrogen Economy

Pulses can fix 30-150 kg N/ha depending upon rhizobial population, host crop and varieties, management level and environmental conditions. The N-sparing and synergistic effects of pulses are well recognized. The intrinsic nitrogen fixing capacity of pulse crops enables them to meet large proportion of their nitrogen requirement and also helps in economizing nitrogen in succeeding non-legume crops. In sequential crop involving pulses, the preceding pulse may contribute 18-70 kg N/ha to soil and thereby considerable amount of N can be saved in succeeding crops. In rice-wheat rotation growing of short duration mungbean in summer may brings nitrogen economy up to 40-60 kg N/ha in succeeding rice crop.

Influence of *kharif, rabi* and summer season pulses on productivity and N economy of succeeding cereals were studied at IIPR, Kanpur. The results revealed that soybean – wheat system were the most productive followed by pigeonpea – wheat among *kharif* pulse based cropping systems. The nitrogen economy due to preceding pigeonpea over sorghum was found to be 51 kg N equivalent/ha. Influence of *rabi* pulses on productivity and N economy in succeeding rice revealed that chickpea, rajmash and lentil exhibited most favourable effect in economizing nitrogen to the extent of 40 kg/ha. Rajmash – rice was the most productive system followed by chickpea – rice. Among summer pulses, mungbean – rice was found most productive (6,620 kg/ha) followed by fodder cowpea – rice (Fig. 10). Further, an improvement in the N budget of soil measured by NO_3-N content left after harvest of *rabi* pulses was recorded. Chickpea ranked first (20.4 kg/ha) followed by fieldpea and lentil in contribution of residual NO_3 in the soil profile. Among the genotypes, chickpea cv. BG 1003, lentil cv. DPL-62 and fieldpea cv. Rachana were highest in increasing the nitrate content in soil.

Table 4. Effect of inclusion of pulses on nutrients availability in soil under LTFE at IIPR, Kanpur

Cropping system	*Available P (kg/ha)*	*Available K(kg/ha)*	*Available S(kg/ha)*	*DTPA –Zn (kg/ha)*	*B(kg/ha)*
Maize based system					
Maize-Wheat	16.0	173.0	17.3	0.6	0.9
Maize-Wheat-Mungbean	17.2	186.0	19.4	1.1	0.9
Maize-Wheat-Maize-Chickpea	18.0	185.9	18.5	0.8	1.0
Pigeonpea-Wheat	16.8	183.2	19.1	0.8	1.0
Rice based system					
Rice-Wheat	18.55	234.20	14.10	1.68	0.86
Rice-Wheat-Mungbean	18.37	271.58	16.71	1.60	0.89
Rice-Wheat-Rice-Chickpea	21.20	247.94	17.54	1.69	0.92
Rice-Chickpea	21.55	243.41	17.15	1.82	0.93

Source: IIPR Annual Report 2011-12

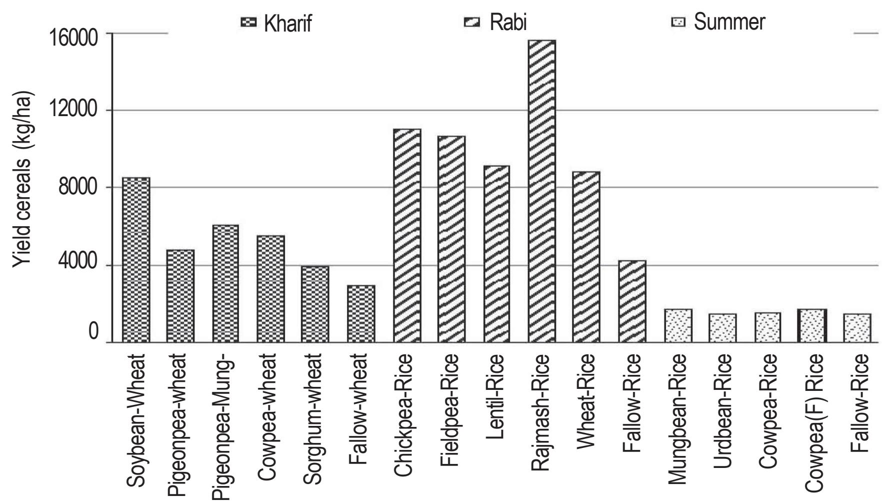

Fig. 10. Effect of pulses on the productivity of succeeding cereal crops (Source: IIPR Annual Report 2009)

6.5 Water economy

Water requirement of pulses is lower than cereals. Global water consumption by cereals is reported to be about 60% as against 4% in pulses. Pulses have ability to use water more efficiently than other crops due to their morphological and physiological features. Due to their deep root system, pulses are able to draw moisture from deeper layer of soil profile thereby having ability to thrive well

Table 3. Cropping system and nutrient management effect on total organic carbon and carbon fractions in experimental soils (Mg/ha)

Treatment	*Very labile(C $frac_1$)*			*Labile(C $frac_2$)*			*Less labile(C $frac_3$)*			*Non-labile (C $frac_4$)*			*Total Organic Carbon*		
Cropping system	*0-0.2[a]*	*0.2-0.4[a]*	*Total*	*0-0.2[a]*	*0.2-0.4[a]*	*Total*	*0-0.2[a]*	*0.2-0.4[a]*	*Total*	*0-0.2[a]*	*0.2-0.4[a]*	*Total*	*0-0.2[a]*	*0.2-0.4[a]*	*Total*
Maize-wheat	5.46	3.23	8.69	3.69	0.51	4.20	2.88	3.63	6.51	3.46	2.51	5.97	15.49	9.88	25.37
Maize-wheat-maize-chickpea	6.35	3.11	9.46	3.76	0.60	4.36	3.37	3.60	6.97	3.93	2.75	6.68	17.41	10.06	27.47
Maize-wheat-mungbean	6.74	3.50	10.24	4.03	0.54	4.57	3.58	3.94	7.52	3.62	2.36	5.98	17.95	10.34	28.29
Pigeonpea-wheat	6.58	3.69	10.27	3.89	0.56	4.45	3.57	3.48	7.05	4.01	2.13	6.14	18.05	9.86	27.91

a=soil depth in meter;
Source: IIIPR Annual Report 2011-12.

under dryland situations. By consuming 1 ha-mm of water, chickpea could produce about 12.5 kg grain as against 7 kg in wheat and 2.5 kg in rice. The water requirement of rice crop is 900-2500 mm, wheat 400-450 mm and sugarcane 1400-2500 mm, however pulses need only 250-300 mm of water. In general under sub-tropical climate like in Indo-Gangetic plains, *rabi* pulses like chickpea and lentil need only one irrigation whereas wheat crop needs 5-6 irrigations. Therefore, the problem of ground water depletion commonly observed in rice-wheat regions of Indo-Gangetic plains can be reverse by replacing one of the cereal crop by pulse crop.

6.3 Cover Crop

Loss of soil from both agricultural and non-agricultural lands is a serious problem throughout the world. Cover crops are fast growing crops planted primarily to check soil erosion. Marked differences among crops in their ability to maintain soil cover emphasize the value of appropriate crop rotation to reduce erosion. Several pulse crops like mungbean, urdbean, cowpea, ricebean, horsegram etc. have dense canopy and thus protect the surface soil against beating action of raindrops and thus reduce splash erosion. Pulse crops like pigeonpea and mothbean reduce wind erosion. The other benefits of using pulses as cover crops are to manage soil quality, weeds, pests and diseases. Thus cover crops are of interest in conservation agriculture because these improve sustainability of agro-ecosystem.

6.4 Nutrient Recycling

Pulses being deep rooted crops have ability to recycle soil nutrients available in deeper layer resulting in more efficient use of applied fertilizer. It also prevent loss of nutrient particularly nitrate below root zone of shallow rooted cereal crops in rotation. The association of pulse crops roots with VAM helps in increasing availability of nutrients and water to crop plants. Pulses add organic matter through leaf fall, root biomass and easily degradable crop residue. Pulses also release organic acids in soil, thereby mobilizing un-available soil nutrients. The ability of pulses to fix atmospheric nitrogen plays a great role in N- recycling in agro-ecosystem. Similarly, the root exudates released by pulses and the organic matter added to the soil make unavailable soil nutrients in plant available forms. Thus, pulses play greater role in nutrients recycling.

6.5 Non-nitrogenous Benefits

Inclusion of pulse crops in cropping system not only economizes nitrogen requirement but also helps in efficient utilization of native phosphorus due to secretion of certain acids by their roots which solubilises fixed or unavailable phosphorus. Thus, pulses not only efficiently utilize the native phosphorus but also increase their availability to other crops in the system. Chickpea has the ability to access P normally not available to other crops by mobilizing sparingly soluble Ca-P through acidification of rhizospere through its citric acid root exudates in Vertisols. Similarly in Alfisols, pigeonpea has been characterized for dissolution of Fe-P. In a study conducted at IIPR, Kanpur revealed that incorporation of mungbean stover after picking of pods in rice-wheat system considerably improved the available P status of soil due to secretion of root exudates that are capable of mobilizing sparingly soluble phosphorus. Pigeonpea added 2.5-5.0 kg P and 13.5-24.0 kg K /ha and rabi pulses add 3-5. 1 kg P and 8-20. 1 kg K/ha through leaf drop in the entire crop growth cycle. Inclusion of deep rooted pigeonpea breaks hard pan and improves soil physical properties.

6.6 Reduce Nitrate Pollution and Green House Gases (GHGs)

Ground water pollution due to leaching of nitrates is a relatively new concern in India especially in rice- wheat growing Indo-Gangetic regions. Choice of appropriate cropping systems and management practices minimize nitrate leaching besides improving N use efficiency. Intercropping of pulses in cereals reduces nitrate leaching (Yadav, 1981). Sugarcane+ urdbean and pigeonpea+ maize resulted in low nitrate nitrogen leaching as compared to sole cropping (Yadav, 1982).

Pulses are known to fix atmospheric nitrogen of about 30-150 kg N/ha. Most of the nitrogen remains in soil for succeeding crop. The nitrogen fertiliser efficiency to succeeding crop was reported upto 40-80 kg/ha. Therefore, pulses reduce the total fertiliser requirement of succeeding cereal crops. Thus, reduced demand of fertilisers will finally reduce the GHGs emission by fertiliser industries.

Pulses do not require fine tilth and perform equally well under zero tillage or conservation tillage. In addition pulses add fairly good amount of quality organic matter into the soil through roots, leaves fall and plant biomass which improves soil carbon pool. Similarly, short duration summer pulses can be used to reduce fallow period between two crops to reduce C-loss and enhance C-sequestration of a system.

7. CONCLUSION

Degradation of natural resources is a serious environmental problem that threatens ecosystem health and food security worldwide. Thus, enhancing and sustaining the natural resource base is of paramount importance. CA aims to conserve, improve and make most efficient use of natural resources through integrated management of available soil, water and biological resources combined with external inputs. Pulses are endowed with unique gift of nature to fix atmospheric N_2 in their root nodules in association with Rhizobium besides adding huge amount of organic matter to soil and protect from erosion. Pulse crops fix 1.0-1.5 million tonnes N globally and thus help in cutting industrial production which contributes to GHGs. Pulses can reverse the negative effect of cereals based cropping systems including rice-wheat. Thus, pulse crops have immense value in CA and therefore inclusion of pulses in crop rotation will fulfil the all three basic principles of CA such as least disturbance of soil, retention of organic cover on soil surface and crop rotation.

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11

Conservation Agriculture under Oilseed-based Systems

S.S. Rathore, Anchal Dass, Raj Singh and Kapila Shekhawat

India meets its 50% edible oil demand through imports and to become self reliant, country needs to produce 92.98 mt of oilseed by 2050, (Anonymous, 2015). However, presently area, production and productivity of oilseed crops in India are 25.7 mha, 26.7 mt and 1089 kg/ha respectively (Anonymous, 2016). Yellow revolution was witnessed through a phenomenal increase in oilseed production and productivity from 2.68 mt and 650 kg/ha in 1985-86 to 6.96 mt and 1,215 kg/ha during 2012-13. In spite of these achievements, there exists a gap between production potential and actual realization (Hegde, 2012). The average productivity in Haryana, Punjab, Gujarat, Rajasthan and UP is above 1,000 kg/ha but in the rest of the states, it is very low. Although, the trends for area, production and productivity has increased in last 5 years, but such increase does not match with the increasing demands of the oilseeds. This has led to an import pressure of more than INR 58,000 crores/year (Anonymous, 2016). The diverse agro-ecological conditions in the country are favourable for growing 9 annual oilseed crops, which include 7 edible oilseeds (groundnut, rapeseed & mustard, soybean, sunflower, sesame, safflower and niger) and two non-edible oilseeds (castor and linseed). Among all agricultural commodities, being imported in India, edible vegetable oils consist of maximum share. India's vegetable economy is 4th largest in world after USA, China and Brazil. India is second to China in world in terms of groundnut production and in rapeseed-mustard India holds 3rd rank after Canada and China. With this distinction in oilseed production scenario in India, the major problem is low oilseed crops productivity (1-1.2 t/ha). Oilseeds cultivation is undertaken mainly on marginal lands, of which 72% is confined to rainfed farming. The oilseed growers have constraint of resources for investing more in oilseed production and due to this reason, oilseeds are mainly cultivated under challenged agro ecosystems, where crops experience various abiotic and biotic stresses. Thus there is ominous need to evolve, refine and adopt oilseed based resource conservation technologies (RCT) which are sustainable on long run with reduced cost of cultivation. There are ample reports, which suggest that oilseed production could be enhanced substantially through use conservation agriculture approach. In this context conservation agriculture (CA) based technological interventions in oilseed crops have great potential to enhance productivity and improve resource use efficiency.

1. CONSERVATION AGRICULTURE TO AUGMENT THE OILSEED BASED SYSTEM

Increasing demand of edible oils and depleting natural resources have put enormous pressure to evolve the technologies which has the potential to overcome the challenges with oilseed based system. Some of the important points wherein CA can augment the oilseed based system sustainability is being discussed here as under.

1.1 Increasing Oilseed Insecurity

Edible oil consumption in India is increasing due to burgeoning population pressure and the improved living standard. Presently, area under oilseed is 25.7 mha and productivity 1037 kg/ha. The annual growth of demand for edible oil is going to be 3.54% during 2011-2050. The contribution of rapeseed-mustard, soybean and groundnut to the domestic edible oil production is 31, 22 and 4 % respectively. It shows that ground nut is an important oilseed crop but widely used for non oil purpose. Conservation agriculture based production technological approaches have clearly proved that the productivity of these crops can be enhanced substantially. This will help in reducing dependence on import significantly.

1.2 Impact of Climate Change

The climate change is the reality of present time due to increasing green house gas emission. The crop production is facing the emerging threats of climate change in terms of rise in temperatures and CO_2 emission in the atmosphere. Rapeseed-mustard, groundnut, soybean, sesame are C3 plants and increase in CO_2 concentration will have positive effect but the simultaneous increase in temperature will be harmful for major oilseed crop's growth and development. The increasing emission due to repeated tillage operations could be largely minimized with CA based crop management. It has also been demonstrated that better CO_2 sequestration is possible with CA based production approach. Thus the miseries of climate change could be minimised to some extent with the adoption of CA based cultivation.

1.3 Scarce Water Resources

Depleting water availability is a major constraint in oilseed production. In general, conservation tillage significantly improves water holding capacity and thereby enhancing water availability to the crops (Rathore *et al*., 2014a). Increasing input use efficiency is one of the main focuses in conservation agriculture and water use efficiency could be enhanced to greater extent through optimum land configuration and efficient scheduling etc. Shekhawat *et at.* 2015, found enhancement of infiltration, water storage and water use efficiency under zero tillage in rapeseed-mustard based cropping system.

1.4 Biotic and Abiotic Stresses

High temperature during crop establishment and terminal stages of the winter oilseeds, prolonged cold spell, fog and untimely intermittent rains during crop growth cause considerable yield losses. This happens due to physiological disorder and proliferation of various diseases like white rust, downy mildew and *Sclerotinia* stem rot along with incidence of insect-pest. Biotic stress caused by insect, nematodes, fungal, bacterial, *Orobanche* and other weeds collectively reduce yield upto 45% annually. Since, CA is based on the ecological principles; therefore the incidence of biotic and abiotic stresses can be mitigated. The lower incidence of *Orobanche* in mustard crop under zero till conditions was reported by Rathore *et al.,* 2014b.

2. STRENGTHENING TRANSFER OF TECHNOLOGY OF CA

To enhance oilseed crop productivity, besides generating new technologies, concerted efforts are also needed to transfer the improved CA based technologies from research institute to the farmers' fields through efficient and effective technology transfer mechanism. In rainfed areas there is misconception of doing repeated tillage to conserve rain water in the field, I this regards, the demonstration of the proven technology at farmers' field through on-field trials, front-line demonstrations and exposure visits of the farmers can help for better understanding among the farmers about the CA and lads to higher adoption.

3. EFFICIENT OILSEED BASED CROPPING SYSTEMS IN INDIA

Oilseed crops are important crops in India especially under rainfed areas (72%) with high risk of biotic and abiotic stresses. This discourage farmers to invest for use of inputs especially nutrients, irrigation water etc., in oilseed production. Rapeseed-mustard, groundnut, soybean and sesame are important edible oilseed crops in the country and the oilseed based cropping systems are popular in many marginal and sub-marginal areas due to inherent features of these crops. Oilseed crops are important component of climate smart strategies in many of the degraded agri ecosystems. It has been reported widely that inclusion of oilseed crops have improved the productivity and enhanced the net return of the system. The system based CA studies for identification of alternative efficient cropping systems, irrigation scheduling, integrated nutrient management, tillage and crop establishments and other management practices, need to be developed. In our country, the predominant edible oilseed based cropping systems are.

3.1 Rapeseed-mustard based System

Rapeseed-mustard contributes maximum in terms of vegetable oil production (>31 %) and the contribution of soybean and groundnut is 26% and 25% respectively. Fallow mustard is popular sequence in major mustard growing areas but studies show that some of the crop result in better resource utilization and high remuneration if included in mustard based cropping system. Based on edaphic factors and agro-ecological characteristics different mustard based cropping systems were identified. Among these pearl millet-mustard, cluster bean -mustard are the most efficient mustard based cropping system in irrigated ecosystem, while in western arid and eastern Indian conditions, fallow-mustard is the most common sequence. The cropping system intensification through black gram-mustard, urdbean-mustard in central India and, greengram-mustard, guar-mustard, and pearl-millet-mustard at western India is possible. Maize-mustard can be a suitable cropping system in higher altitudes as compared to fallow-mustard. The productivity of the system also depends upon the fertility status and the nutrient supply. Potato intercropped with mustard is more remunerative than potato alone. The states where potato and mustard crops are grown simultaneously can follow this practice. Three ridges are planted with potato, and then on every fourth ridge mustard is sown. The selection of the cropping system is different for both rainfed and irrigated conditions under different mustard producing zones of India (Table 1). Under rainfed conditions also, there are ample possibilities of increasing cropping intensity in monocropping mustard areas.

Table 1. Rapeseed-mustard based crop sequences in various states of India

State	*Rainfed*	*Irrigated*
Rajasthan	Fallow-toria/mustard Pearlmillet/cowpea-mustard	Maize/greengram/pearlmillet-mustard *Toria*-wheat
Haryana	Pearlmillet-mustard Fallow-mustard/brown sarson	Maize-*toria*-wheat Groundnut-mustard Fallow-*toria*-wheat Early fodder-mustard
Uttar Pradesh	Fallow-toria/mustard	Maize-mustard-greengram/ Fodder-mustard Blackgram-mustard Maize-toria/mustard Upland rice-toria-sugarcane
West Bengal	Jute-*toria*/mustard-spring greengram Maize-*toria*/mustard Upland rice/jute-mustard/yellow sarson Cowpea-mustard (fodder) Maize (fodder)-sorghum/cowpea – yellow sarson/mustard	Rice-*toria*-summer rice Rice-mustard/jute-yellow sarson Rice-mustard-rice Aman rice-*toria*-boro rice Rice-mustard/yellow sarson-jute

3.2 Soybean Based Cropping Systems

Madhya Pradesh, Maharashtra and Andhra Pradesh are important soybean producing states in India. Soybean has been grown in Madhya Pradesh in an area of about 6.38 Mha producing around 5.4 MT with an average productivity of 842 kg/ha. The major constraints in production include non-availability of adequate amount of quality seed of improved varieties, poor adoption of improved production technology and the risks of crop cultivation in rainfed conditions. Soybean seed is least storable and is vulnerable to mechanical damage. The CA based cultivation practices, using quality seed with high germination will certainly improve overall productivity.

Table 2. Soybean based cropping systems followed in major soybean growing States

State	*Cropping systems*
Madhya Pradesh	Soybean - wheat/mustard/safflower
Maharashtra	Soybean - sorghum (rabi)/safflower/linseed
Andhra Pradesh Rajasthan	Soybean - wheat/mustard Soybean - sorghum/groundnut

3.3 Groundnut based System

About 60% of the total groundnut cultivated area is under mono-cropping during *kharif* season. Major cropping system followed by various groundnut growing States are given in Table 3.

Table 3. Major groundnut based cropping Systems

State	*Rainfed*	*Residual Moisture*	*Irrigated*
Andhra Pradesh	Groundnut- sorghum	Groundnut- bengal gram	Groundnut-maize
	Groundnut -millet	Groundnut- safflower	Groundnut-wheat
	Groundnut -tobacco	Groundnut- sesame	Groundnut-onion
Gujarat	Groundnut-sesame	Groundnut-fodder Sorghum	Groundnut-mustard-Green gram
		Groundnut-mustard-	Groundnut-wheat-Green gram
Karnataka	Groundnut-sorghum	Groundnut-safflower	Groundnut-wheat
			Groundnut-maize
			Groundnut-sunflower
Rajasthan	Groundnut-pearl millet	Groundnut-barley	Groundnut-wheat-green gram
		Groundnut-mustard	Groundnut-wheat

3.4 Sesame based System

Table 4. Sesame based cropping systems

States	*Cropping sequence*
Andhra Pradesh	Rice-groundnut-gesame, Sesame-horsegram, ragi/sorghum/horsegram (Early)-sesame, Sesame- upland rice.
Bihar	Early rice-potato-summer sesamemoongbean, Kharif sesame-maize/ pigeonpea/ rabi gram, Wheat-summer sesame/moongbean
Gujarat	Sesame-wheat/mustard sesame-horsegram/chickpea
Madhya Pradesh	Cotton-sesame-wheat, Rice - summersesame, Sesame-wheat
Maharashtra	Sesame (Early)-rabi sorghum/safflower, Cotton-sesame-wheat
Uttar Pradesh	Sesame (Early)-gram/rapeseed-mustard/lentil/pea

4. CONSERVATION AGRICULTURE UNDER MUSTARD BASED CROPPING SYSTEM

Rapeseed and mustard have lower water and nutrient requirements than cereal crops. Therefore, diversification of cereal based cropping system with rape seed and mustard cropping system will not only increase the availability of edible oil but also conserve the water, soil fertility and other natural resources. Further, cropping system has an immense effect on physical and chemical soil properties and thereby on crop productivity, while soil fertility often changes in response to land use and cropping systems and land management practices. Studies carried out by Sahai *et al.,* (2010) revealed that in maize-mustard cropping system, soil organic carbon and microbial biomass carbon were significantly increased in the zero tillage +residue retention than conventional tillage in the surface, besides increase of yield, minimize the water use with zero tillage (Table 5).

Table 5. Grain yield and water use of maize and mustard crops

Treatment	*Yield (t/ha)*		*Water-use (mm)*	
	Maize	*Mustard*	*Maize*	*Mustard*
Conventional tillage	2.93	1.83	287	189
Conventional tillage + residueincorporation	2.57	1.62	321	195
Zero tillage +residue retention	2.08	1.59	254	165
Zero tillage	1.43	1.32	266	171

Source: Sahai *et al*., 2010

A significant effect of RCTs has been found on growth parameters of mustard like crop growth rate, relative growth rate, net assimilation rate and leaf area index. The highest amount of water is utilized in CT through check basin method. The poor quality of irrigation water due to high EC produced higher yield under FIRB. The highest amount of organic carbon has been found under ZT; RT being at par with it and both are found significantly superior over CT and FIRB. Maximum seed yield of mustard has been recorded under FIRB.

Long term study conducted at Bharatpur, Rajasthan under mustard based cropping system by Shekhawat *et al*., 2016 reported that tillage practices significantly affected seed, stover, and biological yields, production efficiency, and the economics of mustard along with the bulk density and soil organic carbon dynamics. After four years of the experimentation, the highest mustard seed yield was obtained under FIRB (2765 kg/ha) which was 23.6% higher over CT. The seed yield obtained under ZT (2533 kg/ha) was 17.5% higher over CT. The seed yield recorded under RT was found similar with ZT, but significantly higher over CT due to higher dry matter accumulation, higher translocation efficiency, and greater sink/source potential at the seed filling stage. Among the cropping systems, highest yield was obtained under the green manure-mustard system followed by the cluster bean–mustard system. The seed yield enhancement with the green manure–mustard cropping system was 13.9% over the fallow-mustard system. The highest assimilate supply (0.33 g/siliqua) was recorded under ZT (Fig. 1). Sustainability parameters, including harvest index (0.29), sustainability yield index (0.85), and production efficiency (16.1 kg/ha/day) were also found highest under ZT after four years of the experiment. Soil organic carbon increased to 0.39% and 0.36% in ZT and FIRB, respectively, from 0.26% in CT. A higher mass of soil organic carbon and carbon sequestration potential rate was recorded under ZT. The bulk density under ZT and FIRB decreased over CT. The net returns, profitability, and the benefit-cost ratio were highest under FIRB, followed by ZT. Higher assimilate supply implies, which means the units of dry weight diverted in the plant to form one siliqua was also reported (Fig. 1) for *Brassica juncea* under zero tillage system by Shekhawat *et al*, 2016). The sink capacity of plants under ZT was higher due to more siliquae and a higher potential number of seeds/ pod.

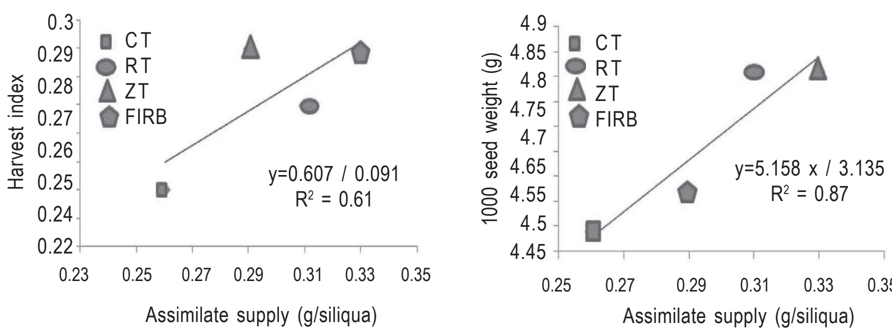

Fig. 1. Relationship between assimilate supply and harvest index/1000-grain weight in *Brassica juncea*

4.1 Effect of Crop Establishment

Ridge and furrow sowing might be superior to conventional flat sowing for growth parameters and yield of *Brassica juncea* where machines has been standardized (Shekhawat *et al*., 2016). The results suggested that to harness the potential benefits of CA appropriate farm machines need to be developed matching with local needs. In bed planting, saving of 35% irrigation water and 32% increase in WUE (Fig. 2). A change from growing crops on flat to raised beds offers more effective control of irrigation water and drainage, thereby reducing aeration stress and increasing yields. In terms of economics, the highest net returns were obtained under furrow irrigated raised bed system. An increase of 35.9% and 12.1% was recorded in net returns with FIRB and ZT, respectively, over CT.

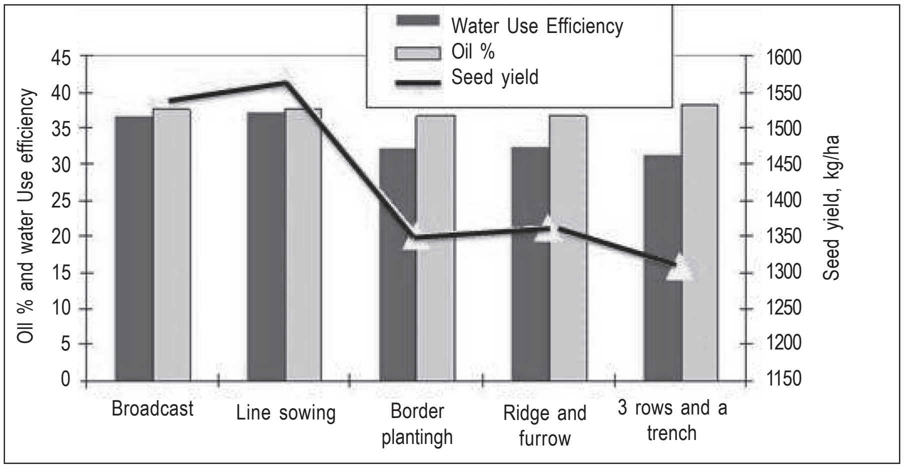

Fig. 2. Seed yield, water-use efficiency (kg/ha-mm) and oil content of Indian mustard as influenced by various planting methods

5. CONSERVATION AGRICULTURE IN SOYBEAN BASED SYSTEMS

The predominant soybean based cropping systems in major soybean growing states are mentioned in Table 2. Soybean is largely grown as rain fed crop, drought stress adversely affects its growth and yield. Retention of wheat residue as mulch (5 t/ha) increased soybean seed yield by 22.9% in 2012 and by 11.4% in 2013, and average oil and protein yield increased by 19 and 17.5%, respectively (Dass, 2015). Soybean [*Glycine max* (L.) Merill] based cropping systems are important for sustaining agricultural production and also to maintain soil fertility with an ecological balance as its inclusion in the system benefits to the succeeding crop through residue N supply.

Inclusion of soybean in a cropping system improve the water use efficiency and crop yield under zero tillage. Fan *et al*. (2012) concluded that corn-soybean performed better in respect of providing higher seed yield and monetary benefit over continuous corn cropping under zero tillage as compared to mould-board plough and ridge tillage in general and during dry season in particular. Soybean grown in soybean-wheat cropping system planted on raised beds recorded about 17% higher water-use efficiency than in flat layout. Several other studies have reported beneficial effect of soybean-based cropping systems of soil health. Khaitov and Allanov (2014) also concluded that crop rotation with legumes especially cotton-wheat-soybean in no till condition significantly improved soil chemical properties and organic matter content compared to cotton-wheat-maize and cotton-wheat-sorghum rotation. A significantly higher concentration of N and P with an associated decrease in soil bulk density suggests that crop rotation in no tillage associated legumes were responsible for soil fertility and subsequently exerting adverse effects on soil restoration. Ram *et al*., 2013 reported that based on the five-year average, the seed productivity of soybean on raised beds was not much influenced in raised bed and straw mulches. Reported the no-tillage and permanent beds need to be popularized among farmers of northwest IGP for improving yields, water productivity, profitability and sustainability of the SW system. The growth and yield of all crops in soybean based cropping system were higher than those under conventional tillage under conservation tillage. Incorporation of plant biomass under conservation tillage, which enhances the water retention capacity of the soil during crop-growing season and also quick build-up of organic matter in conservation-tilled plots, was possible through incorporation of crop residues and weed biomass in high-rainfall areas (Jaybhay *et al*., 2015).

6. CONSERVATION AGRICULTURE IN GROUNDNUT BASED SYSTEMS

Groundnut has been proved its potentiality under different agro-climatic condition of the country. Therefore, diversification of rice-wheat system towards other cropping systems involving ground nut may be one of the alternative system to sustain the crop productivity as it being leguminous crop have low nutrient and water requirement compared to cereal crops, thereby reducing water use and improving soil health. Therefore diversification of cereal based cropping system with groundnut based cropping system may alleviate the many problems which occur due to adoption of cereal-cereal cropping systems. Moreover, most of the legumes including groundnut require P, which is essential for the stimulation of pod setting, pod filling and hasten maturity. Supply of phosphorus observed very useful particularly at flowering and pod formation stage. Phosphorus applied to wheat benefited the succeeding crop in groundnut-wheat crop rotation and vice versa (Pesricha and Tandan, 1990). Sharma and Jain (2014) reported significant increase in wheat grain equivalent yield and available N, P and K content in the soil under groundnut-wheat cropping systems (Table 6). Kuotsu *et al*., 2014 revealed significance of raised bed for ground nut in northeastern region as highest groundnut equivalent yield (GEY) was obtained in RB with residue + hedge leaves incorporation followed by that under RB with residue incorporation (2747 kg/ha).

7. CONSERVATION AGRICULTURE FOR BRIDGING YIELD GAPS IN OILSEED BASED CROPPING SYSTEM

Adoption of conservation agriculture, especially zero tillage and associated practices in the Southern America have revolutionized the oilseed production system over last two decades. Bed Planting, a technique for higher oilseed productivity under water logged conditions. Susceptibility of oilseed to biotic & abiotic stresses is one of the major causes of their low productivity in Indo-Gangetic plains. Bed planting provides a window for several oilseed crops soybean, linseed and Indian mustard to maximize the system productivity.

Table 6. Change in soil fertility status and wheat equivalent yield with inclusion of legumes under maize-wheat system as substitute crop.

Cropping system	*Available nitrogen (kg/ha)*	*Available phosphorus (kg/ha)*	*Available potassium (kg/ha)*	*Available sulphur (kg/ha)*	*Available zinc (ppm)*	*Wheat grain equivalent yield (Kg/ha)*
Maize- wheat	222.43	13.7	182.6	10.6	0.516	6022
Groundnut- wheat	257.75	16.8	223.8	8.9	0.507	7118
Clusterbean- wheat	247.15	14.2	215.8	9.5	0.528	6341
CD (P= 0.05)	8.30	0.75	7.97	0.43	N S	215

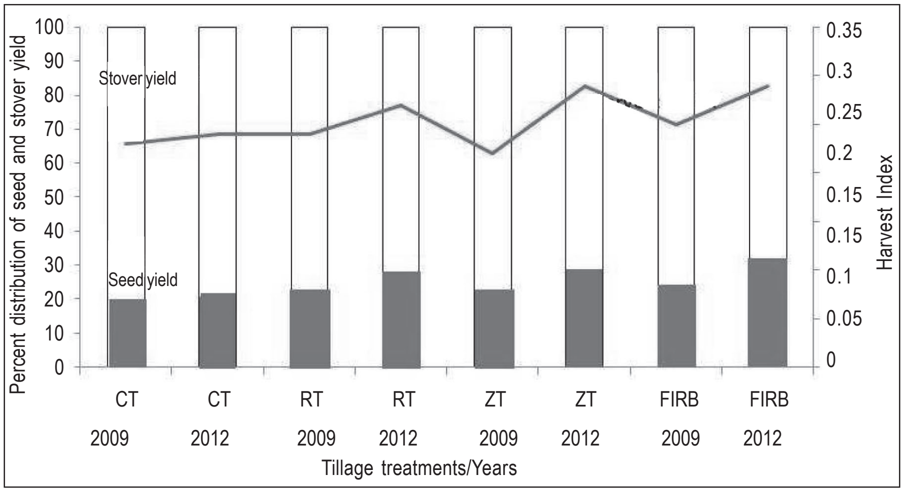

Fig. 3. Influence of various tillage treatments on percent distribution of seed and stover yield, and harvest index of mustard after four years of the experimentation.

Shekhawat et el., (2016) reported, the maximum mustard seed yield under FIRB which was 23.6% higher over CT after four years (Fig 3). The seed yield obtained under ZT was 17.5% higher over CT. The seed yield recorded under RT was found similar with ZT, but significantly higher over CT due to higher dry matter accumulation, higher translocation efficiency, and greater sink/source potential at the seed filling stage. Under reduced tillage disc ploughing followed by disc harrowing is done and under complete zero tillage the crop is sown under undisturbed soil. Minimum tillage, with straw, enhances soil moisture conservation and moisture availability during crop growth. As a consequence, the root mass, yield components and seed yield increase.

Zero tillage can be promoted in mustard as it conserves moisture in the soil profile during early growth period. For successful mustard production under minimum or zero tillage, there should be even distribution of crop residues which will create a firm, moist and uniform seedbed. In *B napus*, although the conventional tillage (CT) shows a greater water retention capacity in the deeper horizons than the minimum tillage (MT), but CT is characterized by a quicker water rate of depletion in the upper soil layers when evapo-transpiration demand is high. The major problem with continuous tillage is the subsurface compaction of soil layers. It deteriorates the soil permeability (Bonari *et al*., 1995). Further, zero tillage creates greater root density in the surface soil but lesser root density below a depth of 15 cm in the soil profile. Therefore, P and K uptake by crops grown under zero tillage is greater than those grown by conventional methods. Increase in groundnut productivity under raised bed/ rduced tillage condition alongwith surface residue retention was reported by several researchers. Ghosh *et al*., 2006 reported straw mulch (wheat or paddy) produced more pod (17–

24%) and haulm yields (16%) of groundnut than polythene mulch (black or transparent). Similarly, broad bed and furrow and raised bed land configurations along with residue and hedge leaves mulching under no tillage improved soil quality and was the most suitable for higher returns of groundnut–rapeseed system under rainfed mid-hills condition. Maximum water use efficiency (WUE) of rapeseed was obtained in raised bed with residue + hedge leaves incorporation (4.64 kg/ha-mm). Sevearl reports indicate that integrated use of these RCTs may have immense potential in bringing oilseeds in rice fallows of lower Gangetic plains and eastern India. In a lowland rainfed ecosystem, adoption of ZT and organic mulching would utilize the residual soil moisture following rice, resulting in rice–yellow sarson as a viable profitable cropping system. Further research related to the applicability of RCTs to oilseed crops needs to be taken up in the country as most of the RCTs have been tested and understood on the basis of their working in rice – wheat cropping systems. Development of suitable machines, studies on residue management in oilseed crops, development and agronomic testing of varieties suitable for zero tillage conditions , advantages and impact of land leveling on oilseed crop production, productivity and input use efficiency etc are some of the indicative areas of research gaps which needs to be addressed in oilseed crops.

8. CONCLUSION

The oilseed production in the country needs a substantial boost to meet the rising edible oil demand in the country. The possibility of the productivity enhancement in oilseed crops is probably highest among any group of the crops through better agronomic management as it is mainly grown in challenged agro-ecologies. In this context conservation agriculture based practices which has potential to mitigate climatic vagaries and is capable of efficient utilization of resources and sustained high level of productivity can augment higher oilseed based system productivity along with judicious use of natural resources.

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12

Relevance of Conservation Technologies in Black Soils

R.K. Sharma, R.S. Chhokar, H.S. Jat and M.L. Jat

The black soils classified as vertisols are a group of fine-textured soils which occur extensively in the tropics, sub-tropics and warm temperate regions and are also known as dark clays, black earths, dark cracking soils, grumusols and regurs in other classification systems (Dudal, 1965). Although, vertisols covers a small area of the world's land surface, are only in sub-dominant proportion in any geographical zone, they are important in semi-arid dry land agriculture. These are amongst the most productive soils, due to their high water-holding capacity as the rainfall is uncertain and variable, the productivity is sometimes too much and often too little. Therefore, for a reasonable harvest, the ability of a soil to store sufficient water to carry crops through drought periods is of great importance under semi-arid dry land area. However, some characteristics of these soils pose problems for the cultivation of crops and some of the problems assume greater importance where the farmer has only small land holdings and limited resources. In view of these soil and socio-economic problems, the attainable production potential of these soils is commonly not met. The vertisols are mainly found in Australia (70.5 m ha), India (70 m ha), Sudan (40 m ha), Chad (16.5 m ha) and Ethiopia (10 m ha). These five countries have more than 80% of the total area of 250 m ha (Table 1) of vertisols in the world.

Table 1. Distribution of dark clay (vertisol) soils

Country	Regions	Total area covered in million ha	Percentage of total area
Australia	Parts of Queensland, northern New South Wales, South Australia, Coastal areas of Northern Territories and Tasmania	70.5	28
India	Central and South-central areas of Deccan Plateau (mainly Andhra Pradeshand Madhya Pradesh, Chhatisgarh states and a part of Maharashtra, Gujarat and Karnataka state)	60.0	24
Sudan	Regions between the Blue and White Nile.Widespread in South Sudan, Upper Nileand Equatoria Province	40.0	16
Chad	Mainly areas in Chad basin butscattered patches in other parts	16.5	7
Ethiopia	Areas covered by the Rift valley and Ethiopian plateau	10.0	4

Source: Adapted from Dudal (1965).

1. MAIN PRODUCTION CONSTRAINTS

Vertisols are generally difficult to work as they have extremes of consistence. They are very hard when dry and very sticky and plastic when wet (Jewitt *et al*., 1979) with consequent loss of trafficability which is suspected to be due to poor air-water relations. Extreme hardness when dry and stickiness and loss of trafficability when wet, permits tillage and seedbed preparation only within a very narrow range of moisture contents. The cultivation of Vertisols when too dry or too wet may therefore result in poor tilth due to cloddy or puddled structure, respectively (Dudal 1965; Krantz and Sahrawat 1974; Krantz *et al*., 1978).

Vertisols are imperfectly to poorly drained leading to limited leaching of soluble weathering products, having high available calcium and magnesium contents and usually alkaline pH. Once they have reached their field capacity, practically no water movement occurs.This is due to the very low infiltration rate of 0.2 mm/h when the soil was saturated (Krantz *et al*., 1978) to extremely low values of 0.5 mm/day terminal infiltration rates (Jewitt *et al*., 1979). The hydraulic conductivity of these soils is also extremely low. In the event of heavy rainfall, flooding leading to crop damage can be a major problem in areas with higher rainfall. Surface water is generally drained by open drains as the ‘mole’ drainage is virtually impossible. ‘Flash flood’ waters can cause irreversible crop lodging leading to rotting of the lodged crop.

Moreover, as these soils are generally found in semi-arid areas, the organic matter is also invariably low leading to poor physico-chemical properties and lower nutrient supplying capacity of these soils. Further, nitrogen as well as phosphorus is generally deficient and potassium content is variable hence requiring appropriate fertilisation. Additionally on many farms, continuous application of chemical fertilizers has led to a loss of soil fertility. This is mainly due to a lack of organic matter as the residues of plant material and organic manures remaining in the soil gets decomposed due to high temperatures and the decomposition of organic matter is further accelerated by application of nitrogen fertilizer.

2. MAJOR PRODUCTION BENEFITS

The basic property of Vertisols that endows them with a high moisture-holding capacity is their clay content, which commonly lies between 40 to 60%, but it may be as high as 80% (Dudal, 1965; De Vos and Virgo, 1969) and the type of clay. In Indian as well as in Ethiopian Vertisols, montmorillonite is the dominant clay mineral (De Vos and Virgo, 1969; Chatterjee and Rathore, 1976) imparting them the swelling characteristic presumably due to inter-crystalline swelling within, “domains” of clay crystals (Emerson, 1959; Aylmore and Quirk, 1959) further enhancing their capacity to hold moisture due to swelling when wet. Generally, the texture of the surface soil is lighter and the clay content increases with increasing depth towards the subsoil (Butler and Hubble, 1977). The clay content of Vertisols remains uniformly high (>35%) throughout the profile to a depth of at least 50 cm or more (Raychaudhuri *et al*., 1963; Dudal 1965; Yule and Ritchie, 1980). The available water range reported for Indian soils is up to 230 mm (ICRISAT, 1978) for the top one meter depth of the soil profile. It has been observed that the moisture content in deeper layers of the soil profile decreases, apparently due to compression effect (Virgo and Munro, 1978) on matric potential.

Vertisols generally are chemically rich and are capable of sustaining continuous cropping. They do not necessarily require a rest period (fallow) for recovery because of their self-mulching characteristics (pedoturbation) which continuously brings subsoil to the surface. Due this self-mulching characteristics also called as self-ploughing, these soils need not be ploughed every year and may require ploughing once in three years. These soils may require frequent and light irrigation as soon as the small cracks appears, if water is available for irrigation, to avoid development of large and deep cracks which adversely affect by tearing of roots of the growing crop in addition to accelerating the evaporation from the manifold area exposed due to vertical cracking.

3. MANAGEMENT OPTIONS

Successful farming needs the appropriate management of soils, plants and the environment in such a way that a maximum return can be obtained on sustainable basis. The most important consideration in soil management is the correct application of the relationship among the soil, the climatic conditions and the crop to be grown. The deep or heavy black cotton soils are suitable for intensive crop production with sufficient inputs of organic manures, intensive crop rotation, and green manuring. It is generally believed that frequent shallow soil cultivation helps to improve soil aeration and nutrient supply and also reduces evaporation and suppresses weeds. The same objective, may be in better way, can be achieved by adopting conservation agriculture practices wherein zero tillage will help in reducing the moisture loss during cultivation and surface retained residues will help in almost cutting off the evaporation from soil leading to moisture conservation as well as avoiding rain beating effect leading to surface sealing facilitating greater infiltration and lower runoff with the resultant none or negligible soil erosion. The moisture conservation by adopting these practices will be even better than shallow cultivation in addition to savings on tillage cost, energy, time and drudgery to the farmers making the crop production more comfortable and profitable. The other benefits of surface retained residues will be substantially reduced or negligible weed infestation, soil temperature moderation and facilitating pumping of water through plants as transpiration leading to higher crop productivity and profitability. These management options involving resource conservation agriculture practices are briefly discussed in the subsequent sections.

3.1 Laser Land Levelling

Laser land leveling (LLL) is the process of smoothening the land within ± 2 cm from the average elevation of the field. Laser-assisted precision land leveling is considered as a precursor technology for realizing the full benefit of other resource conservation technologies to improve crop yields and input-use efficiency including water and nutrients leading to greater profitability. Flood irrigation is a common practice wherein a significant amount (10–25%) of irrigation water is lost during application on the farm because of poor management and uneven fields that lead to lower crop yields, higher irrigation costs and poor resource-use efficiency. The uneven distribution of water and the resultant other inputs is due to the fact that traditionally leveled fields have frequent dikes and ditches within the fields. The LLL helps in bringing more area under cultivation, saves water, improves nutrient use efficiency along with accompanying increase in

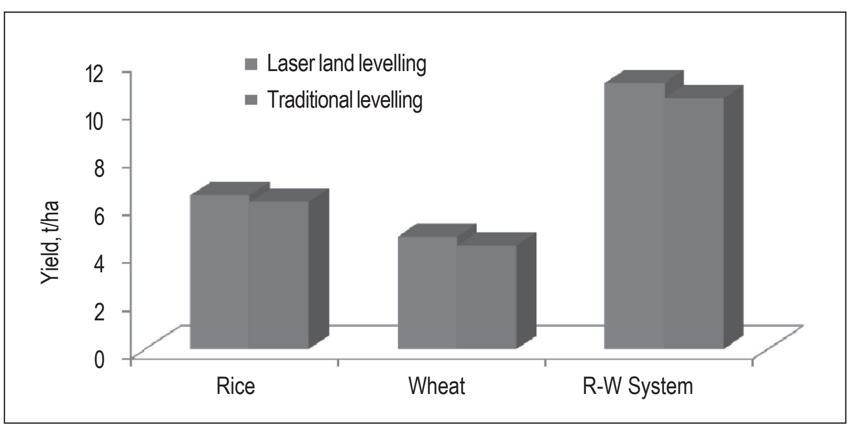

Fig. 1: Effect of laser land levelling on rice-wheat cropping system productivity (Mean of 2 years)
Source: Jat *et al.*, 2009a

yield (Jat *et al*., 2004; 2009a; 2009b; and 2011a). This can be very useful technology for management of black soils by reducing the soil erosion in the event of heavy rain in addition to the above mentioned benefits of this technology.

3.2 Zero Tillage Technology

This is a conservation technology in which the crop is directly seeded into the undisturbed soil after harvesting previous crop using a specially designed machine. In this, seed and fertiliser is placed into narrow slits created by the knife type furrow openers of zero tillage ferti-seed drill. In view of the savings of cost, energy, time and drudgery, along with higher or similar yield (Table3), the benefit cost ratio has been reported to be highest for zero tillage (Sharma *et al*., 2004c) thereby increasing the profit margin of the farmers. Other benefits of this technology are the lower incidence (Table 2) of termite (Sharma *et al*., 2004b), Karnal bunt (Sharma *et al*., 2007) and irrigation water saving compared to conventional tillage. In black cotton soils, this technology can exploit the self mulching characteristic of these soils and by leaving some anchored straw at the surface will help reduce the cracking by holding on to the soil by roots and the water conservation effect of surface residues.

Table 2: Effect of tillage in wheat on termite incidence and yield of wheat

Tillage Options	*Damaged tiller Nos./20m²*		*Yield, t/ha*	
	2000-01	*2001-02*	*2000-01*	*2001-02*
Zero Tillage	9.67	6.33	5.95	6.41
Rotary Tillage	19.67	4.33	6.18	6.72
FIRBS	82.33	37.67	5.38	6.04
Conventional Tillage	12.33	10.25	6.17	6.31
LSD (0.05)	20.49	7.44	0.15	0.31

Source: Sharma *et al*. 2004b

Table 3: Interaction effect of tillage in rice and wheat on wheat yield

Tillage options in wheat	*Tillage options in rice*			
	Puddling rotavator	*Puddling harrow*	*Dry rotavator*	*Dry harrow*
Zero Tillage	5.97	5.92	5.87	6.03
Rotary Tillage	6.07	6.06	6.12	6.47
FIRBS	5.57	5.18	5.21	5.57
Conventional Tillage	6.32	6.17	6.33	5.85
LSD (0.05)	0.29			

Source: Sharma *et al*. 2004b

3.3 Raised Bed Planting Technology

In this conservation technology, the crop is grown on raised beds. This technology saves water, nitrogen (Sharma et. al., 2005) and will also help save energy, time, drudgery and the cost, if permanent beds are used which can be easily adopted in almost all the cropping systems other than rice-wheat, but, may require site specific fine tuning. For example, in the case of black cotton soils, instead of narrow beds of about 70 cm, the broad beds of about 140 cm may prove more beneficial. In addition the furrow which is generally around 30 cm wide may be widened to about 50 cm to quickly drain out water from field in the event of heavy rainfall. In addition, bed planting will be helpful to avoid temporary soil aeration problem after irrigation in black soil leading to better productivity of crops. However, greater incidence (Table 4) of powdery mildew (Sharma *et al*., 2004a) and termite (Sharma *et al*., 2004b) may need to be taken care off when the crop is grown on beds. It has also been observed that yield of water sensitive crops like oilseeds and pulses is higher on beds by 20-40 percent in various crops.

Table 4: Effect of planting options on powdery mildew incidence and yield

	Powdery mildew Percent Disease incidence			*Yieldq/ha*		
	2000-2001	*2001-2002*	*Mean*	*2000-2001*	*2001-2002*	*Mean*
Conventional	47.59	63.46	55.53	52.57	55.33	53.95
Strip 2 rows	51.29	69.39	60.34	45.40	54.51	49.96
Strip 3 rows	48.92	71.38	60.15	47.27	55.26	51.27
FIRBS 2 rows	59.18	82.63	70.91	44.30	52.37	48.34
FIRBS 3 rows	62.59	83.08	72.84	43.77	53.68	48.73
CD (0.05)	8.58	5.77		3.98	NS	

Source: Sharma *et al*. 2004a

3.4 Direct Seeded Rice

Direct seeding has advantages of faster and easier planting, reduced labour and less drudgery with earlier crop maturity by 7-10 days, more efficient water use and higher tolerance of water deficit, less methane emission and often higher profit in areas with an assured water supply. Thus the area under direct seeded rice has been increasing as farmers in Asia seek higher productivity and profitability to offset increasing costs and scarcity of farm labour (Balasubramanian and Hill, 2002). Weed control is a major issue in direct seeded rice and to overcome this problem, intensive efforts are being made by the weed scientists. In some soils, spray of micronutrient like Zn and iron may be needed to remove their deficiency. Seeding depth for rice may be kept at 2-3 cm while using drill for seeding. The seed rate for dry and wet (Sharma *et al*., 2003b) direct seeding may be kept around 30 kg/ha. The yield in light to medium soils has been reported to be marginally higher in conventionally puddled conditions compared to transplanting without tillage, after field preparation by rotary tillage (Sharma *et al*., 2003a) but direct drilling by zero or rotary till drill gave significantly lower yield. The experience over the past about one and a half decades have shown that all the rice varieties are not suitable (Table 5) for direct dry seeding (Chhokar *et al*., 2014) and it may not be possible in all soil types. It will work in soils where water tends to stagnate for 2-3 days after irrigation with effective weed control.

Table 5. Performance of coarse and fine rice cultivars under direct seeding (DSR) and puddled transplanting (PT)

Rice cultivars	*Locations*	*Rice yield (t/ha)*	
		DSR	*PT*
Coarse rice cultivars(HKR 47 and IR 64)	8	5.74a	6.82b
Fine rice cultivars	3	4.77A	4.73A

Mean values within a row of DSR and PT either for coarse cultivars or fine cultivars having same letter are not significantly different at P=0.01 using the paired t-test.
Source: Chhokar *et al*., 2014

Hence, the three conditions which must be fulfilled for the success of direct dry seeded rice are appropriate varieties, effective weed control and the soil type in which water stays for at least 2 days after irrigation. Black cotton soils in view of their low infiltration rate and tendency to flooding might prove to be the best for adopting direct seeded rice cultivation.

3.5 Leaf Colour Chart in Rice and Wheat

Leaf colour is a fairly good indicator of the nitrogen status of plant. Nitrogen use can be optimised by matching its supply to the crop demand as observed through change in the leaf chlorophyll content and leaf colour. (Sen *et al.,* 2011) and Varinderpal-Singh *et al.,* 2012) The monitoring of leaf colour using leaf colour chart helps in the determination of right dose of nitrogen application. Use of leaf colour chart is simple, easy and cheap under all situations. The studies (Table 6 and Table 7) indicate that nitrogen can be saved from 10 to 15 percent using the leaf colour chart.

3.6 Green Seeker Technology

This technology is based on the remote sensing principles wherein active sensor is utilised to determine the level of crop cover and the health of the crop. The active sensor emits radiation in red and near infrared region of the electromagnetic spectrum and the reflected radiation in these bands is detected and used to calculate Normalised Deviation Vegetation Index (NDVI) which detects the greenness of the crop. Compared to leaf colour chart, which is a qualitative index and determines the nitrogen need of the plant by observing leaf colour, the Green Seeker scans the crop canopy for ground cover and the health of that cover and is a quantitative method. By using a rich strip it can be determined whether the rest of the field need additional nitrogen or not (Bijay Singh *et al*., 2011; Bijay Singh *et al*., 2012). The studies in both rice and wheat showed that more than 20 per cent nitrogen can be saved in rice and more than 15% nitrogen can be saved in wheat (Sharma *et al*., 2009) without yield penalty in both the crops (Table 8). This technology has also been found useful in precise phenotyping of quantitative stripe rust reaction (Arora *et al*., 2014) in wheat.

Table 6. Effect of N management options on grain yield, recovery efficiency of nitrogen (RE_N) and agronomic efficiency of nitrogen (AE_N) in wheat

Treatment description	*Fertiliser N application (kg N ha^{-1})*					*Ludhiana*			*Gurdaspur*		
	Basal	*1st irrig†*	*2nd irrig.*	*3rd irrig.*	*Total*	*Yield t ha^{-1}*	*$RE_N$$*	*AE_N#*	*Yield t ha^{-1}*	*$RE_N$$*	AE_N#
No-N control	0	0	0	0	0	1.32a¶			2.21a¶		
Blanket N application–120 kg N ha^{-1}	60	60	0	0	120	4.34c	67.4a	25.1b	5.14c	71.9a	24.4ab
N_{30}¥ basal + N_{45} at 1st irrig.+ N_{30} if LG‡ < LCC 4 at 2nd and 3rd irrig.	30	45	0	0	75	3.49b	72.8a	28.9c	4.42b	79.4a	29.4c
N_{30} basal + N_{45} at 1st irrig.+ N_{30} if LG< LCC 5 at 2nd and 3rd irrig.	30	45	30	30	135	4.42c	70.8a	23.0ab	5.62d	71.7	25.2ab
N_{30} basal + N_{45} at 1st and 2nd irrig.+ N_{30} if LG< LCC 4 at 3rd irrig.	30	45	45	0	120	4.36c	72.6a	25.3b	5.55d	78.9	27.8bc
N_{30} basal + N_{45} at 1st and 2nd irrig.+ N_{30} if LG< LCC 5 at 3rd irrig.	30	45	45	30	150	4.46c	70.5a	21.0a	5.62d	67.3	22.7a
LSD ($p = 0.05$)					0.276	7.06	2.34	0.404	NS	3.45	

¥ Subscripts of N denote kg N ha^{-1}. ¶ With in a column, means followed by same letter are not significantly different at the 0.05 level of probability. $ Recovery efficiency of applied N. # Agronomic efficiency (kg grain per kg applied N). ‡ Leaf Greenness of first fully exposed leaf. † Irrigation

Source: Varinderpal-Singh *et al.*, 2012

Table 7. Effect of N management options on grain yield and N use efficiency in rice varieties

N Management	*N Splits*		*N application*		*Grain Yieldt/ha*		*Agronomic efficiencykg grain/kg N applied*	
	2005	*2006*	*2005*	*2006*	*2005*	*2006*	*2005*	*2006*
NDR-359								
Recommended dose of N	3	3	120	120	3.80	3.60	-	-
20 kg /ha of LCC < 2	4	3	90	70	4.00	3.71	2.21	1.61
20 kg N/ha of LCC < 3	4	3	90	70	4.20	3.93	4.39	4.84
20 kg N/ha of LCC < 4	5	4	110	90	4.61	4.40	7.36	8.88
20 kg·N/ha of LCC < 5	5	4	110	90	4.83	4.59	9.36	10.97
Mean					4.29	4.05	5.83	6.58
Sarju 52								
Recommended dose of N	3	3	120	120	3.23	2.94	-	-
20 kg /ha of LCC < 2	4	3	90	70	3.40	3.12	1.91	.50
20 kg N/ha of LCC < 3	4	3	90	70	3.74	3.46	5.67	7.40
20 kg N/ha of LCC < 4	5	4	110	90	4.03	3.74	7.26	8.89
20 kg·N/ha of LCC < 5	5	4	110	90	4.25	3.88	9.26	10.44
Mean					3.73	3.43	6.03	7.31
HUBR 2-1								
Recommended dose of N	3	3	120	120	2.83	2.54	-	-
20 kg /ha of LCC < 2	4	3	90	70	3.13	2.85	3.38	4.43
20 kg N/ha of LCC < 3	4	3	90	70	3.30	3.01	5.24	6.71
20 kg N/ha of LCC < 4	5	4	110	90	3.73	3.48	8.18	10.44
20 kg·N/ha of LCC < 5	6	5	130	110	3.56	3.24	5.55	6.41
Mean					3.31	3.02	5.29	7.00
CD(P=0.05) Variety					1.64	1.34	2.74	1.96
CD(P=0.05) LCC					1.18	0.89	2.66	1.79

Source: Sen *et al*. 2011

Table 8. Evaluation of GreenSeeker based N management in wheat

	Fertiliser N application (kg N/ha)										
Basal	*CRI[b], 1st irrigation*	*Feekes 5-6 stage, 2nd irrigation*	*Feekes 7-8 stage, 3rd irrigation*	*Total*	*YP_0, t/ha*	*RI*	*Gain Yield, t/ha*	*N Uptake, kg/ha*	*AE*	*RE, %*	*PE*
0	0	-	-	0			1.89	39.2			
75	75	-	-	150			4.56	138.2	17.8	66.1	26.9
80	0	25[a]	-	105	3.56	1.19	4.01	107.7	20.2	65.2	31.3
100	0	20[a]	-	120	3.76	1.14	4.10	119.8	18.4	67.2	27.4
40	40	25[a]	-	105	3.61	1.19	4.24	115.5	22.4	72.7	30.8
50	50	19[a]	-	119	3.82	1.13	4.34	121.2	20.6	68.9	29.9
60	60	17[a]	-	137	3.88	1.12	4.43	133.9	18.5	69.1	26.8
80	0	-	37[a]	117	3.50	1.29	4.21	113.2	19.8	63.2	31.4
100	0	-	32[a]	132	3.59	1.24	4.43	126.9	19.2	66.4	29.0
40	040	-	29[a]	109	3.58	1.22	4.47	112.0	23.7	66.8	35.4
50	50	-	23[a]	123	3.78	1.16	4.35	126.5	18.5	65.6	28.2
60	60	-	13[a]	133	3.91	1.09	4.45	131.1	19.2	69.1	27.9
LSD (p=0.05)						0.423	10.11	3.29	7.45	5.00	

AE agronomic efficiency of applied N (kg grain kg^{-1} N applied), RE recovery efficiency of applied N (%), PE physiological efficiency (kg grain kg^{-1} N uptake), YP0 yield potential with no additional fertilizer N applied, RI response index, RI_{NDVI}, LSD least significant difference [a]GreenSeeker-guided N application; [b]Crown root initiation stage

Source: Bijay Singh *et al*. 2011

3.7 Conservation Agriculture

The Conservation Agriculture (CA) is a practice in which three conditions, of minimum soil disturbance, surface residue cover of at least 30 percent and crop diversification, must be satisfied. Leaving crop residues on the soil surface seems to be a better option than incorporation as it reduces soil erosion and soil evaporation, avoids short-term nutrient tie up, and suppresses weeds. Moreover, the slower decomposition compared with incorporation also helps build up soil organic carbon (Havlin *et al*., 1990; Hooker *et al*., 1982; Unger 1991; Wood *et al*., 1990). Crop residue and tillage practices also influence the weed germination and establishment. Tillage is mainly practised to prepare seedbed and to control weeds, which has already germinated. But the tillage is also responsible for stimulation of the weed germination and emergence of many weeds through brief exposure to light (Ballard *et al*,. 1992). Crop residues may influence the weed seed reserve in the soil directly or indirectly and also the efficiency of soil-applied herbicides (Crutchfield *et al*. 1986). Moreover, incorporated plant residues may release the allele-chemicals, which can be toxic to weeds (Inderjit and Keating, 1999). However, under field conditions it is influenced by numerous factors (Einhellig, 1996). Residue type also influences weed growth, for example, Eguchi and Hirano (1971) found that rice straw mulch reduced the population of weed (Polygonum lapathifolium) in wheat. Residue retention on the soil surface in combination with no till system may also significantly contribute to the suppression of weeds (Teasdale 1998; Liebman and Mohler, 2001). No till system helps in reducing the weed emergence through avoiding the exposure to the light as well as offering the mechanical impedance to the weed seed. Residue retention also influences the soil temperature and soil moisture, which in turn may increase or decrease the weed germination depending on the type of weed flora, soil conditions, type of crop residue and quantity. At lower residue level the weed flora may be higher than the residue free conditions but at higher levels of more than 4 t/ha, the weed infestation is definitely reduced considerably (Chhokar *et. al*., 2009).

The black soils are very difficult to work as they have extremes of consistence being very hard when dry and very sticky and plastic when wet and are low in available nitrogen, phosphorus and soil organic matter. Adopting conservation technologies discussed in this article, especially CA wherein surface residue retention is a must, can help in building up soil organic matter with accompanying improvement in soil physical conditions as well as in nutrient supplying capacity (Table 9). In these soils, in addition to improving water infiltration rate by improvement in organic matter the surface retained plant residue will also help in reducing the runoff, conserving moisture and moderating soil temperature leading to increased productivity and profitability.

Table 9: Effect of different CA-based crop management technologies on yield gain, water saving, and increase in water productivity (WP) over conventional practice in IGPs

Technologies	*Crop/cropping system*	*Yield gain (kg/ha)*	*Water saving (ha-cm)*	*Increase in WP (kg/gm^3)*	*Reference*
Laser levelling	Rice-wheat	750-810	24.5-26.5	0.06	Jat *et al*., (2009 a, b)
No till	Rice	750	22.0	-	Sidhu (2010)
	Wheat	150-140	2-4	0.10-0.21	Malik *et al*., (2005),
	Wheat	610	2.2	0.28	Saharawat *et al*., (2010)Gathala *et al*., (2011)
	Maize	150	8	0.21	Parihar *et al*., (2011)
No till with surface residue	Rice-wheat	500	61	0.24	Gathala *et al*., (2010)
	Wheat	410	10	0.13	Jat *et al*., (2009 c)
Direct seeded rice (DSR)	Rice	120	25	0.08	Jat *et al*., (2006a)
	Rice	510	13	0.09	Gill *et al*., (2006)
	Rice	62	18	0.10	
Raised bed planting	Maize	324	12	0.80	Jat *et al*., (2006 b)
	Wheat	310	16	0.58	Jat *et al*., (2011), Chandra *et al*., (2007)
	Wheat	270	5	0.50	

Source: Chauhan *et al*., 2012

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13

Decision Support System for Conservation Agriculture

M. Shamim, V.P. Chaudhary and N.K. Jat

Conservation agriculture (CA) represents a series of resource-conserving agricultural practices. Reduced or no tillage combined with crop residue and crop rotation are the principal components of conservation agriculture. In addition to these land configuration planting techniques e.g. permanent raised-bed systems are often applied in CA. All these various components add complexity to the cropping system not only challenges the applicability of crop-soil simulation model, but, also the effects of conventional soil tillage, such as the temporal decrease in soil bulk density and increase in water infiltration capacity as well as mixing of soil layers, i.e. of texture, organic matter and nutrients, are often not accounted for in crop-soil simulation models or are represented in a limited way. In classical model applications, this lack may be of little relevance. However, when models are used to explore the crucial differences between CA and conventional agriculture, changes in and effects on soil properties due to one or the other practice becomes highly relevant (Sommer *et al.*, 2004).With three major advantages such as enhanced productivity, richer resources and highly climate resilient agricultural practices, adoption of conservation agriculture (CA) is increasingly being promoted as a way of climate smart agricultural practices towards increasing climate variability. To understand complex interactions among the biophysical processes, computer simulations have become a useful part of mathematical modeling of many natural systems. Crop simulation modeling started in early 1960s when early simple crop models were developed for estimation of transpiration and photosynthesis. The first step towards crop modeling was the development of simple models to estimate light interception and photosynthesis. These simple models were used to quantify the light profile in a canopy and to assess the sensitivity of crop photosynthetic rates. In recent decades, many cropping systems models have been evolved in response to answer not only nutrient and water deficiencies, but also pest and disease damage and processes affecting soil nutrient dynamics including issues on sustainable production, climate change, and environmental impacts. Among many crop simulation models, DSSAT (Decision Support System for Agrotechnology Transfer) is a comprehensive decision support system which, includes several routines to account for the impact of tillage and surface residue retention. Sommer *et al*. (2004) applied DSSAT and found that in the presence of a surface residue layer the classical soil conservation service (SCS) curve number approach fails to describe surface runoff adequately, because the residue layer increases surface roughness and retains water, which is not accounted for in the SCS approach. Also, in the presence of a residue layer soil evaporation is lower leading to comparably higher top soil moisture content and consequently to a higher runoff according to the SCS curves number method. The one-dimensional cascade approach used by the model to simulate soil water infiltration and drainage does not adequately capture the soil water redistribution in raised-bed cropping systems. Modifications are needed to account for these two processes.

In low input systems, where most nutrient becomes available from soil organic matter (SOM) and residue turnover, the applicability of the DSSAT is limited because it recognizes only one type of SOM (i.e. humus) and recently added, but not yet humified, residue and it does not recognize a residue layer on top of the soil. Newly formed is given a fixed C/N ratio of 10; only one litter pool is recognized for N although three are recognized for C. A SOM-residue module from the CENTURY model was incorporated in the DSSAT crop simulation model and a residue layer was added on top of the soil. This CENTURY-based module was added to facilitate simulation of soil organic sequestration potential for different crop rotations over long time periods after initializing soil C and other variables only once at the start of the simulation. The CENTURY model is more appropriate for use in low input agricultural systems, for example those that use green manure where the surface layer is crucial. The main differences between the CENTURY-based module and the CERES-based soil N module are: the CENTURY-based module divides the SOM in more fractions, each of which has a variable C: N ratio and can mineralize or immobilize nutrients, it has a residue layer on top of the soil, and the decomposition rate is texture dependent. The CENTURY-based module distinguishes three types of SOM: (1) easily decomposable (microbial) SOM1, (2) recalcitrant SOM2, which contains lignin and cell walls, and (3) an almost inert - SOM3. At initialization of the simulation, the fractional ratio of these three pools is set, with SOM1 of only about 2% of total SOM, while SOM2 and SOM3 vary with the management history of the soil (grassland or cultivated) and the degree of depletion. The improved SOM module also allows one to perform more realistic simulations on carbon sequestration, *i.e.* the build-up of soil organic C under different management systems. Evaluation of the model showed an excellent fit between simulated and measured values for SOM-C under bared field. By incorporating the CENTURY

SOM-residue module, DSSAT crop simulation models have become more suitable for simulating low-input systems and conducting long-term sustainability analysis (Jones *et al*., 2010).

Conservation agriculture (CA) is increasingly promoted as one way of adapting production systems under changing climate, especially for areas such as southern Africa where rainfall is projected to decrease.The DSSAT model was calibrated using field data and validated against independent data sets of yield to evaluate the ability of DSSAT to predict continuous maize (*Zea mays* L.) yield for conventional tillage (CT) and CA systems as well as maize yield for a CA maize–cowpea (*Vigna unguiculata*) rotation on an Oxicrhodustalf under southern African climatic conditions. Simulation showed that DSSAT could be used for decision-making to choose specific CA practices especially for no-till and crop residue retention. Long term simulations showed that maize–cowpea rotation gave 451 kg/ha and 1.62 kg/mm more maize grain yield and rain water productivity, respectively compared with CT. On the other hand, CT (3131–5023 kg/ha) showed larger variation in yield than both CA systems (3863 kg/ha and 4905 kg/ha). CT and CA systems gave 50% and 10% cumulative probability of obtaining yield below the minimum acceptable limit of 4000/ha, respectively suggesting that CA has lower probability of low yield than CT, thus could be preferred by risk-averse farmers in uncertain climatic conditions (Ngwira *et al*., 2014).

1. ROLE OF CROP MODELING UNDER CLIMATE CHANGE SCENARIO

In recent years there has been a growing concern that changes in climate will lead to significant damage to both market and non-market sectors. The climate change will have a negative effect in many countries. But, farmer's adaptation to climate change-through changes in farming practices, cropping patterns, and use of new technologies will help to ease the impact. The variability of our climate and especially the associated weather extremes is currently one of the concerns of the scientific as well as general community. The application of crop models to study the potential impact of climate change and climate variability provides a direct link between models, agro-meteorology and the concerns of the society. Tables 1 to 3 present the results of sensitivity analysis for different climate change scenarios for rice cultivars under middle Gujarat Agro-climatic region.

2. EFFECTS OF MAXIMUM AIR TEMPERATURE

The effects of altered maximum air temperature (± 1 to ±3°C) on simulated grain yield of various cultivars of rice under optimal date of transplanting and the comparison of this simulated grain yield with base yield and its per cent change from base yield are presented in Table 1.

Table 1: Sensitivity of CERES-Rice model to maximum air temperature (°C) for four different cultivars of rice

Parameters	*Cultivars*							
Base yield	*Pankhali 3793 kg/ha*		*Narmada 4243 kg/ha*		*Gr-104 4887 kg/ha*		*Pusa-Basmati-1 4177 kg/ha*	
Max. air temperature (°C)	*Simulated grain yield (kg/ha)*	*% Change from base yield*	*Simulated grain yield (kg/ha)*	*% Change from base yield*	*Simulated grain yield (kg/ha)*	*% Change from base yield*	*Simulated grain yield (kg/ha)*	*% Change from base yield*
1	3487	-8.1	3962	-6.6	4593	-6.0	4134	-1.0
2	3432	-9.5	3910	-7.8	3914	-19.9	3801	-9.0
3	3399	-10.4	3870	-8.8	3856	-21.1	3686	-11.8
-1	3994	5.3	4380	3.2	5150	5.4	4580	9.6
-2	4287	13.0	4722	11.3	5689	16.4	4764	14.1
-3	4501	18.7	5050	19.0	5457	11.7	5057	21.1

Sensitivity of CERES-Rice model simulated grain yield to incremental units of maximum air temperature showed a gradual decrease in yield while the down scaled maximum temperature increased the yield in all four genotypes of rice. Maximum reduction in yield due to increment of same unit of maximum temperature was recorded in GR-104 genotype whereas cv. Pankhali recorded least reduction for corresponding temperature level. The highest positive percentage change in yield over base yield due to reduction of maximum temperature was recorded in Pusa Basmati-1 and least by the genotype GR-104. Such behavior of the model was mainly due to reduction in duration of anthesis and grain filling with rise in ambient temperature and *vice versa.*

3. EFFECTS OF MINIMUM AIR TEMPERATURE

The result of simulated yield when examined in relation to minimum temperature indicated decrease in yields with increase in temperature above that corresponding to potential conditions in all four genotypes of rice. But, the magnitude of change from base yields in terms of percentage was almost double that corresponding to the preceding level in all the increased level of maximum temperature in the case of Pankhali and Pusa Basmati-1 cultivars (Table 2).

This type of behavior shown by the crops might be due to dual effects of higher rate of respiration during night time resulted in to comparatively higher loss of photosynthates than that was occurred during day time due to increased maximum temperature and differential reduction in crop duration of different cultivars of rice. The reduction was however, less for the heat tolerant cultivar (Pankhali). Paradoxically, the low minimum temperature increased the yield in the all four genotypes of rice, but not in the same magnitude as that of reduction in yield with increase in minimum temperature and decrease in maximum temperature. All the four genotypes behaved differently in relation to change in minimum air temperature as the simulated yield did not increased linearly when minimum temperature was decreased up to 5°C in the case of Narmada and GR-104 genotypes. This result described the tolerant power of various genotypes of rice in relation to minimum temperature where, growth rate affected differently in different cultivars.

4. EFFECT OF ELEVATED CARBON DIOXIDE

The simulated grain yields increased under elevated level (410 ppm concentration over the base value 380 ppm) of CO_2 by 21.0%, 23%, 27.9% and 25.6%(Table3) in cv. Pankhali, Narmada, GR-104 and Pusa Basmati-1, respectively when compared with base yield. This clearly showed that elevated concentration of CO_2 had a significant and positive impact on the grain yield of various genotypes of rice, but GR-104 could be performed better under elevated concentration of rice than that of other genotypes.

Table 2. Sensitivity of CERES-Rice model to minimum air temperature (°C) for four different cultivars of rice

Parameters	*Cultivars*							
Base yield	*Pankhali 3793 kg/ha*		*Narmada 4243 kg/ha*		*Gr-104 4887 kg/ha^{-1}*		*Pusa-Basmati-1 4177 kg/ha*	
Max. air temperature (°C)	*Simulated grain yield (kg/ha)*	*% Change from base yield*	*Simulated grain yield (kg/ha)*	*% Change from base yield*	*Simulated grain yield (kg/ha)*	*% Change from base yield*	*Simulated grain yield (kg/ha)*	*% Change from base yield*
1	3468	-8.6	3936	-7.2	4625	-5.4	3974	-4.9
2	3220	-15.1	3711	-12.5	3738	-23.5	3780	-9.5
3	3118	-17.8	3500	-17.5	3475	-28.9	3488	-16.5
-1	3964	4.5	4383	3.3	5166	5.7	4477	7.2
-2	4215	11.1	4683	10.4	5312	8.7	4686	12.2
-3	4498	18.6	5053	19.1	5504	12.6	4832	15.7

Table 3. Sensitivity of CERES-Rice model to elevated CO_2 concentration for various cultivars of rice

Genotypes	*Base yield(kg/ha)*	*Elevated CO_2 concentration (410 ppm)*	
		Simulated grain yield (kg/ha)	*% Change from base yield*
Pankhali	3793	4589	21.0
Narmada	4243	5241	23.5
Gr-104	4887	6250	27.9
Pusa Basmati-1	4177	5247	25.6

5. EFFECTS OF PLANTING METHODS

The change in planting method (Direct sowing) and their impacts on grain yields of various cultivars of rice as simulated by the model in comparison with base yield are presented in Figure 1. The yield reductions ranged between 12.4 (GR-104) to 14.4 (Pusa Basmati) percentage change from base yield. This indicated that the model functioned extremely well in detecting the effect of planting methods on simulated yield of rice.

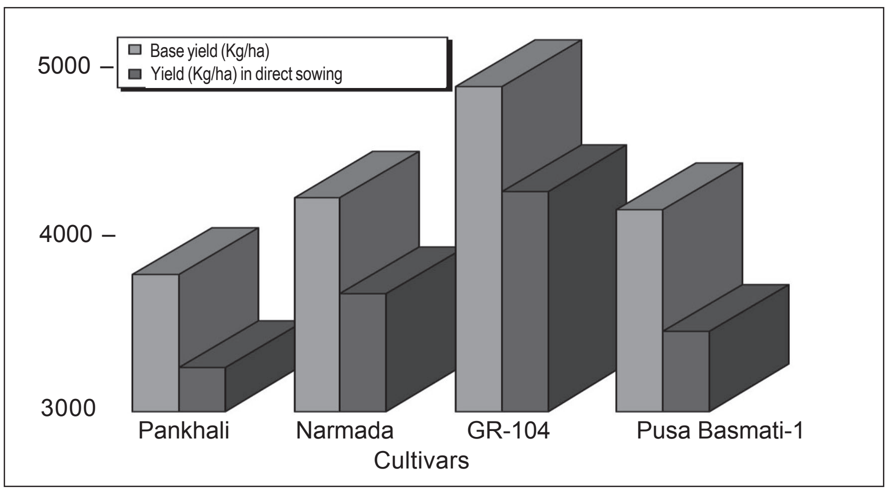

Fig. 1. Effects of direct sowing on grain yield of various genotypes of rice as compared with base yield

6. EFFECT OF PLANT POPULATION

Large yield reductions were observed on decreasing plant population up to 25 plants/m^2 in all cultivars, but Pusa Basmati-1 recorded highest (Table 3). However, model did not show any noticeable percentage change when compared with the base yield in relation to increasing the plant population from 75 to 200 per sq. meter. This showed the insensitivity of the model to varying plant population level.

Table 3. Sensitivity of CERES-Rice model to plant population (plant/m^2) for four different cultivars of rice

Parameters	*Cultivars*							
Base yield	*Pankhali 3793 kg/ha*		*Narmada 4243 kg/ha*		*Gr-104 4887 kg/ha*		*Pusa-Basmati-1 4177 kg/ha*	
Max. air temperature (°C)	*Simulated grain yield (kg/ha)*	*% Change from base yield*	*Simulated grain yield (kg/ha)*	*% Change from base yield*	*Simulated grain yield (kg/ha)*	*% Change from base yield*	*Simulated grain yield (kg/ha)*	*% Change from base yield*
25	3125	-17.6	3475	-18.1	3847	-21.3	3269	-21.7
75	3802	0.2	4340	2.3	5092	4.2	4387	5.0
100	3862	1.8	4376	3.1	5125	4.9	4495	7.6
125	3919	3.3	4455	5.0	5151	5.4	4457	6.7
150	3862	1.8	4325	1.9	5212	6.7	4471	7.0
175	3902	2.9	4382	3.3	5291	8.3	4485	7.4
200	3942	3.9	4408	3.9	5321	8.9	4495	7.6

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14

Development of Soil Quality Index and its Usefulness in Conservation Agriculture

Tapan Jyoti Purakayastha[*1], Debarati Bhaduri[2]

The last century has evidenced green revolution for dramatic enhancement in production of food crops including cereals, pulses and oilseeds. But, these impressive gains in food production were achieved at the cost of soil health and environmental quality. The agricultural expansion and intensive use of irrigation, fertilizers and agro-chemicals have led to soil degradation, environmental pollution and soil salinization. Besides, deforestation, excessive soil tilling has increased dependence upon the fossil fuels.

Ideally, a stagnant food production was often observed in many important and highly productive agricultural zones like Indo-Gangetic plains (IGP). A serious decline in soil quality was often presumed to be the cause of it which may have resulted due to exhaustive use of soil resources, following the same cropping pattern, over use of chemical fertilizers, unscientific methods of cultivation *inter alia* years after years.

1. DEGRADATION OF SOIL RESOURCES

Degradation of soil resources has been a repetitive topic yet a burning global issue to be addressed. Though all the degraded lands around the globe cannot be restored or managed and some may have lost the potentiality to revive, still some soils at local or regional levels can be rejuvenated and can be taken into cultivation. This could be done once proper management measures like reclamation, afforestation, mechanical interferences (for turbulence in soil layers, breaking

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of large clods etc.) and partial regaining of soil fertility (by green manuring, legume crops etc.) are effective. In many parts of the world, some barren or uncultivated or unused lands have been taken care of considering the limited land resources. Apart from these some of the soil related problems which commonly being noticed are here as under:

- Soil erosion by water
- Reduced top soil depth (reduced water and nutrient retention capacity)
- Wind erosion/dust storms, mobile sand dunes
- Nutrient depletion (loss of organic matter, acidity)
- Salinization and alkalinity (under-irrigation, over-irrigation)
- Compaction/Crust formation
- Toxicity or pollution by pesticides, nutrients, acid rain

2. SOIL QUALITY

Soil quality is defined as the capacity of soil to function within natural or managed ecosystem boundaries, to sustain plant and animal productivity, maintain or enhance water and air quality, and support human health and habitation (Karlen and Stott *et al.*, 1994). Some of the specific definitions given by different researchers time to time are here as under:

"Soil quality is the sustained capability of a soil to accept, store and recycle water, nutrients and energy" (Arshad and Coen, 1992).

"The degree of fitness of a soil for a specific use" (Pierce and Larson, 1993).

"Soil quality is the soil's capacity or fitness to support crop growth without resulting in soil degradation or otherwise harming the environment." (Gregorich and Acton, 1995).

3. SOIL HEALTH

Soil health can be defined as the capacity of soil to function as a vital living system, within ecosystem and land-use boundaries, to sustain biological productivity and maintain the water quality as well as plant, animal, and human health.

3.1 Soil Health vs. Soil Quality

Soil health and soil quality are being used interchangeably. In general soil quality term is used by soil scientists and soil health by others. Soil health is monitored by dynamic soil quality indicators. Whereas soil quality refers to inherent as well as dynamic soil properties. The interaction of different soil processes (Physical,

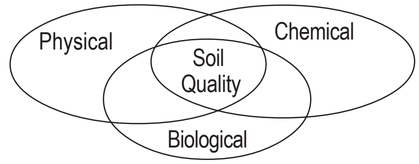


Fig.1: The interference zone of three major aspects of soil processes

chemical and biological) determines the soil quality (Fig. 1).

The significance of soil quality/health can be visualized here as under:

- Soil is a dynamic living body and its health is vital to terrestrial ecosystem
- Healthy soils are critical to agricultural sustainability
- Soil quality/health is directly linked to food production and poverty
- Soil health determines plant health and human health

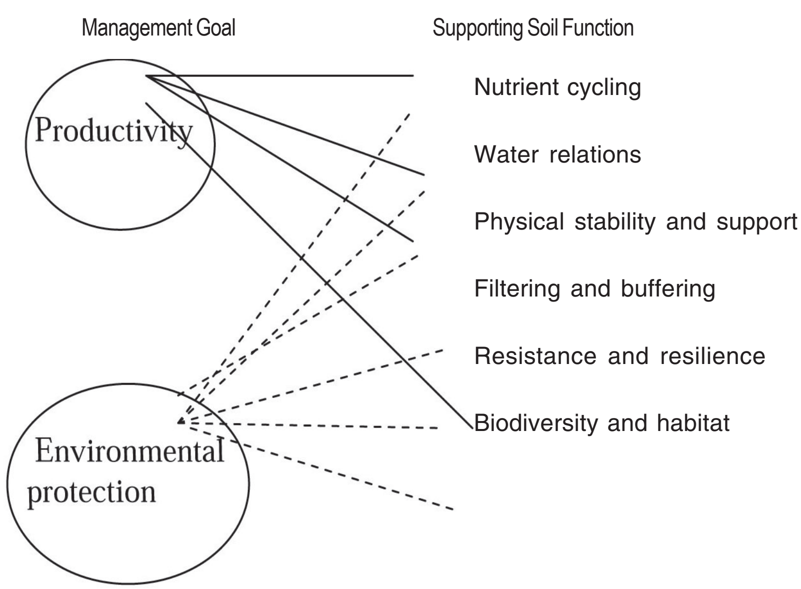
Soil quality indices can be developed by considering following major aspects:

1. Management Goal: Productivity and environmental protection
2. Soil Management Assessment Framework (SMAF) Design.

Both productivity and environmental protection are *inter-alia* to achieve the goal. (The important soil functions which are interlinked for enhanced productivity and environmental protection are being given in Table 1.) Both productivity and environmental protection are *inter alia* to achieve the goal. The conceptual framework for the soil management and assessment proposed by Andrews, 1998 (Fig.2) involve three major steps as indicated below:

1) Indicator Selection
2) Indicator interpretation
3) Integration

Table 1: Potential management goals and associated soil functions used to select appropriate soil quality indicators



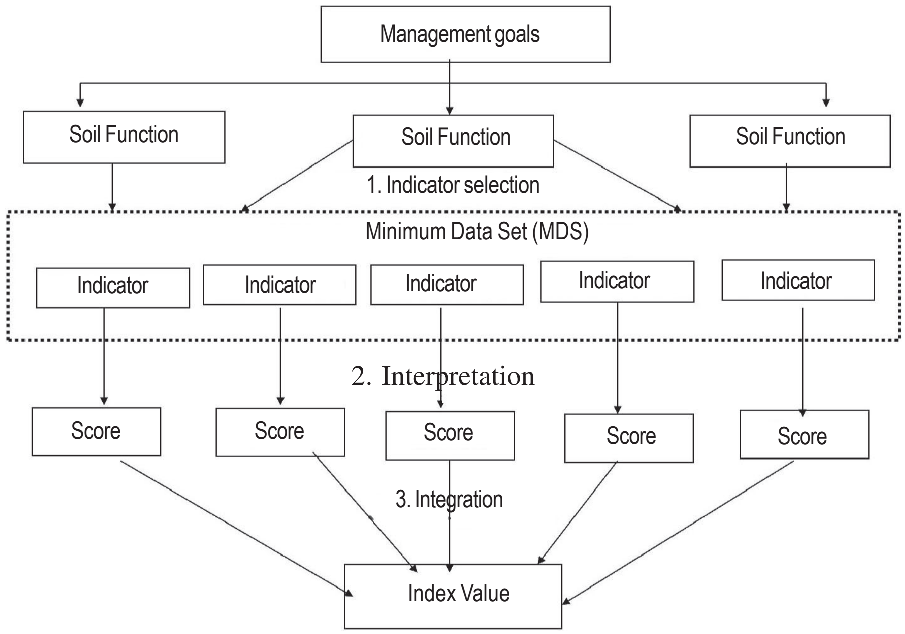


Fig. 2. Conceptual framework for the soil management assessment tool as proposed by Andrews, 1998

3.2 Soil Quality Indicators

Soil quality is the result of interaction among physical, chemical and biological properties of the soil. A single soil property is of limited use in evaluation of soil quality. It is not feasible to measure all soil properties for evaluation of soil quality. A group of soil properties are carefully selected for evaluation of soil quality. These selected soil properties are known as soil quality indicators. There are four general groups of soil quality indicators:

1. Visual indicators
2. Physical indicators
3. Chemical indicators
4. Biological indicators

The important soil quality indicators which can be used for assessing the soil functions are given in Table 2.

Table 2. Soil quality indicators used to assess soil function

Indicator	Soil function
Visual: crusting, ponding, soil loss	Soil aggregation, water transmission
Physical: Soil aggregate stability, infiltration and bulk density	Retention and mobility of water and nutrients; habitat for macro and micro fauna
Chemical: Organic matter, pH, extractable	Soil structure, stability, nutrient retention; soil erosion soil

soil nutrients: N-P-K and base cations Ca Mg and K	biological and chemical activity thresholds; plant available nutrients and loss of N; Ca, Mg and K
Biological: Microbial biomass C and N, potentially mineralizable N	Microbial catalytic potential and repository for C and N; soil productivity and N supplying potential

5. CONSERVATION AGRICULTURE (CA) AND SOIL QUALITY: ALLIANCES AND OPPORTUNITIES

Conservation agriculture mainly addresses two issues: 1. Conservation of resources and 2. Use of locally available resources (crop resides, organic manures) in best efficient manners. Hence these will provide the farmers a healthy soil environment at a reduced cost. Soil quality indices (SQI) were observed to be higher under non-puddled condition in rice cultivation indicating the unsustainability in terms of environmental quality in rice-based cropping system prevailed under continuous puddling on the same piece of land owing to soil structural deterioration and nutrient depletion, despite regular applications of recommended inorganic and organic fertilizers. In a subsequent wheat crop of rice-wheat rotation, no-tillage practice also proved most effective for soil quality as observed by increased indicators and SQI values (Bhaduri *et al*., 2014; Bhaduri and Purakayastha, 2014). Many other reports also suggested that no-tillage or zero tillage remained beneficial for soil quality (Wander and Bollero, 1999; Mohanty *et al*., 2007). Wienhold and Halvorson (1999) concluded that more intensive cropping and conservation tillage increased N-mineralization rates and improved soil quality when compared to crop-fallow. A positive influence of minimum tillage in combination with crop rotation on soil quality was also indicated by another recent study under Irish arable farm management (Aksari and Holden, 2015).

The balanced fertilization along with manures improves the soil aggregation as well as biological activity of soil and maintains soil quality and sustainable productivity of rice-based cropping system in Indo-Gangatic alluvial soils of India (Choudhary *et al*., 2005). Similarly, Kang *et al*., (2005) reported that long-term applications of organic manures in rice/corn-wheat cropping system increased the sustainability index value combining nutrient index, microbial index and crop index. Another study carried out by Masto *et al*. (2007) found that highest SQI ratings for the combined NPK fertilizer plus manure treatment (100% NPK + FYM) followed by 15% NPK and 100% NPK, while lowest found in unfertilized control soil in a long-term fertilizer experiment under maize-wheat cropping system in Inceptisol of Delhi. For rice-wheat cropping system in the similar region 100% N substituted by various organic sources maintained highest SQI for both the crops (Bhaduri and Purakayastha, 2014).

6. CONCLUSION

Adoption of Resource Conservation Technologies (RCTs) under conservation agricultural practice is beneficial for sustaining or enhancing soil quality indicators and overall quality of soil or health. Many experimental findings supported that conservation agriculture (CA) in the forms of minimization of tillage and partial substitution of fertilizer nutrients through FYM, compost, green manure, crop residues in many important crops and cropping systems emerged as the promising management strategies for enhancing soil quality with maintaining productivity. This will also ensure an eco-friendly and sustainable scenario with respect to crop cultivation especially under long-term agro-ecosystems. In other way, the cost of cultivation can also be reduced by lowering the costly fertilizer input and heavy mechanization cost involved than that of the conventional farming.

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15

Resource Conservation through Enhancing Input use Efficiency

N. Ravisankar

Agricultural inputs are what go into the farm. There are two types of input. The natural or physical inputs include weather, climate, relief (height, shape and aspect), soil, geology and latitude. Farmers have little or no control over these. Changing the natural inputs can sometimes be done but it usually involves a lot of expense. For example areas with not enough rainfall get water from irrigationschemes, steep slopes can be cut into terraces and the climate can be greatly altered by using green houses. The intensive cropping system pushing up the agricultural output level parallel with the present demographic transition imparts a cruel attack on the scarce and precious soil resources. With rising cost of inputs, ever increasing demand for food with mounting pressure of human and animal population, limited available area for cultivation, scarce fresh water resources for agricultural use make it imperative to lay emphasis for increasing the input use efficiency (IUE). Proper assessment of available inputs and their use in a synergistic manner, preventing losses, judicial allocation of inputs among the competing demands to achieve maximum return and development of site-specific technologies are the means of achieving input use efficiencies (Acharya and Bandyopadhyay, 2002). Among the inputs, water and nutrient plays important role in final output of the crop and any measures which are taken to increase its use efficiency will lead to saving of resources.

Physical inputs include land, labour, capital, seeds, water, nutrients, pesticides and machineries increasing the use efficiency of these inputs is always a challenge to producers. The glory of green revolution was on the basis of the use of high yielding varieties (HYV), chemical fertilizers, pesticides, and farm mechanization that led to unprecedented pressure on our natural resource base including natural way of controlling pest and diseases. Green revolution has encouraged an increase in the production of mainly two crops, wheat and rice, but the cost paid was in terms of destruction of other crops (especially coarse cereals and pulses) and

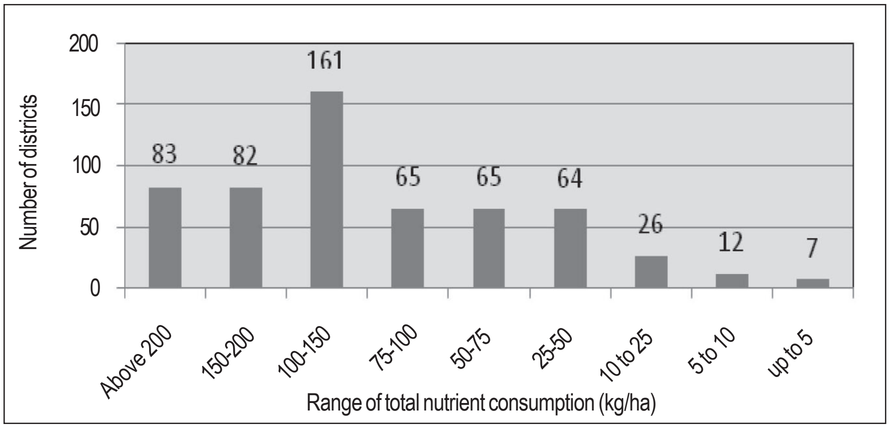

Fig. 1. Classification of districts according to range of total nutrient consumption (kg/ha) during 2013-14 (*Source:* FAI, 2014)

over exploitation of precious water resources and fertile soils. The high dosage application of fertilizers (Fig. 1) deteriorated the physical, chemical and biological properties of soil on one side, on the other, increased soil salinity and pollution of ground water resources. The use of pesticides has been posing serious environmental and health problems. The 59th round of survey conducted by National Sample Survey Organization during 2003 indicates over dependency of farmers for seeds, fertilizers and pesticides from outside farm makes farming costlier.

1. SOIL HEALTH

Total factor productivity and growth rate of productivity of crops are decreasing year after year and deterioration of soil health is the major contributor for the same. Inspite of 326 districts receiving more than 100 kg of nutrient/ha, it has been found that, soils in majority of the districts are low in nitrogen (228 districts), phosphorus (170 districts) and potassium (47 districts). Exhaustive cropping systems cause mining of soil nutrients far in excess of external supply. Nutrient uptake of major systems (Table 1) indicates continuous mining of soil nutrient resource in the intensively cultivated areas. Rice-wheat-cowpea fodder system removes around 800 kg/ha. Further, wider nutrient application gap between recommended and farmers practice also adds to the problem. Across the major systems, farmers are applying 33.3, 38.8, 57.1 and 93% less application of NPK and micro nutrients compared to recommended doses. Among the systems, rice-rice is having the minimum gap in application in terms of NPK (1.1, 12.6, 36.4%, respectively). Continuous application of under doses of nutrients and wider NPK ratio (8.2:3.2:1 during 2012-13 reported by Ministry of Chemicals and fertilizers, 2013) to intensive systems like rice-rice, rice-wheat, and maize-wheat leads to decline in soil health.

Table 1. Nutrient uptake in high intensity cropping in India

Cropping systems	*System yield (t/ha)*	*Nutrient uptake (kg/ha/year)*		
		N	*P_2O_5*	*K_2O*
Rice-wheat	8.8	235	92	336
Pigeonpea-wheat	4.8	219	71	339
Maize-wheat-greengram	8.2	306	62	278
Rice-wheat-greengram	11.2	328	69	336
Maize-potato-wheat	8.6 +11.9 (t)	268	96	358
Rice-wheat-cowpea	9.6 +3.9 (f)	272	153	389

t, f represents tuber and fodder yield
(*Source:* Tandon and Sekhon, 1988)

2. CURRENT STATUS OF VARIOUS SOIL AND CROP MANAGEMENT PRACTICES ON INPUT USE EFFICIENCY

2.1 Soil management

Soil management practices like balanced fertilization, application of amendments and integrated nutrient management, inclusion of crop rotation, mulching with crop residues and tillage influences the nutrient and water use efficiency. Dwivedi *et al*. (2003) indicated in rice, puddling reduces leaching of nutrients and provides effective control of weeds. The partial factor productivity in rice was better with increase in the number of passes (Table 2). In the rice-wheat system, due to acute shortage of time, direct seeding was found to improve crop yields as it gave solution to delayed sowing associated with conventional tillage. Similarly, reduced tillage practices resulted in improving rainfed seed cotton yields as well as the factor productivity (Table 3).

Table 2. Effect of puddling in rice on the grain yield and partial factor productivity (PFP) of nitrogen in rice at Modipuram (Dwivedi *et al*., 2003)

Puddling passes	*90 kg N/ha*		*120 kg N/ha*	
	Grain (kg/ha)	*PFPn*	*Grain (kg/ha)*	*PFPn*
One	3496	38.8	4165	34.7
Two	3747	41.6	5077	42.3
Four	3996	44.4	5452	45.4

Table 3. Effect of tillage methods on seed cotton yields and factor productivity in Bt transgenic cotton at Nagpur

Tillage method	*Yield (kg/ha)*	*PFP (kg seed cotton/kg NPK)*
Conventional till	1526	9.8
Reduced till-1	1874	12
Reduced till-2	2054	13.2

Conservation tillage is found to reduce the cost of production thus increases the IUE. These practices affect crop growth and development depending upon many specific factors *viz* soil type, climate, cropping pattern and other attributes of overall farming operations. In certain situations, a combination of various components of the conventional and conservational tillage i.e. integrated tillage management system may be more profitable than either conventional or conservation tillage alone. Acharya *et al*. (1998) reported higher grain yield under conservation tillage owing to greater root proliferation and utilization of higher amount of soil moisture stored in 0-30 cm soil layer (Table 4). Superiority of conservation tillage with respect to yield of wheat was more pronounced at 60 kg N/ha than 120 kg N/ha thus saving of 60 kg of N/ha. This shows that moisture conserved under conservational tillage was just optimum for more efficient N utilization at 60kg N/ha.

Table 4. Effect of tillage and N on grain yield of rainfed wheat

Tillage practices	*Grain yield (Mg/ha)*		
	Nitrogen	*1989-90**	*1990-91***
Lantana application to preceding maize and its incorporation at sowing of wheat	N^{60}, N^{120}	2813.27	3494.29
T1 + conservation tillage in wheat	N^{60}, N^{120}	3103.83	4124.27
Repeated tillage in maize (farmers practice)	N^{60}, N^{120}	1631.83	2232.77
CD (P=0.05)	-	0.27	0.24

*5 rains of 69.5 mm in Nov., 5 rains of 114 mm in Dec.; **3.4 mm in Nov., 7 rains of 262 mm in Dec.

2.2 Mulching

Mulching is needed on soil surface to check evaporation and improve soil water. It influences nutrient use efficiency (NUE) and water use efficiency (WUE) of crops. Mulching affects biological processes of nutrient transformation and chemical processes of sorption, desorption and fixation, and diffusion of nutrients in soil through moderation of temperature and moisture in the soil. Acharya and Kapur (2001) reported that application of pine needle mulch @ 10 t/ha at the time of sowing of potato in a shallow depth silty clay loam soil significantly improved tuber yield and WUE, and resulted in saving of one irrigation equivalent to 40 mm. Application of mulch @ 10 t/ ha with 60kg N/ha registered significantly higher tuber yield and WUE than 120kg N/ha without mulching, indicating saving of 60kg N/ha through the former treatment.

2.3 Irrigation management

Under optimum nitrogen application, both water and nitrogen efficiency varies with varying irrigation schedules (Table 5). Normally WUE values are higher under water stress condition as compared to optimum and sub-optimum levels of irrigation. The total water use and water use efficiency of consumptive use increased in all the crop sequences with the increase in frequency of irrigation, whereas the water use efficiency was highest under irrigation at 0.75 IW/ CPE ratio in case of high water requirement crops such as wheat and groundnut and at 0.40 IW/ CPE in case of low water requirement crops *viz.* safflower, sorghum and gram (Bharambe *et al*., 2003). Singandhupe *et al*. (2003) observed that the application of nitrogen through the drip irrigation in ten equal splits at 8-days interval saved 20-40% nitrogen on a clay loam Inceptisol as compared to the furrow irrigation when nitrogen was applied in two equal splits (at planting and 1 month thereafter). Experiments carried out on cash crops like sugarcane, cotton, banana, and other high value crops (Table 6.) in various agro-ecological regions of India in medium to fine textured soils showed that the drip fertigation technology has the potential to maximize the yield levels and enhance the input use efficiency.

2.4 Fertilizer Management vis-à-vis Input use Efficiency

2.4.1 Nutrient Management

Fertilizer use efficiency/ NUE depend upon the right rate, right time, and right method of application and sources. Split application of N during the growing season, rather than a single, large application prior to planting, is known to be effective in increasing N use efficiency (Cassman *et al*., 2002). Numerous studies have demonstrated that interaction between N and other nutrients, primarily P and K, impact crop yields and N efficiency. ~~For example, data from a large number of multi-locations on farm field experiments conducted in increasing crop yield and improving N efficiency.~~ Adequate and balanced application of fertilizer nutrients is one of the most common practices for improving the efficiency of N fertilizer and is equally effective in both developing and developed countries.

2.4.2 Partial Factor Productivity (PFP)

Partial factor productivity (PFP) being a measure of unit quantity of grain produced from unit quantity of applied and native nutrient was proved to be higher under balanced nutrient application in all the systems compared to application of N alone or with P and with K PFP of N can be increased to 55.6% and 54.6% in maize-wheat and rice-rice systems, while in rice-greengram and rice-wheat, it was found to be 35.7 and 33.9 % respectively (Fig 2). The increase in recovery of N was observed in all the systems by way of combining recommended quantity of P and K with Nitrogen application. Similarly, the recovery of P and K was higher when the same is applied together with N in all the systems. Among the different systems, rice-rice system recorded higher PFP of P (116 kg/ha) with NK followed by rice-greengram system (101.3 kg/kg of P with NK). However, PFP of K was higher in maize-wheat system (147.3 kg/kg of K with NP) followed by rice-rice and rice-wheat system. Balanced application of nutrients have helped in better recovery of N, P and K from native soil as well as from the applied fertilize as it is evident from the partial factor productivity analysis of nutrients in major cereal based systems.

Table 5. Input use efficiency of different crops under irrigated conditions in different agro-ecological situations of India

Crops	*Locations*	*Soil Types*	*Nitrogen level (kg/ha)*	*IW/CPE schedule*	*No. & depth of irrigations*	*Yield (t/ha)*	*WUE (kg/hacm)*	*NUE (kg grain/kg of N)*
Wheat	Belvatgi (Karnataka)	Clay	80	0.80	4 (6)	3.73	155	47
				0.90	5 (6)	3.83	128	48
				1.00	6 (6)	3.92	109	49
Maize	Rahuri (MS)	Clay loam	50	0.50	2(6)	3.00	250	60
				0.60	3(6)	3.50	194	70
				0.80	4 (6)	3.61	150	72
Pigeonpea	Morna (TN)	Sandy loam	20	0.80	2 (7)	1.78	127	89
				0.90	3 (7)	2.00	95	100
				1.00	4 (7)	2.12	76	106
Chickpea	Kota (Rajasthan)	Clay loam	30	0.50	1 (6)	2.41	204	80
				0.60	2 (6)	2.45	204	82
				0.80	2 (6)	2.46	205	82

Source: Annual Reports, AICRP (WM) 2004-06, 2006-07

Table 6. Effect of drip fertigation splitting on yield and input use efficiency of crops

Crops	*Locations*	*Soil types*	*Drip schedule*	*Nitrogen level (kg/ha)*	*No. of splits*	*Yield (t/ha)*	*WUE (kg/ha cm)*	*NUE (kg grain /kg N)*
Sugare	Sriganganagar (Rajasthan)	Sandy clay loam	80 % PE	225	10	160	640	711
					15	175	700	778
					20	185	740	822
Cotton	Ranhuri (MS)	Clay loam	80 % PE	120	3	2.51	125	21
					5	2.65	132	22
					6	2.94	147	24
Banana	Bhavanisagar (TN)	Sandy loam	100 % PE	200	10	82	532	41
					20	98	637	49

Source: Annual Reports, AICRP (WM), 2004-05, 2005-06 and 2007-08

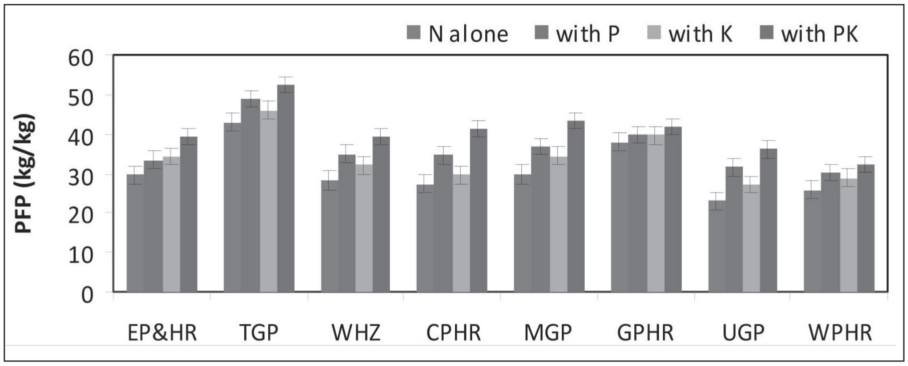

Fig. 2. Partial factor productivity of N in rice-wheat system

2.4.3 Agronomic Efficiency (AE)

Farmers, specially the marginal and dryland farmers, generally, tend to apply only N. However, the AE_N of applied N can be largely increased by adequate P and K fertilization. Agronomic efficiency of N can be increased to 238.9 % in rice-rice system by applying the recommended quantity of N with recommended quantity of P and K instead of N alone as being practiced in many regions having the cereal based systems. Rice-greengram recorded 167.7% (Fig 3) increased AE of N with PK followed by maize-wheat systems (140.7 %). Though, application of N with P or K had registered increase in AE of N in all the systems compared to N alone, the magnitude of increase was lesser than the balanced application of NPK. Similar to N, AE of P was found to be better in all the systems when P is applied with N and K rather than N alone which can be attributed to positive interaction effect of these nutrients in growth and

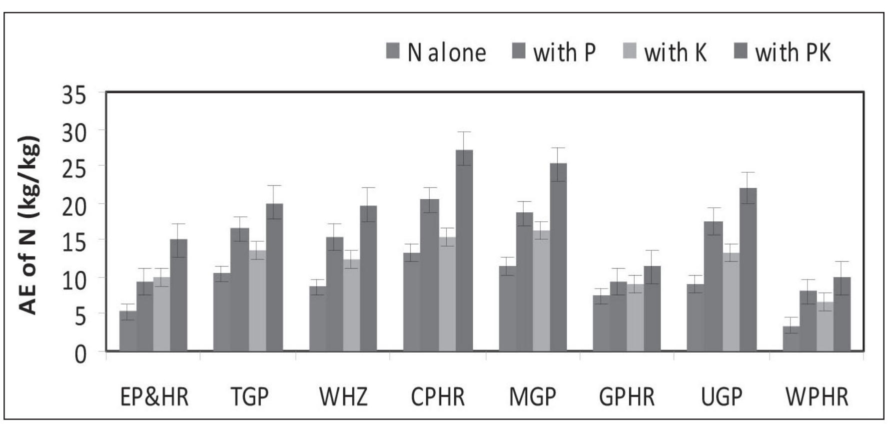

Fig. 3. Agronomic efficiency of N in rice-wheat system in different agro-climatic zones.

development of plants. Among the systems, AE of P and K was found to be higher in rice-rice and rice-greengram systems. More recovery of K due to balanced application was found in maize-wheat system (70.1%). On an average, AE of N, P and K can be increased to the tune of 165, 40.4 and 57.9% respectively through balanced application of nutrient in major cereal cropping systems.

2.4.4 Relative Response and Native Nutrient Supply

Relative response of balanced application of nutrients over control also exhibited the similar trend as that of partial factor productivity and Agronomic efficiency. Relative response of application of NPK over control was found to be 1.04, 1.14, 0.74 and 1.79 in rice-rice, rice-wheat, rice-greengram and maize-wheat systems respectively, which is higher than the N, NP and NK treatments. Among the various system evaluated, maize-wheat had recorded higher relative response with NPK over control which is mainly due to the fact of higher and efficient utilization of nutrients by this system which is also evident from higher partial factor productivity of N and K. Inclusion of greengram in the system led to higher supply of native soil N to the rice-greengram system (47 kg REY/kg of native nutrient). Among the different systems, higher P and K supply from soil was observed in rice-rice and rice-greengram systems. In case of maize-wheat systems, one kg of native N, P, K have contributed for 17.5, 39 and 55.8 kg REY.

2.5 Effect on Economics

Cost of cultivation was higher in balanced application of nutrient in all the systems and it ranged from Rs. 6825 /ha in rice-greengram to as high as Rs. 11651 /ha in rice-rice system. However, the net returns were found to be much higher in all the systems under NPK application compared to control, N alone, NP and NK combinations. The increase was found to be 87.5, 64.6, 53.7 and 127.3% under NPK over N alone in rice-rice, rice-wheat, rice-greengram an maize-wheat systems, while the cost of cultivation increase due to additional application of P and K was found to be only 14, 13.3, 16.1 and 11.2 for the respective systems. Marginal returns were found to be higher with combined application of NPK than N alone, NP and NK. Among the systems, maize-wheat recorded higher (476%) marginal returns under balanced application followed by rice-rice (426%), rice-greengram (339%) and rice-wheat (254%) systems. Application of N alone or with P and with K recorded lower marginal returns in all the systems compared to balanced application of nutrients.

3. FARMING SYSTEMS APPROACH FOR IMPROVING RESOURCE USE EFFICIENCY

Crop and livestock cannot be separated for small holder agriculture as crop + livestock is the pre-dominant farming system existing in the world and livelihood of millions of marginal and small farm holdings revolves around this system. Natural and intentional integration of components takes place in the farming systems being practiced by the cultivators. Natural integration is one that exists in the farm households while intentional integration aims for higher profitability through better recycling and reduced external inputs. Vertical expansion in small farms is possible by integrating appropriate farming system components requiring less space and time and ensuring periodic income to the farmers.

Integrated Farming System (IFS) is considered to be powerful tool and holds the key for ensuring income, employment, livelihood and nutritional security in a sustainable mode for small and marginal farmers who constitute 84.97 % of total operational holdings in India and has 44.31 % operational area. Integrated system meets the above goals through multiple uses of natural resources such as land, water, nutrients and energy in a complimentary way thus giving scope for round the year income from various enterprises of the system. Besides ever growing population, the consumption pattern in rural and urban areas is fast changing ~~thanks to the~~ raising income and economic liberalization. The share of calories by food crops are already declining and it is expected to be below 50 % by 2050 indicating the increase in requirement of non-grain crops and animal products. IFS is whole system approach and linked to horse hoeing husbandry prescribed by Jethrotull (1674 -1741). Tillage is the oldest art associated with development of agriculture and farming system. The best examples include "pig tractor" systems where the animals are confined in crop fields well prior to planting and "plow" the field by digging for roots, poultry used in orchards or vineyards after harvest to clear rotten fruit and weeds while fertilizing the soil, cattle or other livestock allowed to graze cover crops between crops on farms that contain both cropland and pasture. Water based agricultural systems also provides way for effective and efficient recycling of farm nutrients besides irrigation water in the process.

3.1 Farming System Approach and its Principles

Farming system can be simply defined as a positive interaction of two or more components within the farm to enhance productivity and profitability in a sustainable and environmental friendly way. A judicious mix of two or more of these farm enterprises with advanced agronomic management tools may compliment the farm income together with help in recycling the farm residues. The selection of enterprises must be based on the cardinal principles of minimizing the competition and maximizing the complementarity between the enterprises. In general, farming system approach is based on the following objectives:

- Sustainable improvement of farmhouse hold systems involving rural communities
- Farm production system improvement through enhanced input efficiency
- Raising the family income
- Satisfying the basic needs of farm families

Major steps involved in farming systems approach are i) Systematic characterization of existing farming systems in various agro-climatic regions, ii) Farm constraints identification, iii) Collective, compatible and convenient farm interventions iv) Convergence of resources for making a self-reliant farm, v) Auditing of input-output vi) Assessing the impact of interventions on employment generation, productivity enhancement, sustainability of natural resources and vi) Large scale demonstration of farming systems in participatory mode.

In the intentionally integrated farming system models, the crop, livestock, complimentary and supplementary enterprises are selected aiming higher profitability by way of resource recycling. Proper recycling of farm wastes and crop residues within the system could reduce cost of production to the extent of 42 to 75 % depending upon the components and its connectivity. In the natural integrations, the internal supply of N, P_2O_5 and K_2O in crop + livestock system is only 80, 33 and 80 kg/ha where as in the intentionally integrated farming systems, it increases to 170, 110 and 150 kg/ha. In the improved farming systems, about 65, 85 and 100 % of N, P_2O_5 and K_2O requirement can be met with in the farm. Further, the recycling of wastes also supplies sufficient level of micronutrients.

In India, 19 pre-dominant farming systems exists with majority as crop + livestock (85%). Livestock is a major source of supplementing family incomes and generating gainful employment in the rural sector, particularly among the small and marginal farmers and farm women besides serving as nutrient source. The results of on-farm farming system modules evaluated in various NARP zones through AICRP on Integrated Farming Systems promises 6.8 times increase in net returns over variable cost of interventions in improved farming systems with value of household consumption (produced within the farm) increasing by 51.4 %. Further, the recycling of wastes increases by 40-45 % against the <20 % in the naturally integrated systems.

3.2 Enhancing Water Productivity Through Farming System

Integrated farming system provides a better scope for most effective use of water by putting the same water for several uses like producing crop, fish, dairy, mushroom, poultry, duckery etc. simultaneously within a farm. Multiple uses of water are best possible through diversification of farming systems. Rice-fish system can be described as micro-watershed for effective land and water uses. The system explored synergy leading to increased grain yield of rice by 5–15 %, enrichment of organic matter and nutrients. On-farm studies reveals that integration of fishery and piggery gave maximum water productivity (net returns of ~~RS~~ 5.67/m^3, 1.23 kg grain of rice/m^3 of water). The technologies viz. adoption of furrow irrigation instead of check basin or border method of irrigation, raised bed planting technology, pressurized irrigation system, laser land leveling etc. are suitable under diversified farming systems and lead to considerable amount of saving in water use.

4. LESSONS LEARNT SO FOR

Input use efficiency increases the conservation of resources but it should not be at the cost of yield and economic returns of the cropping systems. Resource conservation practices needs to be adopted based on the locational requirements along with best management practices.

5. POSSIBLE RESOURCE SAVING

Costs of inputs would make the difference on the total production costs. In a system where herbicides would replace land preparation activities the overview could look like figure 4 in conservation and conventional systems (Montoyo, 1984).

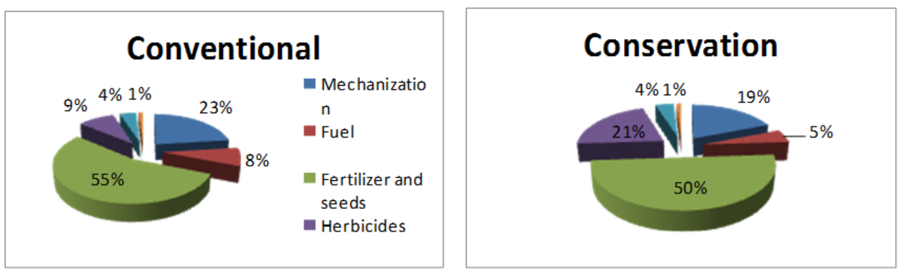

Fig. 4: Changes in different costs under conventional and conservation system

6. CONCLUSION

Improving input use efficiency is a worthy goal and fundamental challenge facing the agriculture in general. One should be cautious that improvements in efficiency do not come at the expense of the farmers' economic viability or the environment. Farm input interactions play an important role in determining the resource use efficiency of the vitalinputs *viz* water, fertilizer and energy, and it is therefore, important that the management practices that moderate and modify these relationships are evaluated and understood.

7. MAJOR FUTURE CONCERNS

- Integration of compatible components in farming systems mode for reduce, reuse, recycle and recovery of resources is essential for enhancing the input use efficiency to greater extent.
- Possible positive interactions of physical inputs of agriculture are to be evaluated which can contribute notably to the resource conservation and efficiency.
- Study on nutrient-water-seed nexus for optimizing the use efficiency of inputs and farm productivity
- Development and propagation of low cost energy sources are essential for resource conservation especially in the fuel, fertilizer and mechanization.

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16

Integrated Farming System Approach for Resource Conservation

J.P. Singh

Agricultural research in India emphasized mainly component and commodity based research involving development of animal breed, crop varieties, farm implements and machinery, fertilizer use and other production and protection technologies mostly conducted in isolation and at the institute level which enabled the farmers to grow more but at the same time over exploited the resources. It resulted in decreasing factor productivity, declining resource use efficiency and ultimately less farm productivity and profitability. It further coupled with the national problems like environmental degradation, ground water contamination and entry of toxic substances in to the food chain etc. Keeping in view the worsened situation of most of the farm resources as above, adoption of conservation agriculture is utmost needed to safeguard the livelihoods of resource poor small and margnal farm holders who constitute about 86% of more than 121 million farm families in India cultivating about 295 or even less of the total consolidated and scattered arable land with an average holding size of 1.23 ha with small and 0.4 ha with marginal farmers. Small and that too fragmented land holdings do not allow farmers to keep independent farm resources like draught animals, tractors, bore wells/tube wells and other sophisticated farm machineries for various cultural operations. Most of them are literary illiterate or poorly educated, economically poor and are devoid of knowledge advancement made in the field of agricultural sciences. In past, the focus had been on maximization of crop yields only and that to for well-endowed resource rich farmers. To fulfil the basic needs of household including food (cereals, pulses, oil seeds, milk, fruit, honey, fish, meat etc.) for human, feed, fodder, fuel and fibre, a well-focused attention towards integrated farming system research is warranted. Integrated farming system (IFS) is a resource management strategy to achieve economic and sustained production to meet diverse requirements of farm households while preserving resource base and maintaining a high level environmental quality (Lal and Miller, 1990). In farming system approach the whole attention is given to optimization and conservation of resources so that farming can be economically profitable, livelihood of a family may be ensured and environment may be kept clean and safe (Singh and Gill, 2010). For this, emphasis is given to proper allocation of resources, promotion to organic farming, recycling of crop residues and all the farm wastes within the system and integration of low cost but cost effective technologies. Present chapter include some of the IFS technologies involving conservation of resources and their impact on livelihood of a family.

1. PRESENT FARMING SCENARIO

The small and marginal categories of farmers in general are literally illiterate, financially handicapped (more than 30% are below poverty line), small and scattered land holdings not suited for high-tech agricultural machinery, work in resource poor and risk prone diverse conditions. Further, these farmers most often are laggards and practice whatever their neighbors do and because of wide spread poverty among these categories of farmers, they cannot take much risk to adopt new innovations in the field of agriculture and hence could not achieve advantages of several revolutions (Green, white, blue) took place in the field of agriculture in India. Even after six decades of independence and eleven five year plans completed, the economic conditions of small farm holders is still bad to worst. It is because the efforts made so far were in favour of resource rich and large holding farmers and not planned according to real conditions of these categories of farmers representing 4/5th of the total farm holdings of the country. Small farm holders because of their poor economic conditions and lack of technological know–how do not follow scientific measures of resource conservation. Further, technological innovations are meant only for large resource rich farmers only and there are no any specific implements or farm machineries suited for small pieces of land. Hence, these categories of farmers till depend on traditional farm practices using hand driven tools and involvement of family labour.

2. POSSIBLE RESOURCE CONSERVATION

Increased cost of cultivation, quality deterioration of farm resources and reduced farm profits have been the major concerns of Indian agriculture in recent past. To enhance the farm profit and combat with the problems as above, immediate attention is required for effective check on degradation of soil fertility, adoption of cost effective and energy efficient farm machinery for tillage and crop establishment, efficient resource utilization and allocation of farm land as per need of the family to make the farming more sustainable. Some of the technologies developed and tested in India are described here.

2.1 Organic Carbon Sequestration

The advent of intensive agriculture has led to dramatic losses of organic matter and hence organic carbon from cultivated soils. The lesser addition of organic carbonaceous inputs to soil coupled with oxidative losses associated with tillage (Lal *et al*., 1995) are the major reasons for loss of soil organic carbon. Soil organic matter improves the physical and chemical properties of soil (Kanojia and Kanawjia, 2004). The carbon in soil organic matter supports soil microbes by providing energy for their activities and thus keeps the soil 'live'. Hence organic carbon sequestration a management strategy which ensures the storage of carbon in soil sinks assumes much significance in the present day agricultural scenario. Integrated Farming System (IFS) approach involving diversification in cropping systems as well as farming system as a whole, lesser exposure of soil layers through reduced tillage and recycling of crop residues and farm wastes promote higher organic carbon sequestration than mono cropping. The conventional practices of tillage and residue management accelerate the oxidative losses of soil organic carbon.

2.2 Nutrient Cycling

Nutrient cycling is a complex phenomenon. While considering nutrient cycling and their management in farming system mode requires a clear understanding about the various process of individual nutrient cycling in every component of the farming system. Farm nutrient budget may be calculated for each individual component in a logistic manner. In view of the gravity of the global warming, the carbon budget of the farm is most important. Our strategies should focus on sequestering highest amount of carbon by recycling crop residue, animal waste and other on-farm organic wastes.

In IFS model at Indian Institute of Farming Systems Research (IIFSR), Modipuram, all the farm wastes and crop residues were recycled either *in situ* incorporation in to the soil (green manure crops, cowpea intercropped in sugarcane, cane trash, leaves of potato and redgram , roots of berseem and other leguminous crops and green biomass added after picking of pods etc.) or by composting (Vermicompost, FYM) of cow dung & urine mixed with farm wastes. A detail account of recyclable farm resources and nutrients availability is given in Table 1.

Table 1. Nutrient budgeting under Integrated Farming System at IIFSR, Modipuram

Source of nutrients and % nutrient content (N:P:K) on dry wt. basis	*Nutrient release (kg/ha)*				
	Available quantity at farm (kg)	*N*	*P*	*K*	*Total NPK in the IFS*
Green manure crops					
Sesbania spp. (1.29:0.36:1.64)*	8800	18.9	5.3	24.0	48.2
Cowpea (1.29:0.36:1.64)	8500	18.3	5.1	23.2	46.6
Crop residues (dry wt.)					
Sugarcane leaves (0.4:0.18:1.28)	900	3.6	1.6	11.5	16.7
Pigeonpea leaves (1.29:0.36:1.64)	232	3.0	0.8	3.8	7.6
Potato leaves (0.52:0.21:1.06)	1450	7.5	3.0	15.4	25.9
Cow dung (dry wt.) (0.4:1.2:1.9)	17600	70.4	211.0	334.0	615.4
Total nutrients added in to soil	-	121.7	226.8	411.9	760.4
% of total requirements	-	42.6%	>100%	>100%	
Nutrient requirement/year (field + plantation crops)	-	285.3	116.3	109.9	511.5

**Values in parenthesis are N, P,K content (%)*

 # Nutrients from silt and water of fish pond is not included in the table.

This nutrient budgeting indicate that through recycling of all the available farm resources, plant nutrients equivalent to 121.7 kg N, 226.8 kg P and 411.9 kg K could be added in to the soil. Considering a realizable amount of 30% of the total nutrient incorporated in to soil through recycling, a saving of 228 kg of NPK (44.6% of 511 kg of NPK–annually required for field and plantation crops) was observed. The average annual requirement of NPK, however, was 285.3 kg, 116.3 kg and 109.9 kg, respectively). In addition to this, nutrient rich pond silt and pond water recycled for crop production also add a total amount of 18.56 kg N, 6.21 kg P and 74.24 kg K. The OC content of pond silt was as high as 1.20% with an average value of 0.95%. Addition of pond silt and water was found to increase the yield of rice and wheat by 3.48 q/ha and 2.41 q/ha, respectively. Organic source of nutrients are rather cheap than chemical fertilizers and also help in maintaining soil health and keep environment safe.

2.3 Enhanced Fertilizer use Efficiency

Commercially available fertilizers supply essential elements in a variety of chemical forms, but most are relatively simple inorganic salts. Advantages of commercial fertilizers are their high water solubility, immediate availability to plants, and the accuracy with which specific nutrient amounts can be applied. Because they are relatively homogeneous compounds of fixed and known composition, it is very easy to calculate precise application rates. This is in contrast to organic nutrient sources which have variable composition, variable nutrient availability, and patterns of nutrient release that are greatly affected by temperature, moisture, and other conditions that alter biological activity. However, fertilizer use efficiency has also been in question and is greatly affected by soil conditions, time and rate of application and so many biotic and abiotic factors. The solubility of commercial fertilizers can also be a problem, because soluble nutrients leach when applied in excess or when large rains occur soon after fertilizer application. Increasing soil cation exchange capacity by increasing organic matter reduces the leaching potential of some nutrients. Management practices that synchronize nutrient availability with crop demand and uptake also minimize leaching. Both application timing and the amount of fertilizer are important. Splitting fertilizer applications into several smaller applications rather than a single, large application is especially important on sandy, well-drained soils. Excess nutrient applications can be eliminated or at least significantly reduced by soil testing on a regular basis, setting realistic yield goals and fertilize accordingly, accounting for all nutrient sources such as manure, legumes, and other amendments, and using plant tissue analysis as a monitoring tool for the fertilizer program.

2.4 Use of Cost Effective and Energy Efficient Farm Machinery under IFS

Conservation agriculture technologies are rapidly gaining popularity among farmers as they result in higher production at less cost with significant benefits to the environment and more efficient use of natural resources. The conservation agriculture technologies of zero strip and rotary till drilling, bed planting of rice and wheat saved 64 to 85% resources (time, labour, cost, fuel and energy). The bed planting also saved 39 and 34% irrigation water in rice and wheat, respectively. These technologies provided higher rice and wheat yields (2 to 8%), B: C ratio (9 to 27%) and energy efficiency (21 to 32%) compared to conventional sowing. The continuous use of these technologies has also improved soil health by increasing the soil organic carbon and mean weight diameter of the soil aggregates. This ultimately results in higher profits, cheaper food, and improved farmer livelihoods.

2.5 Precise Allocation of Farm Iand and Other Resources

To meet minimum essential annual requirements of food and fodder of a household with 7 family members and overall improvement in livelihood, it is must to allocate farm land and other resources appropriately. For this, a farmer need 1.33 ha gross cultivated area under irrigated conditions. Under irrigated conditions, more than two crops per year are taken from the same piece of land. Considering an average 250% cropping intensity, the net cultivated area required comes to 5320 sq.m. or say 0.54 ha only. The remaining land area (4600 sq.m.) out of 10000 sq.m. (1.0 ha) is available for diversification of the prevailing on – farm farming systems either with high value crops (sugarcane in this case) or by integrating some additional more paying enterprises (horticultural crops, forestry and/or fishery) to make the system holistic and also more profitable and sustainable too. Vermicompost and boundary plantations are mandatory and most essential for all type of IFS models. Based on the IFS study conducted at Indian Institute of Farming Systems Research, Modipuram, resource allocation for 1.0 ha irrigated land area representing marginal and small farmers both is given in Table 2.

Table 2. Allocation of one hectare irrigated farm land for livelihood improvement

Farm commodities	*Minimum family needs (kg/year)*	*Land allocation for basic food & feed commodities (ha)*	*Distribution of left out land area under high value crops / enterprises (ha)*
Cereals	1550 kg	0.35	-
Oilseeds	130 kg	0.11	-
Pulses	200 kg	0.17	-
Sugarcane	1600 kg	0.03	0.14
Green fodders	40 t	0.67	A part of cropping systems followed
Fruits	200 kg	-	0.20 (Fruit orchard of mango / guava / mandarin var. kinnow / banana / papaya)
Vegetables	900 kg	-	No separate area allocated. Vegetables will be grown as intercrops in fruit orchards and kitchen gardening .
Milk	1120 kg	-	No separate area allocated for green fodders as these are integral part of cropping systems .
Meat / fish etc.	160 kg	-	0.10 (Under fish pond)
Mushroom	-	-	0.01
Apiary	-	-	0.01 (5-10 bee boxes)
Total area	-	Gross area: 1.33 Net area: 0.54	Net area: 0.46

The estimated values of expenditure involved in IFS model developed and outputs in term of gross and net returns is given in Table 3. The analysis envisage the economic viability of the suggested IFS model which not only provide sufficient feed and fodder for the household but after meeting production cost create an additional saving of Rs.75,060/ha/year to assist the family in other liabilities including health and education etc.

Table 3. Estimated values of input and output details of the proposed IFS model

Enterprises	*Size of the unit*	*Gross returns (Rs.)*	*Cost of production (Rs.)*	*Net returns (Rs.)*
Crops including fodders	6800 sq.m.	1,65,345	63,220	1,02,125
Dairy animals + Vermicompost	Two milch animals & their young ones	1,89,360	1,08,310	81,050
Horticulture	2200 sq.m.	94000	54472	39528
Fishery	1000 sq.m.	20,000	5293	14707
Mushroom	500 bags x 4 harvests/year	60,000	20,000	40,000
Apiary	20 bee boxes	42,000	16,000	26,000
Total	1000 sq.m.	5,70,705	2,67,295	3,03,410

Note: The income from farm boundary plantations will be long run additional advantage in subsequent years.

The production and economic values/figures (achievable) included in the table show the economic viability of the IFS approach. However, it takes two to three years to achieve the targeted goals because the project involve enterprises like fruit plantations, boundary plantations etc. which start giving returns from third or more than third year of establishment of the project.

2.6 Conservation of Farm Resources

Under diversified/intensified type of farming, the produce /output of one enterprise works as input for other enterprise/enterprises. Similarly, one or more enterprises supplement and or complement each other during the process of implementation and production. For example: cowdung of animal unit used as input (FYM, vermicompost etc.) in crop production and in turn crop production provide green and dry fodder to the animal unit. Similarly, honey bee collect nectar from the flowers of many crops and in turn help in cross pollination and increased crop yields. A detail account of such supplementary as well as complementary interactions and contribution thereof is summarised in the Table 4 below:

Based on last six years information on various input and output used and or recycled within the system included in the table above and average cost of production at farm, it is visualized that about 58% (Rs.1,15,146) of the total cost of production (Rs.1,97,883) is met on the farm itself which is directly or indirectly a saving in costly inputs which otherwise to be procured from the market. Further, recycling of farm wastes and residues etc. conserve resources and have environmental benefits.

3. MULTIPLE USES OF RESOURCES

Multiple uses of major farm resources including land, water and human is utmost essential to encourage vertical growth in agriculture. For this, diversification of cropping systems/farming systems for maximum utilization of cultivated lands, promoting agro-horti and agro-forestry systems, use of irrigation water for raising multi-storeyed enterprises like rice+fish+poultry/piggery/duckery, use of farm products and by products for raising mushroom, preparation of vermicompost, interaction of bee keeping and flowering crops and efficient use of manpower by engaging in multifarious activities of diversified agriculture in an IFS mode may bring maximum returns per unit time per unit land area.

4. CONCLUSION

Farming system approach is of paramount significance to improve livelihood of small farm holders. An integration of conservation agriculture technologies coupled with Integrated Farming System approach not only increase the efficiencies of available farm resources and save environment from various type of land, water and air pollutions but simultaneously improve livelihood of small

Table 4. Inter-relationship of different enterprises included in the IFS model (Average values of 2004-10)

Intermediate inputs generated at farm	*Quantity (kg or liters)/Nos.)*	*Value(Rs)*	*Farm produces and / or by products of one enterprise used as inputs for other enterprise/enterprises within the system (kg or lit.)/Nos.)*						*Value of the inputs recycled (Rs.)*
			Crops	*Dairy*	*Horti-Culture*	*Fishery*	*Vermi-compost*	*Total*	
A.	Crops								
Cereals (kg)	3280 @Rs.9/kg	29,520	48	900	-	-	-	948	8532
Pulses (kg)	380 @Rs.30/kg	11,400	5	-	-	-	-	5	150
Oilseeds (kg)	180 @ Rs.30/kg	5,400	2	-	-	-	-	2	60
Sugarcane (t)	24.48 @ Rs.1500/t	36,720	3	-	-	-	-	3	4500
Green fodders (t)	61.03 @ Rs.600/t	36,618	-	44	-	0.36	-	44.36	26616
Straw/stalks (t)	9.20 @ Rs.3500/t	32,200	-	8.20	-	-	1.0	9.20	32200
Green manure (t)	17.30 (94.8 kg NPK)	1346	13.00	-	4.00	0.30	-	17.30	1346
Crop residues (t)	2.58 (50.2 kg NPK)	712	2.00	-	-	-	0.58	2.58	712
Weeds (t)	2.10	-	-	2.10		-	-	2.10	-
Total crops (A)	1,53,916	-	-	-	-	-	-	74116	
B.	Horticulture								
Fruits (kg)	1520 @ Rs.15/kg	22,800	-	-	-	-	-	-	-
Vegetables (kg)	3280 @ Rs.8/kg	26,240	-	-	-	-	-	-	-
Green fodders	1000 kg@Rs.1.0/kg	1,000	-	1000	-	-	-	1000	1000
Crop residues (t)	2.10 (40.86 kg NPK)	580	2.00	0.10	-	-	-	2.10	580
Fuel wood (t)	2.50 @ Rs.1500/t	3,750	-	-	-	-	-	-	-
Total horticulture (B)-	54370							1580	
C.	Dairy								
Milk (lit.)	5890 @ Rs.28/lit.	1,64,920	-	-	-	-	-	-	-
Vermicompost (t)	15.00 @ Rs.5000/t	75,000	5.00	-	2.00	0.05	-	7.05	35250
FYM (t)	5.80 @ Rs.250	1,450	5.00	-	0.80	-	-	5.80	1450
Urine (lit.)	14235	N A	-	-	-	4235	10000	14235	-

(Contd.)

Intermediate inputs generated at farm	*Quantity (kg or liters)/Nos.)*	*Value(Rs)*	*Farm produces and / or by products of one enterprise used as inputs for other enterprise/enterprises within the system (kg or lit.)/Nos.)*						*Value of the inputs recycled (Rs.)*
			Crops	*Dairy*	*Horti-Culture*	*Fishery*	*Vermi-compost*	*Total*	
Calves (Nos.)	3 @ Rs.3000/calve	9,000	-	-	-	-	-	-	-
Total dairy (C)	2,50,370	-	-	-	-	-	-	36,700	
D.	Fisheries								
Fish (kg)	261 @ Rs.50/kg	13,050	-	-	-	-	-	-	-
Pond silt (Cu.m.)In term of NPK	120 (18.56 kg N+6.21 kg P+74.24 kg K)	950	120	-	-	-	-	120	950
Pond water(Cu.l.)	2400	N A	1800	-	600	-	-	2400	-
Fodder from pond dykes (t)	2.10 @ Rs.600/t	1,260	-	2.10	-	-	-	2.10	1260
Total Fishery (D)	15,260	-	-	-	-	-	-	2,210	
E. Honey (lit.)	160 @ Rs.150/lit.	24,000	-	-	-	-	-	-	-
F. Green fodder (t)	0.90 @ Rs.600/t	540	-	0.90	-	-	-	0.90	540
G. Fruits (kg)	200@ Rs.15/kg	3,000	-	-	-	-	-	-	-
H. Fuel wood (t)	3.50 @ Rs.1500/t	5,250	-	-	-	-	-	—	-
I.	Boundary Plantations	-	8,790						540
Grand total		5,06,706							1,15,146

farm holders as well. The multiple use of resources under different farm enterprise may further improve the sustainability of farming situation in long run.

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Organic Farming under Conservation Agriculture Perspectives

Kamta Prasad

The environment-friendly concepts of 'Organic Farming' and 'Conservation Agriculture', as such, are not new to Indian agriculture, but they gained prominence only during past two decades or so; when un-sustainability issues crept into major production systems of the country, mainly rice-wheat and rice-rice. It is a well known fact that in Indian context during last half century, modern agriculture technologies have helped miraculously in improving agricultural productivity which has lead to achievement of self-sufficiency in food grains production but at the same time they are leading to degradation of natural resource base, emergence of soil-nutrient disorders, soil and environmental degradation, loss of bio-diversity, development of new biotypes of pathogens and pests, chemical contamination of soil and water bodies and finally to human and animal health hazards. During later part of 1990s, some disturbing reports started appearing in national and international scientific journals, highlighting the onset of second generation problems or ill-effects of high-input, chemical-intensive agricultural production technologies (also known as Green Revolution Technologies) – on system productivity, soil-water environment as well as quality of crop-human-animal food chain. Consequently, an immediate need was felt by all the stakeholders to accelerate the development and adoption of technologies which may help in mitigating these ill effects and make the agricultural production systems ecologically sustainable and economically viable. 'Conservation Agriculture' and 'Organic Farming' were considered to be two of such approaches. Although the ultimate goal of both the approaches is same but scope of organic farming is much broader, and in true sense, conservation agriculture is an intrinsic component of organic farming. This chapter deals with the concepts of conservation agriculture and organic farming, commonalities between the two and need for their integration, in Indian perspective.

1. THE UN-SUSTAINABILITY AND ENVIRONMENTAL ISSUES IN INDIAN AGRICULTURE

In India, the dawn of 'Green Revolution Technologies (GRTs)' – the introduction of high yielding, photo-insensitive, input-responsive dwarf varieties of rice and wheat, adequately supported by development of infrastructure for high input agriculture – during late sixties and early seventies, led to miraculous growth in agricultural production, especially among the major cereal and commercial crops. Within a short span of time, say, less than a decade or so, the agriculture got revolutionized and crop cultivation concepts with respect to tillage, planting time and techniques, fertilizer use, irrigation, pest control and other management practices, changed dramatically. The determined efforts on part of all stakeholders (researchers, policy planners, development agencies and farmers) changed the entire scenario of Indian agriculture leading India to become a 'food-grain basket' from a 'begging bowl'. During later half of the century, the national food grain production registered nearly four times increase from mere 82 m t in 1960-61 to 212 mt in 2001-02. It is noteworthy that during this period, area under food grain crops increased merely from 115.58 m ha to around 122 m ha and the major share of enhanced food production may be ascribed to improvement in crop productivity, which had increased from 710 to 1739 kg/ha.

The miraculous attainment of green revolution not withstanding, the growth in system productivity, so achieved, could be sustained up to late eighties only. But, in subsequent years, signs of system fatigue started appearing and rate of growth showed a plateauing effect, especially in rice-wheat and rice-rice systems. This stagnation in growth had been attributed mainly to wide-spread occurrence of ill-effects of GRTs – popularly also known as 'Second Generation Problems'- in all intensively cultivated irrigated areas. These problems included; soil degradation mainly on account of over-mining of soil nutrients (wide-spread occurrence of multiple nutrient deficiencies), decline in factor productivity, lowering of water table in good quality ground water zones (especially in Trans and Upper Gangetic plain regions of Punjab, Haryana and western Uttar Pradesh) due to indiscriminate overdraft of ground water from good quality aquifers to meet the irrigation needs of intensive cropping systems involving the crops like rice and sugarcane, water quality deterioration in coastal areas, formation of hardpan (especially in rice-wheat system areas), adverse effects on beneficial soil microflora and native bio-diversity, wide-spread problems associated with the toxic residues of agro-chemicals entering into the human and animal food chains and buildup of several biotic stresses such as diseases, insect-pests and weeds.

Nevertheless, under changed scenario of modernization of agriculture and our endeavors to attain self-sufficiency in food production through large inputs of agro-chemicals (synthetic, high analysis fertilizers and pesticides), inevitable dependence on irrigation, and high cropping intensity have lead to chemical contamination of food, pollution of ground water, eutrophication of surface water bodies, degradation of soil and deterioration of air quality. There is increasing damage to the ecological foundations of agriculture, such as land, water, forests, bio-diversity and the atmosphere, and there are distinct possibilities for adverse changes in climate and sea level. In many regions both surface and ground waters are already becoming unfit for human and animal consumption due to high concentrations of arsenic, NO_3^-N and pesticides. Several pesticides have entered into the food chain and have severely endangered human health. Indiscriminate exploitation of agricultural and forestry ecosystems disturbs the ecological balance, disrupts the carbon cycle, depletes soil and biotic-carbon pools, and lead to emission of C (as CO_2 and CH_4) and N (as N_2O and NO_2) into the atmosphere. These gases (CO_2, CH_4 and N_2O), being relatively active (green house gases), are contributing to adversely influence the global climate.

2. CURRENT FOOD PRODUCTION SCENARIO

Currently, Indian agriculture is passing through a very critical phase. On one hand, it has onus of providing national as well as household food and nutritional security to its teeming millions in a scenario of plateauing of genetic potential in all major crops and little improvement in productivity of vast tracts of rainfed/dryland areas – constituting approximately 44.2% of net cultivated area. A mismatch between the national food-grain production and requirement has already crept into the system, which is further widening. The present population of the country for the year 2015 is estimated to be 1292 million, and with present growth rate of 1.2% is projected to reach at 1530 million by 2030 as compared to 1028 million during 2001. Although, during the last quarter of the 20th century the green revolution solved the problems of food, and we started talking of food self-sufficiency, but in true sense, we are yet to achieve it. Even today, the current food grain production is estimated to be about 256 million tons (mean for 2013-14, 2014-15 and 2015-16), but more than 269 million people, living below the poverty line, are unable to buy enough food. At present level of food availability, projections for the year 2030 have been made at 289 million tons. However, if we assume that with increasing income levels, requirement is enhanced by only 10% to eradicate malnutrition in lower strata of the society, this demand will increase up to 318 m t. That means, on one hand country has to strive hard for improving its food production, mainly through enhanced yields per unit area, without further deterioration of land and water resources. But, on the other hand, wide-spread ill-effects of indiscriminate uses of agro-chemicals and over-exploitation of natural resources in all intensively cultivated irrigated areas – a backbone to national food security – are threatening the very sustainability of the agricultural production system. Moreover, a large chunk of productive agricultural land, is being diverted to non-agricultural purposes every year, which is adding to the greater emphasis on enhanced productivity per unit of land area. This situation is further complicated as nation has to share local as well as global responsibility to ensure environmental safety for human kind.

3. CONCEPT OF "CONSERVATION AGRICULTURE"

Conservation Agriculture (CA) has globally come to be referred as a set of practices that contribute to sustained productivity enhancement while conserving resources and arresting the resource degradation process. As the definition suggests, 'conservation agriculture' aims primarily to attain higher crop yields on sustainable basis, while conserving the natural resources. Globally, CA has been around as a cohesive agricultural practice for decades. Farmers have been practicing it around the world, but in India it's only now that it started to get a lot of attention as an eco-friendly approach of agriculture. Practices and technologies, used in conservation agriculture, have a foundation in well researched and sound scientific principles. They are reflected among others through:

- Minimum soil disturbance through practices such as no-tillage or zero-tillage.
- Keeping the soil covered through crop residues and other management options.
- Adopting crop sequences in a spatial (intercropping, agro-forestry) and temporal (rotations) sequencing.
- Precise placement of in-field traffic.

Based on past knowledge we may highlight that practices based on principles of CA, when adopted in an integrated manner, offer multiple benefits that include:

- Reduced cultivation costs, primarily on account of savings in fuel, energy and labor costs
- Help improve resource base quality (soil, water, biodiversity)
- Enhance productivity and use-efficiency of external inputs through improved functioning of natural processes of regulation, transformations and cycling
- Bring about reversal in processes that cause resource degradation by way of nutrient depletion, soil erosion, carbon depletion
- Constitute a practical adaptive strategy to build resilience of frail production systems to climate change variations
- Change and contribute to mitigation through carbon sequestration and reduced GH gas emissions

4. CONCEPT OF "ORGANIC AGRICULTURE"

Broadly speaking, organic agriculture is a production system which avoids, or largely excludes, the use of synthetic compounded fertilizers, pesticides, growth regulators and livestock feed additives. To the maximum extent possible, organic farming systems rely on natural systems such as crop rotations, crop residues, animal manures, legumes, green manures, off-farm organic wastes and aspects of biological pest control to maintain soil productivity and to manage insects, weeds and other pests.

In its simplistic form organic agriculture may be defined as "a kind of diversified agriculture wherein crops and livestock are managed through use of integrated technologies with preference to inputs/ resources available either at farm or locally. It emphasizes more on optimising the yield potential of crops and livestock under given set of farming conditions rather than maximization". The World Board of International Federation of Organic Agriculture Movements (IFOAM) has approved the following definition in March 2008:

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

4.1 Aims of Organic Farming

Organic farming tries to bridge the widening gap between man and nature with the following broader aims. However, the relative importance, for an individual or a community of farmers, may vary.

4.1.1 Sustainability of Natural Resources

Organic agriculture is a holistic way of farming and besides production of goods of high quality; it primarily aims at conservation of the natural resources (soil, water, climate, biodiversity and non-renewable energy) for sustainable productivity in agriculture. In context of organic farming, the term 'sustainability' is used in a wider sense, to encompass not just conservation of non-renewable resources (soil, water, minerals, energy, biodiversity), but also issues of environmental and social sustainability. The very basic approach to organic farming envisages to:

- improve and maintain the natural landscape and agro-ecosystem,
- avoid over-exploitation and pollution of natural resources,
- minimize consumption of non-renewable energy sources,
- exploit synergies that exist in natural ecosystems,
- maintain and improve soil health by stimulating activity of soil organisms with organic manures and avoid harming them with pesticides,
- obtain optimum economic returns, within a safe, secure and healthy working environment, and
- acknowledge the virtues of indigenous knowledge and traditional farming systems (ITKs).

4.1.2 Minimizing Cost of Cultivation

Organic farming is one of the environment-friendly approaches of reducing dependency on external inputs and achieving the optimum productivity by making the best use of ecological principles and processes, leading to reduced costs of cultivation. This is very important for resource poor farmers, especially for those who are operating in high risk-prone areas of dryland and rainfed agriculture.

4.1.3 Healthy Food

Healthy food means a food which is free from harmful chemicals and heavy elements, tasteful and nutritious. Nevertheless, the organic agriculture practices cannot ensure that products are 'completely free' of harmful residues, as they may possibly trespass into the organic production systems through general environmental pollution also, but this is one of the major aims of organic farming and all feasible methods are used to minimize pollution of not only farm products but also of surrounding environment, including air, soil and water.

4.1.4 Augmentation of Profits

Organically produced foods have a great demand in export markets, especially those of European and North American countries and they fetch a sizeable premium, as compared to conventionally grown farm products. In domestic sector also demand for organic food is increasing tremendously, especially among mid and high income segment, which has become more cautious about harmful effects food grown with use of pesticides and synthetic fertilizers, and potential hazards of environmental pollution caused due to modern practices in agriculture.

4.1.5 Improving Soil health

As such, the objective of soil health and production sustainability lies at the heart of organic farming and is one of the major considerations determining its acceptability. In organic production systems, soil health is maintained and improved through stimulation of activity of soil organisms with organic manures and by avoiding harming them with the use of synthetic pesticides as well as fertilizers. The some of the important features of organic farming in context of soil health and environment protection are listed below.

- Organically managed soils have a high potential to counter soil degradation, erosion and desertification, as they are more resilient both to water stress and to nutrient loss.
- Organic farming protects the long-term fertility of soils by maintaining organic matter levels, fostering soil biological activity, giving due importance to the basic principles of crop rotation and intercropping, and providing crop nutrients indirectly by using sources which are not readily soluble.
- In organic farming the supply of the nutrients is more balanced, which helps to keep plants healthy and soil biological activity is enhanced, which improves nutrient mobilization from organic matter and native soil reserves and minimizes the losses of nutrients, thus protecting the environment.

- Microorganisms have a good feeding base and create a stable soil structure.
- Inclusion of legumes/ cover crops, mulching, intercropping and agro-forestry play an important role in protection against soil erosion and degradation.
- Organic agriculture technologies increase the organic matter content of the soil, which has a positive effect on soil aggregation and water-holding capacity.
- Animal manure, green manure and composts favour the composition processes and can replenish nutrients required by crops and supply the soil with essential organic matter.
- Legume crops are a highly valuable source of nitrogen. Closed nutrient cycles and efficient use of local resources – for example compost, dung or seeds – are especially important for subsistence farmers depending on few and limited assets.
- Water retention capacity of soil is increased due to their higher level of organic matter content and permanent soil cover. Due to the resulting higher moisture retention capacity, the amount of water needed for irrigation is reduced.
- Organic agriculture helps mitigate climate change, because it reduces emission of greenhouse gases, especially nitrous oxide, as no chemical nitrogen fertilizers are used and nutrient losses are minimized.
- Minimizes energy consumption by 30.70% per unit of land by eliminating the energy required to manufacture synthetic fertilizers and pesticides, and by using internal farm inputs, thus reducing fuel used for transportation.
- Organic agriculture helps farmers adopt to climate change because it prevents nutrient and water loss through high organic matter content and soil covers, thus making soils more resilient to droughts and land degradation processes.
- Preserves seed and crop diversity, which promotes natural cycles in the production systems. Maintenance of diversity also helps farmers evolve contingent cropping systems to adapt to climatic changes.
- Organic agriculture encourages natural habitats of agriculturally beneficial flora and fauna and forbids the clearances of primary ecosystems.

Thus, organic farming systems offer some solutions to the problems arising from modern agricultural technologies, which aim at maximization of productivity per unit area per unit time and promote the cultivation of high yielding varieties/ hybrids/ genetically modified plants with intensive use of fossil-fuel-based energy, synthetic chemical fertilizers, pesticides and irrigation water. According to Scialabba (2007) the strongest benefits of organic agriculture are its reliance on fossil fuel independent, locally available resources that incur minimal agro-ecological stresses and are cost-effective. She describes organic agriculture as 'neo-traditional food system', which combines modern science as well as indigenous knowledge.

5. ORGANIC AGRICULTURE *VIS-À-VIS* CONSERVATION AGRICULTURE

A critical appraisal would reveal that both the approaches, conservation agriculture as well as organic farming, strive to achieve balance between people and the land so that the land can continue to meet peoples' needs, perhaps indefinitely. But they go about achieving this goal in different ways. However, the debate between conservation agriculture and organic farming has to do more with their practices rather than their overall ideology, as both the approaches try to maintain a balance between agriculture and resources in their own way. In conservation as well as organic farming we rotate crops in order to keep the land fertile, plant cover crops to retain water, and replenish soil's organic matter to cultivate pest-resistance and high nutrient value. Coming to its most basic, there is one primary difference between organic and conservation agriculture approaches, that is, by adoption of conservation agriculture we follow the practices which help in saving of natural resources in quantitative terms only, whereas in organic farming our aim is not only to save natural resources in quantitative terms but also improve upon their quality, while producing healthy (devoid of harmful chemicals) food in a healthy environment. Nevertheless, objectives of conservation agriculture are taken care of, by design, under organic farming, but reverse is not true. Thus, it may be inferred that both the approaches have their own merits and any of them may be adopted depending upon the overall goal and objectves.

6. CURRENT STATUS OF ORGANIC FARMING IN INDIA

India has traditionally been a country of organic agriculture, but the growth of modern scientific, input intensive agriculture has pushed it to the wall. However, with the increasing awareness about the safety and quality of foods, long term sustainability of the system and accumulating evidences of being equally productive, the organic farming has emerged as an alternative system of farming which not only addresses the quality and sustainability concerns, but also ensures a profitable livelihood option. Emerging from 42,000 ha under certified organic farming during 2003–04, the organic agriculture has grown many folds during the last decade. By March 2014 India, has brought more than 4.72 million ha area under organic certification process. Out of this cultivated area accounts for 0.60 million ha while remaining 4.12 million ha is wild forest harvest collection area (FiBL-IFOAM, 2015).

Worldwide certified organic agriculture is practiced on nearly 43.1 m ha land, spread over 170 countries, constituting 1% of the total agricultural land of the countries under study (FiBL-IFOAM, 2015). The regions with the largest areas of organic agricultural land are Oceania (17.3 m ha) and Europe (11.5 m ha). Latin America has 6.6 m ha followed by Asia (3.4 m ha), North America (3 m ha) and Africa (1.2 m ha). Among countries, the top three countries with largest area under organic agriculture are; Australia (17.2 m ha), Argentina (3.2 m ha), and United States of America (2.2 m ha). In addition to cultivated agricultural land, there are non- agricultural land organic areas, mainly under aquaculture, forests, and grazing, which constitute more than 35 m ha, making the total area under organic 78 m ha (agricultural and non-agricultural areas).

As per the available statistics the total area under organic certification was 5.71 m ha during 2015-16. This included 26% cultivated area (1.49 m ha) and rest 74% (4.22 m ha) forest and wild area for collection of minor forest products. During 2015-16, India produced around 1.35 m t of certified organic products which include all varieties of food products namely; sugarcane, oil seeds, cereals, millets, minor millets, cotton, pulses, medicinal plants, tea, fruits, spices, dry fruits, vegetables, coffee etc. The production is not limited to the edible products but it also produces organic cotton fibre, functional food products *etc*. Among all the states, Madhya Pradesh has covered largest area under organic certification followed by Himachal Pradesh and Rajasthan. The total volume of organic exports during 2015-16 was 263687 tons. The organic food export realization was around 298 million USD. 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. Since 2004, many states embraced organic farming and drafted policies. So far 11 states, namely Andhra Pradesh, Karnataka, Kerala, Uttarakhand, Maharashtra, Madhya Pradesh, Tamil Nadu, Himachal Pradesh, Sikkim, Nagaland and Mizoram have drafted the organic agriculture promotion policies. Sikkim has taken up the task of converting the entire state into organic by 2015 and has already brought more than 65,000 ha are under organic certification process.

7. APPROACHES AND PRACTICES FOR ORGANIC FARMING

While going for organic production it should be kept in mind that organic management is an integrated approach and manipulation and adoption of one or few steps may not yield significant results. For optimization of productivity all the essential components need to be developed in a systematic manner. In the most parts of our country, poor soil health due to loss of organic matter and soil microbial load, is a major problem. Declining irrigation water availability and increasing temperature is further adding to the problems. Too much dependence on market for supply of inputs and energy has made the agriculture a cost-intensive enterprise with diminishing returns. Therefore, we need to address all these concerns and develop a system which is not only productive and low cost but also resource conserving and sustainable for centuries to come. To start with, following issues need to be addressed:

7.1 Integration of Farm

Develop an integrated farming system, having components of cattle, field crops and horticulture (fruits/ vegetables) to ensure better farm-waste/ nutrients/ water recycling, maximizing the profits and minimizing the economical risks

7.2 Enrichment of Soil

- Stay away from use of agro-chemicals (fertilizers/ pesticides/ growth regulators *etc*.). Use only organic manures and bio-fertilizers.
- Adopt close nutrient cycles by enhanced use of farm residues/ waste as mulch/ organic manure and planting of deep rooted trees/ bushes on bunds all around the field.
- Adopt multiple cropping (crop rotations/ intercropping) based on scientific principles.
- Avoid excessive tilling and keep soil covered with green cover or biological mulch.

7.3 Conservation of Soil and Rain Water

- Dig percolation tanks.
- Maintain contour bunds and adopt contour row cultivation on a sloppy land.
- Dig farm ponds and maintain low height plantation on dykes.

7.4 Harvesting of Solar Energy

- Maintain green stand for maximum duration of the year through combination of different crops and plantation schedules.
- Adopt summer ploughing as component of integrated pest management strategy.

7.5 Self-reliance in Inputs

- Develop your own mechanism for on-farm production of seeds, manures (compost, vermi-compost, vermi-wash, liquid manures etc.), panchgavya, bio-pesticides (cow urine, botanical extracts etc.) and other inputs.

7.6 Maintenance of life Forms

- Develop natural habitat for proliferation and sustenance of all useful life forms, including birds, insects, and soil microbes by creation of enough bio-diversity.
- Never use synthetic pesticides.

7.7 Use of Renewable Energy

- Maximize use of solar energy, bio-gas and bullock driven farm machines.

8. DEVELOPMENT OF FARM FACILITIES AND HABITAT

8.1 Infrastructure

- Reserve 3–5% of farm space for utilities, such as space for cattle, vermi-compost unit, compost pits, vermi-wash, bio gas, liquid manure unit *etc*.
- Plant 5–7 multi-purpose trees, such as neem, karanj, subabool, *etc*. on this space, as all utility infrastructure needs shade.
- Irrigation well, water pumping infrastructure etc can also be in this utility area.
- Dig some percolation tanks of any size (depending upon the rainfall and run-off pattern) for rain-water conservation at appropriate places depending on slope and water flow.
- If possible develop a farm pond of suitable size (preferably 20 m × 10 m size for 2.0 ha farm.
- Keep few 200-litre HDPE tanks (1/acre) for liquid manure preparation and few containers for botanicals.
- For 2.0 ha farm, develop 1–2 vermi-compost beds, 1 NADEP tank, 2 biodynamic compost beds, 2–3 vermi-wash units, 5 liquid manure tanks, 5 cow pat pits and 1 underground cattle-urine collection tank.
- Efforts should also be made to produce sufficient quantities of BD-500 (cow horn manure) and BD-501(cow horn silica). 10–12 horn products are sufficient for 2.0 ha farm.

8.2 Habitat and Biodiversity

Management of an appropriate habitat for sustenance of different life forms is an essential component of organic farming. This can be achieved by ensuring crop diversity and by maintaining a wide variety of trees and bushes as per climatic suitability. These trees and bushes will not only ensure the nutrients from air and deep soil layers to surface layer but also attract the birds and other predators, friendly insects and also provide the food and shelter. There may be some loss of productivity due to shading effect but that loss can be compensated with reduced pest problems and natural biological pest control system. As far as these trees should be multi-purpose. Some examples of such trees are; neem (*Azadirachta indica*), karanj (*Millettia pinnata*), tamarind (*Tamarindus indica*), subabool (*Leucena leucocephala*), gular (*Ficus glumerata*), ber (*Ziziphus* spp.), bael (*Aegle marmelos*), aonla (*Emblica officinalis*), drumstick (*Moringa oleifera*) *etc*.

8.3 Conversion of Soil to Organic

In organic farming systems there is no place for chemicals and we have to switch over to low-cost alternatives. Initially inclusion of legumes for grain/ pod/ fodder/ green manure in the cropping system, integrated use of different organic sources of nutrients (FYM/ compost/ vermi-compost/ enriched compost/ non-edible oil cakes, liquid manure etc.), bio-fertilizers, consortia of beneficial microorganisms *etc.* is suggested.

8.4 Multiple Cropping and Crop Rotation

Multiple cropping is the outstanding feature of organic farming in which variety of crops are grown simultaneously or at different time on the same land. In every season care should be taken to maintain legume to be at least 40 percent. The legumes fix atmospheric nitrogen and make it available for use of companion or succeeding crops. Each field/ plot should have at least 2-4 types of crops in a year, out of which one should preferably be a legume. Crop rotation is the backbone of organic farming practices and should be followed religiously to keep the soil healthy and to allow the natural microbial systems working.

9. OTHER FORMS OF ORGANIC MANAGEMENT

9.1 Biodynamic Agriculture

Biodynamic agriculture is a method of farming that aims to treat the farm as a living system, which interacts with the environment to build up a healthy and living soil and to produce food that nourishes and vitalizes and helps develop mankind. The underlying principle of biodynamic agriculture is making life-giving compost out of dead material. The methods are derived from the teachings of Rudolf Stainer and subsequent practitioners. The important components of biodynamic farming are as follows:

- Turning in plant materials such as green crops and straw,
- Not using chemical fertilizers and pesticides.
- Avoiding soil compaction by machinery or animals, particularly in wet weather.
- Keeping soil covered with grass, crops or mulch.
- Not destroying the soil structure by poor farming practices such as excessive use of rotary hoe or cultivation in unsuitable weather (too wet or too dry).
- Mandatory use of biodynamic preparations BD-500 and BD-501.
- Compost/ liquid manure/ cow pat pit manure made with biodynamic preparations BD-502/503/504/505/506/507.

These biodynamic preparations named BD-500 to BD-507 are not food for the plants, but they facilitate the effective functioning of ethereal forces. They are also not the usual compost starters, but can stimulate compost organisms in various ways. In short, they are biologically active dynamic preparations which help in harvesting the potential of astral and ethereal powers for the benefit of the soil and various biological cycles in the soil. So far nine biodynamic preparations have been developed, named as formulation 500 to 508. Out of these, formulation-

500 (cow horn compost) and formulation-501 (horn-silica) are very popular and are being used by large number of organic farmers. Formulations-502 to 507 are compost enrichers and promoters, while formulation-508 is of prophylactic nature and helps in control of fungal diseases.

9.2 Rishi Krishi

Based on principles of ancient Holy Scriptures – the Vedas, the Rishi Krishi method of natural farming has been mastered by Indian farmers of Maharashtra and Madhya Pradesh. In this method, all on-farm sources of nutrients, including composts, cattle dung manure, green leaf manure and crop biomass for mulching are exploited to their best potential with continuous soil enrichment through the use of Rishi Krishi formulation known as 'Amrit pani' and virgin soil. Amrit pani is prepared by mixing 250 g ghee into 10 kg cow dung and 500 g honey and diluted with 200 litres of water. This formulation is utilized for seed treatment (Beej Sanskar), enrichment of soil (Bhumi Sanskar) and foliar spray on plants (Padap Sanskar). For soil treatment (Bhumi Sanskar), 15 kg of virgin rhizospheric soil – collected from beneath a banyan tree (*Ficus bengalensis*) – is spread over 0.4 ha land and then the soil is enriched with 200 litres of Amrit pani.

9.3 Panchgavya Krishi

Panchgavya is a special bio-enhancer prepared from five products obtained from cow–dung, urine, milk, curd and ghee. Panchgavya contains many useful microorganisms such as fungi, bacteria, actinomycetes and various micronutrients. The formulation acts as tonic to enrich the soil and induce plant vigour with quality production.

9.4 Natural Farming

Natural farming emphasizes on efficient use of on-farm biological resources and enrichment of soil with the use of Jivamruta to ensure high soil biological activity. Use of Bijamruta for seed/ planting material treatment and Jivamruta for soil treatment and foliar spray are important components. Jivamruta has been found to be rich in various beneficial microorganisms. A quantity of 200 litres jivamruta is needed for a single application in 0.4 ha. It can be applied through irrigation water by flow, by drip or sprinkler or even by drenching of mulches spread over the field or under the tree basin.

9.5 Natueco Farming

The Natueco farming system follows the principles of eco-system networking of nature. It is beyond the broader concepts of organic or natural farming in both philosophy and practice. It offers an alternative to the commercial and heavily chemical techniques of modern farming. Instead, the emphasis is on the simple harvest of sunlight through the critical application of scientific examination, experiments, and methods that are rooted in the neighborhood resources. It depends on developing a thorough understanding of plant physiology, geometry of growth, fertility, and biochemistry. Natueco farming emphasizes 'Neighborhood Resource Enrichment' by 'Additive Regeneration' rather than through dependence on external, commercial inputs. Three relevant aspects of Natueco farming are:

- Soil - Enrichment of soil by recycling of the biomass by establishing a proper energy chain.
- Roots - Development and maintenance of white feeder root zones for efficient absorption of nutrients.
- Canopy - Harvesting the sun through proper canopy management for efficient photosynthesis.

In all biological processes, energy input is required and solar energy is the only available resource. No time and no square foot of sun energy should be lost by not harvesting it biologically. Lost sun energy is lost opportunity. Photosynthesis is the main process by which solar energy is absorbed. It is of course the objective to obtain a higher degree of photosynthesis. Although genetically photosynthesis efficiency is around 1.5% to 2.5%, we can increase leaf-index [area of leaf for every square meter of land] by caring for healthy canopies, use of multiple canopy utilizing direct and filtered sunrays.

9.6 Homa Farming

Homa farming also has its origin in Vedas and is based on the principle that "you heal the atmosphere and the healed atmosphere will heal you" The practitioners and propagators of homa farming call it a 'revealed science'. It is an entirely spiritual practice that dates back from the Vedic period. The basic aspect of homa farming is the chanting of Sanskrit mantras (Agnihotra puja) at specific times in the day before a holy fire. The timing is extremely important. While there is no specific agricultural practice associated with homa farming, the farm and household it is practiced in, is energized and 'awakened'. The ash that results from the puja is used to energize composts, plants, animals, etc. Homa organic farming is holistic healing for agriculture and can be used in conjunction with any good organic farming system. It is obviously extremely inexpensive and simple to undertake but requires discipline and regularity. Agnihotra is the basic Homa fire technique, based on the bio-rhythm of sunrise and sunset, and can be found in the ancient sciences of the Vedas. Agnihotra has been simplified and adapted to modern times, so anybody can perform it. During Agnihotra, dried cowdung, ghee (clarified butter) and brown rice are burnt in an inverted, pyramid-shaped copper vessel, along with which a special mantra (word-tone combination) is sung. It is widely believed that through burning organic substances in a pyramid-formed copper vessel, valuable purifying and harmonizing energies arise. These are directed into the atmosphere and are also contained in the remaining ash. This highly energized ash can successfully be used as organic fertilizer in organic farming.

10. EFFECTIVE MICROORGANISMS TECHNOLOGY

Effective microorganisms (EM) is a consortium culture of different effective microbes commonly occurring in nature. Most important among them are: N2-fixers, P-solubilizers, photosynthetic microorganisms, lactic acid bacteria, yeasts, plant growth promoting rhizobacteria and various fungi and actinomycetes. In this consortium, each microorganism has its own beneficial role in nutrient cycling, plant protection and soil health and fertility enrichment.

11. CERTIFICATION, LABELING AND ACCREDITATION PROCEDURES

Certification is a process for producers of organic food and other organic agricultural products. In general, any business directly involved in food production can be certified, including seed suppliers, farmers, food processors, retailers and restaurants. Requirement varies from country to country, and generally involves a set of "Standards" for growing, storage, processing, packaging and shipping that include:

- Avoidance of synthetic chemical inputs (e.g. fertilizer, pesticides, antibiotics, food additives, etc.) and genetically modified organisms;
- Use of farmland that has been free from chemicals for a number of years (often, 3 or more);
- Keeping detailed written production and sales records (audit trail);
- Maintaining strict physical separation of organic products from non-organic products;
- Undergoing periodic on-site inspections.

11.1 Purpose of Organic Certification

Organic certification addresses a growing worldwide demand for organic food. It is intended to assure quality and prevent fraud. For organic producers, certification identifies suppliers of products approved for use in certified operations. For consumers, 'certified organic' serves as a product assurance, similar to 'low fat', '100% whole wheat', or 'no artificial preservatives'. Certification is essentially aimed at regulating and facilitating the sale of organic products to consumers. Individual certification bodies have their own service marks,which can act as branding to consumers. Most certification bodies operate organic standards that meet the National government's minimum requirements.

11.2 The Certification Process

In order to certify a farm, the farmer is typically required to engage in a number of new activities, in addition to normal farming operations:

- Study the organic standards, which cover in specific detail what is and is not allowed for every aspect of farming, including storage, transport and sale.

- Compliance - farm facilities and production methods must comply with the standards, which may involve modifying facilities, sourcing and changing suppliers, etc.
- Documentation - extensive paperwork is required, detailed farm history and current set-up, and usually including results of soil and water tests.
- Planning - a written annual production plan must be submitted, detailing everything from seed to sale: seed sources, field and crop locations, fertilization and pest-control activities, harvest methods, storage locations, etc.
- Inspection - annual on-farm inspections are required, with a physical tour, examination of records, and an oral interview.
- Fee – Fee is to be paid by the grower to the certification body for annual surveillance and for facilitating a mark which is acceptable in the market as symbol of quality.
- Record-keeping - written, day-to-day farming and marketing records, covering all activities, must be available for inspection at any time.
- In addition, short-notice or surprise inspections can be made, and specific tests (e.g. soil, water, plant tissue analysis) may be requested. For first-time farm certification, the soil must meet basic requirements of being free from use of prohibited substances (synthetic chemicals, etc) for a number of years. A conventional farm must adhere to organic standards for this period, often, 3 years. This is known as being in transition. Transitional crops are not considered fully organic. A farm already growing without chemicals may be certified without this delay.
- Certification for operations other than farms is similar. The focus is on ingredients and other inputs, and processing and handling conditions. A transport company would be required to detail the use and maintenance of its vehicles, storage facilities, containers, and so forth. A restaurant would have its premises inspected and its suppliers verified as certified organic.

11.3 National Standards for Organic Production in India

National Standards for Organic Production (NSOP) are grouped under six categories, namely; (i) Conversion, (ii) Crop production, (iii) Animal husbandry, (iv) Food processing and handling, (v) Labeling, and (vi) Storage and transport. Standard requirements for crop production, food processing and handling are listed below:

11.3.1 Conversion Requirements

The time between the start of organic management and cultivation of crops or animal husbandry is known as the conversion period. All standard requirements should be met during conversion period. Full conversion period is not required where organic farming practices are already in use.

11.3.2 Crop Production

- *Choice of crops* and *varieties*: All seeds and planting materials should be certified organic. If certified organic seed or planting material is not available then chemically untreated conventional material can be used. Uses of genetically engineered seeds, pollen, transgenic plants are not allowed.
- *Duration of conversion period*: The minimum conversion period for plant products, produced annually is 12 months prior to the start of the production cycle. For perennial plants (excluding pastures and meadows) the conversion period is 18 months from the date of starting organic management. Depending on the past use of the land and ecological situations, the certification agency can extend or reduce the minimum conversion period.
- *Fertilization policy*: Biodegradable material of plant or animal origin produced on organic farms should form the basis of the fertilization policy. Fertilization management should minimize nutrient losses, avoid accumulation of heavy metals and maintain the soil pH. Emphasis should be given to generate and use own onfarm organic fertilizers. Brought in Fertilizers of biological origin should be supplementary and not a replacement. Overmanuring should be avoided. Manures containing human excreta should not be used on vegetation for human consumption.
- *Pest disease and weed management including growth regulators*: Weeds, pests and diseases should be controlled preferably by preventive cultural techniques. Botanical pesticides prepared at farm from local plants, animals and microorganisms are allowed. Use of synthetic chemicals such as fungicides, insecticides, herbicides, synthetic growth-regulators and dyes are prohibited. Use of genetically engineered organisms or products is prohibited.
- *Soil and water conservation*: Soil and water resources should be handled in a sustainable manner to avoid erosion, salination, excessive and improper use of water and the pollution of surface and groundwater. Cleaning of land by burning (e.g. slash and burn and straw burning) should be restricted. Clearing of primary forest for agriculture (jhum or shifting cultivation) is strictly prohibited.
- *Collection of non-cultivated material of plant origin and honey*: Wild-harvested products shall only be certified organic, if derived from a stable and sustainable growth environment and the harvesting shall not exceed the sustainable yield of the ecosystem and should not threaten the existence of plant or animal species. The collection area should not be exposed to prohibited substances and should be at an appropriate distance from conventional farming, human habitation, and places of pollution and contamination.

11.3.3 Food Processing and Handling

- *General principles*: Organic products shall be protected from co-mingling with non-organic products, and shall be adequately identified through the whole process. Certification programme shall regulate the means and measures to be allowed or recommended for decontamination, clearing or disinfection of all facilities where organic products are kept, handled, processed or stored. Besides storage at ambient temperature, the following special conditions of storage are permitted.
- *Pest and disease control*: For pest management and control following measures shall be used in order of priority Preventive methods such as disruption, and elimination of habitat and access to facilities. Other methods of pest control are: Mechanical, physical and biological methods Permitted pesticidal substances as per the standards and Other substances used in traps. Irradiation is prohibited. Direct or indirect contact between organic products and prohibited substances (such as pesticides) should not be there.
- *Packaging*: Material used for packaging shall be ecofriendly. Unnecessary packaging materials should be avoided. Recycling and reusable systems should be used. Packaging material should be biodegradable. Material used for packaging shall not contaminate the food.
- *Labeling*: When the full standard requirements are met, the product can be sold as 'Organic'. On proper certification by certification agency 'India Organic' logo can also be used on the product.
- *Storage and transport*: Products integrity should be maintained during storage and transportation of organic products. Organic products must be protected from co-mingling with non-organic products and must be protected all times from contact with the materials and substances not permitted for use in organic farming.

12. SCOPE AND POTENTIAL FOR ORGANIC FARMING IN INDIA

The world demand for organic products is growing rapidly in developed countries like Europe, the USA, Japan and Australia. The current estimated share of organic foods in these countries is approximately 1 to 1.5%. Worldwide, food trends are changing with a marked health orientation. Since organic foods are free from chemical contaminants, the demand for these products is steadily increasing. Organic agricultural export market is one of the major drivers of organic agriculture in India. India exports 31 organic products. It is estimated that more than 85% of total organic production, excluding wild herbs from Uttar Pradesh and Madhya Pradesh, is exported. India is best known as an exporter of organic tea and also has great export potential for many other products. Other organic products for which India has a niche market are spices and fruits. There is also good response for organic rice, vegetable, coffee, cashew, oilseed, wheat and pulses. Among the fruit crops, bananas, mangos and oranges are the most preferred organic products. The domestic market is nascent but has huge growth potential. The organic food industry has been growing remarkably for the past several years. Against the 2–3% growth in the conventional food industry, the organic food industry has been experiencing an annual growth between 17% and 22% over the past several years. The major markets for organic food products are in the United States, the European Union (Germany, France, Italy, Belgium and the United Kingdom), and Japan. The burgeoning European and US organic markets provide enormous scope for Indian exporters. The US retail sale for organic product has grown 20–24%/year for the past 12 years and the same growth trends are expected to continue for future. Europe is the second largest market of organic produces in the world and consumes around half of the world organic produce. Japan is the largest organic food market in Asia. Though the organic food market is not more than 0.5% of total food market of Japan but according to the Japanese Integrated Market Institute, import of organic products is likely to grow by 40%. Other global markets for organic products are Saudi Arabia, UAE and South Africa.

During past few years, there has been a consistent demand for organic products. In fact, our policy planners, farmers as well as many of our scientists are fully convinced with the advantages, scope and a vast potential for organic farming in India but ever-increasing requirements of foodgrains as well as other commodities to meet out the essential needs of teeming millions has become one of the major impediments in the development of organic farming. However, there should not be any doubt about the fact that India is bestowed with lot of potential for conversion to organic production due to prevalence of 'crops + livestock' integrated farming systems, high biodiversity on account of diverse agro-climatic situations and multiplicity of small and marginal farmers. Inherited tradition of low input agriculture on a very large part of the country, particularly in hills, drylands and other rainfed ecosystems, is an added advantage and holds promise for the farmers of these areas to convert to organic production and tap the market which is growing steadily in the domestic as well as overseas sectors.

13. LIMITATIONS AND FUTURE STRATEGIES

Despite of great potential and opportunity, growth of organic farming in the country is not up to the desired level and some of the probable reasons for this are:

- Lack of awareness among farmers as well as consumers about ecological and health benefits of organic farming.
- Governance of commercial interests (agri-export agencies, private certification agencies etc.), rather than public interests in whole affair of organic agriculture.

- Inadequate research and extension backstopping from different governments, in order to improve region-specific farming techniques and disseminating available knowledge for conversion and management of organic farms in integrated farming system mode. Dr M.S. Swaminathan while drafting National Policy for Farmers 2007, has very well documented this fact. It envisages that organic farming movement in India suffers from a lack of adequate institutional support in the areas of research, extension, certification and marketing and it requires more scientific support than chemical farming.
- Perceived high costs of organic farming among farmers, which is mainly due to incomplete knowledge about principles and practices of organic agriculture among farmers. Farmers often seek for off-farm inputs, leading to escalation in production costs, which is against the basic philosophy of organic agriculture. Moreover, very high government subsidies on chemical fertilizers in conventional agriculture are not taken into account while comparing the production costs.
- Non-availability of adequate quantities of organic manures and other organic inputs in the local market from reliable sources. Farmers are, more often than not, forced to recycle major quantities of crop residues as animal fodder and animal dung as source of household energy. Sizable quantities of crop residues are also sold off to paper and cardboard industry to earn cash for household needs.
- Complex and costly procedures of certification.
- The risks involved in marketing of organic produce as demands as well as premium rates for organic produce are not available in domestic markets and organic growers remain dependent primarily on certified processors and exporters.

To overcome these limitations and promoting organic farming, following issues are needed to be addressed in a strategic manner by involving all the stakeholders, including NGOs and different service providers in public-private-partnership (PPP) mode:

- On production side, adequate research and extension support needs to be provided in order to develop improved region-specific farming techniques and disseminate findings for conversion and management of organic farms in farming system mode. There is a greater need to undertake basic and applied research to understand the scientific basis behind the organic farming and identify technologies for improved yields. Some basic studies like; development of innovative crop management practices, nutrient budgeting and soil quality improvement indicators (carbon sequestration, dehydrogenase activity, microbial biomass C and N) in major organic-based cropping systems, understanding nutrient release pattern of different organic sources in combination and alone, developing relationship between the crop-N demand and supply, screening of crop/ vegetable varieties and to develop and assess bio-agents and bio-pesticide for effective control of insect-pests and diseases of organic based cropping systems. In field, a holistic approach of research with integration of livestock and crops is required to achieve the benefits of organic agriculture. The inputs from agronomists, soil scientists, microbiologists, plant pathologists and entomologists would be highly critical.

- On consumption side, there is a great need for research on the human health benefits of consuming organic foods compared to non-organic food diets. The conversation needs to be expanded beyond the argument over "is organic more nutritious or not" and encompass full analysis of different agriculture and food systems, their environmental impacts, and their impacts on public health. A great deal of work has yet to be done to identify how farmers in general can implement practices which increase the nutritional content of food. Looking beyond nutritional content, analysis is needed to quantify the pesticide reduction potential that can be achieved through widespread adoption of organic management systems and the corresponding impacts on water quality, biodiversity, pollinator survival, farm worker health, public health, market opportunities/profitability, budgetary savings, and societal change.
- Central and state government should acknowledge organic agriculture as an effective mechanism to reduce green house gases and sequester carbon. They should help farmers by promoting organic agriculture through research and extension services.
- Agriculture produce marketing sector needs major thrust on developing supply chains and related infrastructure to ensure competitive price of organic produce to the grower in domestic and international markets.
- Mission-mode programmes for on-farm demonstrations, training for capacity building of institutions, organic farmers, service providers, NGOs and processing/ packing industry, with full research backup are needed. Model organic farms are needed to be established in public-private-partnership mode.

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Economic Aspects of Conservation Agriculture

Harbir Singh and B. Gangwar

Agriculture sector in the country is facing lot of challenges concerning sustainable food and nutritional security, loss of biodiversity, natural resource degradation and plateauing of productivity growth mainly in green revolution areas. Further, the issues concerning climate change has necessitated a re-look at the development strategy being followed to overcome the challenges and revitalize the agriculture sector for improving livelihoods of vast majority of farm families. It is widely accepted that the problems of agriculture sector is highly location-specific and those can be addressed better if the problems are viewed from systems perspective through an integrated approach to managing farm resources. Conservation agriculture (CA) aims at making better use of agricultural resources through the integrated management of available soil, water and biological resources, combined with limited external inputs. Zero or reduced tillage, direct seeding and a varied crop rotation are important elements of conservation agriculture. Conservation agriculture is being practised in different countries with varying level and extent of adoption. Agricultural systems relying on such approaches are not only able to support high productivity, but also preserve biodiversity and safeguard the environment with lower cost of farming. Conservation agriculture has come up as a new paradigm to achieve goal of sustained agricultural production. It is a major step toward transition to sustainable agriculture. While there may be visible benefits from adoption of CA practices, farmers and other stakeholders who intend to adopt these practices would always look for the magnitude of tangible benefits and impacts of CA practices on farm operations. Therefore, it becomes pertinent to understand whether CA will significantly increase productivity and food security of small and poor farm families? Will CA help farmers to save on production costs and generate additional income? These and other questions can be answered more objectively by learning from past experiences in CA and its socioeconomic impact on stakeholders.

This chapter draws from published literature and synthesizes the evidences about the economic impact of conservation agriculture.

1. CURRENT STATUS

Conservation Agriculture which has its roots in universal principles of providing permanent soil cover (through crop residues, cover crops, agro-forestry), minimum soil disturbance and crop rotations is now considered the principal road to sustainable agriculture. In South Asia, rice-wheat cropping systems cover 13.5 million hectares (M ha) and provide incomes and food to many millions of people (Gupta *et al*., 2003; Timsina and Connor, 2001). However, increasing water scarcity is also seen as a major contributor to stagnating productivity in the rice-wheat cropping systems of the IGP (Byerlee *et al*., 2003; Kumar *et al*., 2002). Due to the absence of efficient water-pricing mechanisms, the scarcity value of water is not reflected in water prices (Pingali and Shah, 2001). In the face of unreliable canal water supplies, many farmers have increased their reliance on private tube wells, placing tremendous pressure on groundwater supplies (Abrol, 1999; Ahmad *et al*., 2007; Qureshi *et al*., 2003). Negative environmental effects related to irrigation are increasing as overexploitation of groundwater and poor water management lead to the dropping of water tables in some areas and increased waterlogging and salinity in others (Harrington *et al*., 1993; Pingali and Shah, 2001; Qureshi *et al*., 2003).

Over the past three decades or so rapid strides have been made internationally to evolve and spread resource conservation technologies like zero and reduced tillage systems, better management of crop residues and planting systems which enhance water and nutrient conservation. Thus, it is seen as one of the most effective ways to achieve goals of higher productivity while protecting natural resources and environment. Conservation agriculture is currently practiced on over 80 million hectare in more than 50 countries and the area is expanding rapidly (Abrol *et al*., 2005). In India, significant efforts to develop and spread these technologies are underway through the combined efforts of several state and national institutions and CG centers, particularly Rice-Wheat Consortium (RWC) for Indo-Gangetic Plains (IGP). The new technologies, on the one hand, are exciting the farmers to take up new ways of managing their resources more productively and, on the other hand, throwing new challenges to the scientific community to solve emerging problems associated with adoption of these technologies. Developing and promoting conservation agricultural practices require multi- disciplinary team efforts and strong farmer participation in finding answers to emerging questions.

In India, rapid expansion of wheat zero tillage in the Indo-Gangetic Plains has seen a surge of interest in resource conserving technologies. In the 2004-2005 wheat season, zero tillage is estimated to have been used on nearly 2 million hectare of sown area (RWC, 2005). Zero-tillage in wheat is seen by many as merely the first step in a broad movement towards the development and adoption of an ever richer bundle of resource saving, conservation agriculture technologies.

At global level also, many regions of the world have made substantial progress in fostering use of conservation agriculture practices among farmers. For example, zero-tillage direct sowing of crops has become especially widespread in the Southern Cone of South America. Work on resource conserving technologies has also been done in Mexico and Mesoamerica with some success. The use of conservation agriculture is being explored in areas of sub-Saharan Africa and is making good progress in China and Central Asia. There are substantial areas covered by conservation agriculture in the USA, Canada and Australia. In the developing world, conservation agriculture has been most successful in the South American countries of Brazil and Argentina. In these countries, 45-60% of all agricultural land is said to be managed by conservation agriculture systems (Derpsch, 2001). In the 2001-2002 season, conservation agriculture practices are estimated to have been used on more than 9m ha in Argentina and 13 million hectare in Brazil. Conservation agricultural practices include the use of specialized, locally-adapted no-till planters, a mulch cover on the soil surface, and suitable crop rotations. Ekboir (2002) has succinctly discussed how the conservation agriculture practices came to be so predominant in Brazil.

2. LESSONS LEARNT SO FAR

The previous section illustrates the development of CA practices across a wide range of production environments ranging from the high-rainfall, sloping fields of southern Brazil to the semi-arid sandy fields of southern Africa to name a few. In these varying situations, conservation agriculture practices have been used to address a wide range of productivity and sustainability problems. Despite this variability, there are a number of factors that all examples have in common, and there are lessons to be learnt from these observations:

- Due emphasis should be given to development and adaptation of suitable implements. Without locally adapted implements, conservation agriculture rarely makes any progress.
- Implement development and adaptation might take around ten years. The swift adoption of wheat zero tillage that began in the late 1990s in the Indo-Gangetic Plains would not have taken place without the Pantnagar seed drill, which was an adaptation of a prototype drill imported from New Zealand.
- In Brazil, direct sowing implements were adapted from prototypes imported from Kentucky. In Shanxi Province in China, the key components were adapted from prototypes brought in from Australia.
- Basic elements of the no-till drill now being manufactured in northern Kazakhstan were brought in from Brazil. Even in Tanzania, work continues on local adaptation of the Magoye Ripper, developed in Zambia.

- Participation of the private sector in implement development, adaptation, manufacture and marketing is a common factor across regions. For example, National Agro-Industries in India, Greenland in Pakistan, Semeato in Brazil, the Shanxi Xinjiang Machinery Factory in Shanxi Province of China, have played a key role in production and supplies of desired machineries which helped adoption of conservation agricultural practices.
- Technical backstopping and support was invaluable in bringing to fruition the development and adaptation of CA practices to local circumstances. Research organizations in different countries have played major role in popularizing the concept. For example, China Agricultural University and local partners in Shanxi and Rice Wheat Consortium for the Indo-Gangetic Plains in South Asia, and Haryana Agricultural University (Hisar) have played pioneering role in adoption of zero-tillage particularly in rice-wheat belt.
- A crisis mentality brings with it a willingness to consider radical departures from conventional practices. For example, unprecedented problems of soil erosion and land degradation drove development of CA in Brazil, so did the problem of herbicide-resistant phalaris in Haryana lead to an urgent need to try desperate measures (among them, zero- tillage). Soil compaction in the north China plain and drought problems in southern Africa have played similar roles in maintaining interest in adapting CA principles to local circumstances.

3. POSSIBLE RESOURCE SAVING

The adoption of ZT/RT technology, though on a limited scale, has shown promising results. In rice-wheat systems concentrated in the Northwestern IGP, adoption of zero tillage is primarily in the wheat crop. According to the estimates by the Rice-Wheat Consortium, the total estimated wheat area under the zero and reduced tillage together was approximately 8.2 lakh hectares in the Indian IGP during 2003-04. Most of the adoption was concentrated in Haryana (46% of 2003–04 ZT/RT area), Punjab (26%), and Western Uttar Pradesh (21%). These areas are characterized by high agricultural productivity. The ZT/RT adoption has started to pick up in the eastern part of Uttar Pradesh and Bihar also, where agricultural productivity is lower. So far, ZT has spread more widely in the better-endowed areas. In 2004–05, the total estimated area under the combined zero tillage/reduced tillage was approximately 1.6 million hectares in the Indian IGP. The zero-tillage technology is currently in the mass adoption phase in the Indian IGP.

Traditionally, wheat is grown under conventional tillage in India's rice-wheat systems. Due to the adoption of ZT technology, the number of field operations for the wheat crop (including tillage) decreased from an average of seven to only one (Sharma *et al*., 2002). Due to this, about 8 to 12 hr/ha of tractor operational time were reportedly saved (an 80–88% savings (Malik *et al*., 2004; Sharma *et al*., 2002; Yadav *et al*., 2002). The corresponding seasonal savings in diesel for land preparation is reported to be in the range of 15–60 liters/hectare (l/ha), representing a 60–90% savings (Hobbs and Gupta, 2003; Laxmi *et al*., 2003; Malik *et al*., 2002; Malik *et al*., 2004; Yadav *et al*., 2002). In Haryana, ZT saved 59 l/ha of fuel, 8 hr/ha of tractor time, and approximately 3,000 Mega Joules/ ha of energy in tractor operations as compared to CT (Sharma *et al*., 2002). Similar results have been also been reported from Central India (Madya Pradesh), where zero tillage had saved 75 l/ha of fuel by reducing tillage operations from seven to one (Yaduraju and Mishra, 2002). Zero tillage does not generate significant savings in labor use in land preparation and crop establishment, especially as mechanization is already widespread in the Indian IGP. A few studies reported marginal labor savings, in Haryana and Bihar (Sharma *et al*., 2002; Laxmi *et al*., 2003). Further, the saving of tillage time led to wheat planting to be advanced by 7–10 days in Haryana and by 8–25 days in Bihar (Nagarajan *et al*., 2002; Singh *et al*., 2002). Bed planting of wheat in Punjab not only resulted in reduction of input use but also increased the yield and net returns to the farmers, with reduction in use of inputs like seed, irrigation and fertilizers (20.4, 32.7 and 5.6% reduction, respectively). Water requirement of wheat crop was reduced by almost one-third (Grover *et al*., 2005; Dhaliwal and Singh, 2005). Recent two country studies confirmed widespread adoption of ZT wheat in the rice-wheat systems of Haryana, India (34.5% of surveyed households) and Punjab, Pakistan (19%). The combination of a significant “yield effect” and “cost-saving effect” makes adoption worthwhile and is the main driver behind the rapid spread and widespread acceptance of ZT in Haryana. In Punjab, adoption is driven by the significant ZT-induced cost savings for wheat cultivation. Thus, the prime driver for ZT adoption is monetary gain in both sites, not water savings or natural resources conservation. Water savings are only a potential added benefit (Erenstein *et al*., 2007). Thus apart from reduction in cost and higher yield, the bed planting of wheat has the potential to improve water table in the state which has become a very serious problem. On the basis of the above, it can be inferred that conservation agriculture has significant economic potential in subsistence production systems as well as in well-endowed regions.

4. MAJOR FUTURE CONCERNS

In the second half of the 1990s, the zero-tillage (ZT) and reduced tillage (RT) technology was primarily in testing phase in India. Farmers’ interest in these technologies in the Western IGP were driven by considerations for late planting, herbicide resistance (*P. minor*), and labor scarcity. The technology diffusion process has picked up in recent times. This was possible because of the demonstration effect of early adopters and active involvement of all the stakeholders in the mode of participatory research development which was supported by the consortium of international, national and state research organizations, private manufacturers and input agencies including farmers. However, several concerns still remains which will have bearing on wider adoption of the technology. For example, supply-side factors and government policy will play a very crucial role in determining the success of the technology. Since conservation agricultural practices require more precision, any defective intervention– which may happen mainly due to scarcity of machine service providers and incomplete information – may have negative effect on its adoption, farm productivity, profitability and sustainability. Further, development of input markets (for seeds and agrochemicals) is very important as being complementary to the ZT systems. When markets and institutions are not well developed, even the most promising technology may fail to meet farmer expectations (Krishna, *et al*., 2011).

5. FUTURE THRUSTS

A lot needs to be done for wider adoption of conservation agricultural practices. One of the important thrusts areas for future research would be continuous improvement of suitable ZT-drills. Ideally, they should be multipurpose and not heavy. Standardization of metering system for planting of pulses, oil seeds, rice and wheat, refinement in fertilizer distribution system, proper management of paddy straw and interchangeability of different components especially furrow on different makes of drills needs to be worked out in researchers and manufacturers partnership. Zero tillage offers high potential economic, environmental, and social gains in the Indian IGP. Nonetheless, significant challenges remain, not least in terms of actually realizing these potential gains on the ground. This implies moving beyond mere production cost savings to natural resources savings and using ZT as a stepping stone to conservation agriculture (Laxmi *et al*., 2007). The complex contexts and the institutional history of conservation agriculture also bring in new policy research questions. There is a felt need for policy analyses to understand how conservation technologies integrate with other technologies, policy instruments and institutional arrangements that promote/repress conservation agriculture. Applying pro-poor criteria to this successful innovation system may bring out other wider policy questions, especially about the employment impacts due to widespread adoption of conservation agriculture (Raina *et al*., 2005). Empirical studies have identified some areas for further empirical research which are as follows (Erenstein *et al*., 2007):

- More rigorous documentation of the water savings of resource-conserving technologies like ZT.
- A better understanding of the ZT dis-adoption process – particularly in terms of disentangling the underlying causes. For instance, the site-specific circumstances disadopters faced in terms of their access to drill, the quality of the drill, timeliness, quality of soil, the skill of the operator, etc. Participatory approaches could provide useful complementary information.

- A better understanding of partial ZT adoption – particularly in terms of the rationale and underlying field selection criteria and the eventual biases this may imply in terms of technology performance.
- A better understanding of the adoption and impacts of ZT in the eastern Gangetic Plains. In fact, pick up in uptake of ZT in the eastern plains calls for a closer scrutiny of the adoption, impacts and implications of ZT.
- The possible refinement and extrapolation of recommendation domains for technologies like ZT. For instance, anecdotal evidence coming from Pakistan suggests ZT by soil type interactions. Also the implications and potential use of ZT in wheat-cotton systems with low cotton-residue-retention levels and the extrapolation to other systems like the maize-wheat and the rain-fed systems.
- More intensive, participatory and timely monitoring of the performance and impact of new technologies like ZT in farmers' fields.

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Socio-Economic Impact of Resource Conservation Technologies

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Seventy percent of Indian population depends on farming for their subsistence and livelihoods. Agriculture remains vital for the continents development and economic growth. However, the recent stagnation and decline in crop productivity in all parts of the country is a major concern. Besides, the input cost particularly labour and engine oil are increasing very fast which increased the production cost and reduce the profit margin of the crop commodities. If the situation is not improved of these farm groups, the growth in poverty may be accelerated in future. Again due to intensive cropping, the soil health is being deteriorated day by day which influence the crop yield. In addition, the average annual rainfall is declining in many parts of the country. Low rainfall has also caused for sharp depletion of ground water table in all the states. All these problems influence the crop productivity and farm income in one way or the other. Recent studies, however, indicated a slowdown in productivity (Kumar *et al*., 2002) and growth (Byerlee *et al*., 2003). Evidence from long-term experiments shows that crop yields are stagnating and sometimes declining (Duxbury *et al*., 2000, Ladha *et al*., 2003) and soil quality is governed primarily by the tillage practices used to fulfill the contrasting soil physical and hydrological requirements of the rice and wheat crop. Current crop cultivation practices in these systems degrade the soil and water resources thereby threatening the sustainability of the system (Fujisaka *et al*., 1994, Byerlee and Siddiq, 1994, and Hobbs and Morris, 1996). The prevailing policy environment has encouraged inappropriate land and input use and cropping system constraints (Pingali and Shah, 1999). Agricultural technologies that can save resources, reduce production costs and improve production while sustaining environmental quality are therefore becoming increasingly important (Hobbs and Gupta, 2003).

1. CURRENT STATUS

In 2003-04 the total estimated wheat area under the combined zero and reduced tillage was approximately 820,000 hectares In the Indo-Gangatic Plains (IGP) of India. Most of the adoption was concentrated in Haryana (46% 2003-4), Punjab (26%) and Western UP (21%). These areas are characterized by high agricultural productivity (Pal *et al.,* 2003; RWC 2004). The zero till/reduce till adoption has started to pick up in the eastern part of Uttar Pradesh and Bihar, where agricultural productivity is lower. So far zero tillage has spread more widely in the better – endowed area. For instance, the the estimated rural poverty head count ratio in 1999-2000 was 44.3% in Bihar (second highest in India) and 31% in UP. The corresponding ratio for Punjab and Haryana were 6.4% and 8.3%, respectively (MOA 2004). In 2004-05 the total estimated area under the combined zero tillage /reduced tillage was approximately 1.6 million hectares in the Indian IGP (Soran 2005). The 2004-05 estimate for the first time disagreegated the estimated ZT and RT areas with ZT comprising 27% and reduced tillage 73%.

2. LESSONS LEARNT SO FAR

Zero tillage is generally reported to save irrigation water in the range of 20–35% in the wheat crop compared to conventional tillage (CT), reducing water usage by about 10 cm/ha, or approximately one million /ha (Hobbs and Gupta, 2003). A study in Haryana reported a smaller but significant tube well irrigation water saving of 13% with zero tillage (ZT) (Erenstein *et al*., 2007), within the range of 10–27% irrigation water savings reported by another study in the same rice–wheat area (Chandra *et al*., 2007). The saving is generally reported for the first irrigation (e.g., 21% water saving: Erenstein *et al*., 2007; 28% time saving: Singh *et al*., 2002; ZT 8–10 hrs. CT 13–17 hrs: Hobbs *et al*., 1997). With regards to weed management, the adoption of ZT in rice–wheat systems in the Indo Gangatic Plain (IGP), comparatively less weeds were found in the wheat crop (Malik *et al*., 2002, Chauhan *et al*., 2002, Yaduraju and Mishra, 2002, Sen *et al*., 2002, Prasad *et al*., 2002, and Singh *et al*., 2002). By reducing soil movement ZT serves as an effective control measure of *Phalaris minor* (Malik *et al*., 2002). The ability to control herbicide-resistant *Phalaris minor* thereby became a major initial driver for adoption of ZT in North West (NW) IGP, which in combination with new herbicides. Rice–wheat systems are often characterized by late planting of wheat (Fujisaka *et al*., 1994). Except Punjab, earlier studies estimated 25–35% of the wheat area in the Indian IGP established late, which significantly reduces wheat productivity. Terminal heat implies that the potential of wheat yield decreases by 1–1.5% per day if planting occurs after mid November (Randhawa *et al*., 1981 and Hobbs and Gupta, 2003). The delay in planting of wheat crop is mainly due to the late harvest of the previous crop and/or a long turn-around time. The late harvest of the previous rice crop can be linked to both the late rice establishment and the duration of the rice crop. Generally positive yield effects of ZT wheat in rice–wheat systems was noticed because of (i) timely sowing and (ii) increased input use efficiency and weed control. Malik *et al*. (2002) reported ZT induced yield gain of 15.4% in on-farm trials in Haryana, which they decompose into 9.4% due to timeliness and 6.0% due to enhanced efficiency, ascribed primarily to enhanced fertilizer- and water-use efficiency and to a significant reduction in weed population. The few exceptions with a decline in ZT yield are all in the NW IGP, which may reflect that planting of wheat – particularly in Punjab – is already timely (Hobbs, 2001) whereas CT wheat yields are markedly higher in the north-west compared to the eastern IGP. The highest on-station yield gain (+62.5%) was reported in Eastern Uttar Pradesh (Sen *et al*., 2002), and was associated with very late wheat establishment.

3. POSSIBLE RESOURCE SAVINGS

A study was conducted in state of Haryana for the crop year 2007-08 in Panipat, Karnal, Kurukshetra, Kaithal and Yamunanagar districts. Sampling were done at two levels (village and house hold) in consultation with the scientists of KVK Panipat and Kurukshetra, and two types of controls (villages and farmers with respect to adoption and non-adoption) and three forms of comparisons – (with, without and across regions and cropping systems) was kept. Ninety five farm households were covered across five districts of Northern Haryana and the resources conservation technologies covered were green manuring, zero tillage, laser leveling, bed planting, rice mechanical transplanter, bed planting, intercropping in sugarcane and summer planting of moong. The farm level impact indicators identified were yield increase, income augmentation, cost reduction, cropping intensity and resource conservation, whereas aggregate level indicators were agricultural production and employment. Partial budgeting and simple statistical tools were used for statistical validation of the technology performance over the existing practices of the adopters.

The results of the study indicated that most of the sample farmers (35 %) adopted residue management (RM) plus zero Tillage (ZT) followed by green manuring (GM) plus RM+ZT (Table 1).

Table 1. Adoption profile of RCTs across sample farms

Technology used	*No. of farmers*	*(%)*
Only Green Manuring (GM)	12	12.77
Only Residue Management (RM)	12	12.77
Only Zero Tillage (ZT)	5	5.32
GM+RM	4	4.26
GM+ZT	8	8.51
RM+ZT	33	35.11
GM+RM+ZT	15	15.96
RM+Rotavator	9	9.57
Land Leveler +ZT	2	2.13
Use of Rice Mechanical Trans planter	1	1.06
Bed Planting & Intercrops	1	1.06

The comparative resource use and return recorded in zero tillage vis-à-vis conventional tillage given in Table 2 and 3 were land preparation time (hr/ha)- 1.5- 1.75 vs 6-7, land preparation cost Rs. 1500 vs 6000-7000; the indirect benefit in terms of fuel savings ranged from 35-40 l/ha. As the technology facilitates timely sowing, the additional yield recorded was 2.23 quintals worth Rs. 2030 and thus the net benefit worked out to Rs. 4635/ha.

Table 2. Comparative resource use and return – ZT vs CT

Resources/ return	*Zero tillage*	*Conventional tillage*
Land preparation time (hr/ha)	1.5-1.75	111-13
Land preparation cost (Rs/ha)	1500	6000-7000
Seed rate (kg/ha)	05-100	115-120
Fuel consumed (Rs/ha)	1.75-5.0	45-50
Yield realized (t/ha)	4.33	4.10

Table 3. Partial Budgeting of zero tillage over conventional tillage

Added cost (Rs/ha)	Added benefit (Rs/ha)
• Increase cost in ha	• Decrease in cost/ha
• Zero till expenses 1500	• Saved tillage cost - 2200
• & Residues management cost	• Reduced seed rate - 225
• Harvesting transport and marketing of added yield 120	• Saving in irrigation & weed costs
Increase in return/ha Nil	b) Increase in return @ 2030/ha
Total = 1620	Total = Rs. 4455/ha
Net return= Rs . 3835/ha	

Table 4 indicated that more than 5% sample farmers partially retained residues followed by full retention (24%). About 10% farmers burn residues before sowing the field by zero till machine.

Table 4: Distribution of zero tillage practitioners as per nature of residue management

Nature of residue management	*Number*	*%*
Burning	6	9.52
Partial burning	13	20.63
Partial retention	35	55.55
Full retention	9	24.29
Total	63	100.00

Another study conducted during 2008-09 of a sample of fifty three adopter and 14 non adopter farm household in U.S. Nagar district of Uttarakhand. The farm level impact indicators identified were yield increase, income augmentation, cost reduction, cropping intensity and resource conservation, and aggregate level indicators were agriculture production and employment. The analysis indicated that the majority of the sample households invariably adopted zero tillage in various degrees and shades, in sole or in combination with other resource conservation technologies like residue management, green manuring, and laser levelling.

Table 5. Farm size wise percent area under zero tillage in Uttarakhand

Farm category	*Farm size (ha)*	*Area under zero tillage (ha)*	*% Area*
Adopters			
Small	1.64	1.34	81.71
Medium	3.23	1.66	51.33
Large	13.48	6.39	47.40
Total	9.89	4.81	48.65
Non Adopters	18.59	0	0

The data in Table 5 indicated that area under zero tillage increased with increase in farm size. It shows that adoption of zero tillage was highly correlated with farm size. The average farm size in adopters was 9.89 ha. The data in Table 6 showed the effect of age and education on adoption of zero tillage. The analysis of data did not depict wide variation in respect of age and education between adopters and non adopters of zero tillage.

Table 6. Effect of age and education on adoption of zero tillage

Particulars	*Average*	*Standard deviation (I)*	*Coefficient of (%)*
Adopter			
Small			
Age (yrs)	46.40	11.90	25.65
Education (class)	3.00	1.15	38.49
Medium			
Age (yrs)	48.43	7.91	16.34
Education (class)	3.00	1.83	60.86
Large			
Age (yrs)	54.39	13.06	24.02
Education (class)	3.53	1.68	47.67
Total			
Age (yrs)	52.09	12.58	24.15
Education (class)	3.36	1.61	47.83
Non Adopter			
Age (yrs)	59.38	22.51	37.90
Education (class)	2.64	1.95	73.62

The Figure (1) Indicated that, there was 6-7 days early sowing in zero tillage in comparison to non adopters and also seed rate was also lower in case of zero tillage (128 kg/ha) than adopters (144 kg/ha). Among the different farmers' categories, only small and large farmers adopt early sowing whereas farmers hardly accrued the benefit of early planting with zero tillage adoption. A saving of 20-25 kg/ha seed was always with all categories of farmers as compared to non adoption (Fig.2).

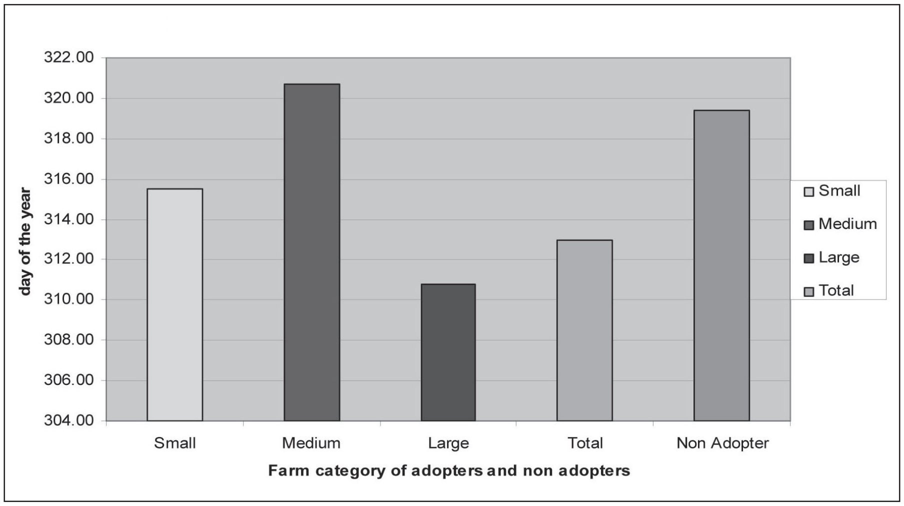

Fig. 1. Difference in wheat sowing time of adopters and non adopter farmers of zero tillage

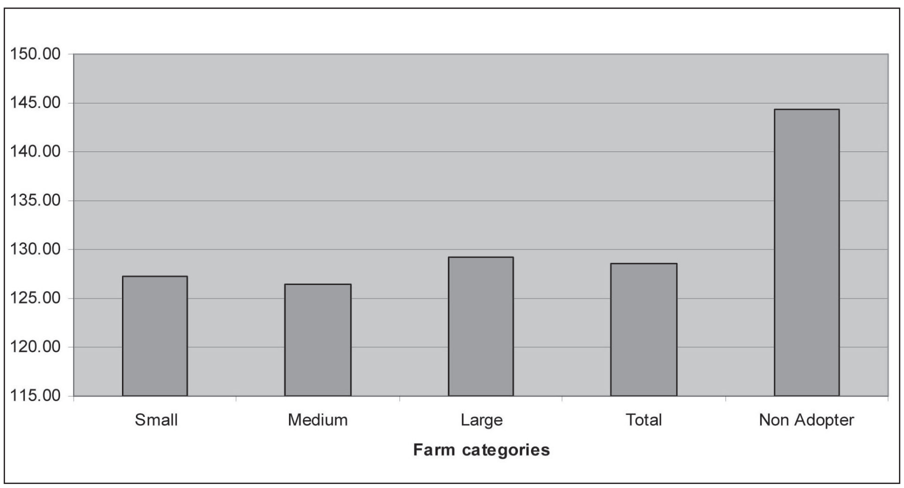

Fig. 2. Changes in seed rate with adoption of zero tillage in wheat

The Fig.3 showed that the cost of sowing was lower for adopters of zero tillage as compared to non adopters. The analysis of data further showed that the expenditure on sowing was Rs. 3000 ha^{-1} by the non-adopter which was much higher compared to adopters (Rs. 500/ha).

Non adopter incurred marginally higher expenditure on irrigation than adopters as their number of irrigations are more as compared to non adopter (Fig. 4). Further Table 7 indicates the marginal variation in utilization of urea and di-ammonium phosphate (DAP) between both the cases. Use of potash was relatively higher with non-adopters as compared with zero–till adopter farmers again

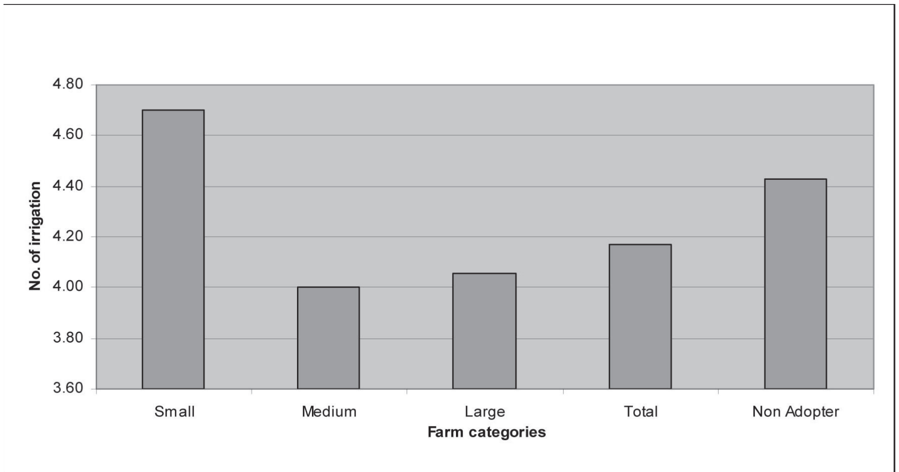

Fig. 4. Number of irrigation used by the adopter and non adopter farmers of zero- tillage

indicates non-adopters were using higher doses of fertilizer as compared to adopters of zero tillage. There was a more variation for use of potash by adopters of zero tillage than the non adopters.

Table 7. Quantity of fertilizer applied by adopter and non adopter farmers of zero- tillage

Particulars	*Average (kg/ha)*	*Std. Deviation (+)*	*CV (%)*
Small			
Urea	72.50	34.26	47.25
DAP	55.00	10.54	19.17
Potash	38.00	30.20	79.48
Medium			
Urea	82.14	31.34	38.15
DAP	55.00	9.57	17.41
Potash	52.14	38.50	73.83
Large			
Urea	82.92	28.27	34.09
DAP	60.14	13.39	22.26
Potash	35.42	32.01	90.39
Total			
Urea	80.85	29.51	36.50
DAP	58.49	12.50	21.38
Potash	38.11	32.41	85.03
Non Adopter			
Urea	84.64	34.16	40.36
DAP	55.36	10.09	18.23
Potash	67.50	12.36	18.32

Table 8 indicated that the wheat yield was higher by 1.68 q/ha in case of adopter than non adopters of zero tillage. Yield variations were more in adopters than non adopters.

Table 8. Difference in yield of zero till adopters and non adopter farms

Farm category	*Yield (q/ha)*	*Standard deviation*	*Coefficient of Variation*	*Difference*
Small	48.50	6.03	12.44	1.18
Medium	48.93	5.56	11.37	1.61
Large	48.78	5.46	11.19	1.46
Total	49.00	6.58	13.44	1.67
Non Adopter	47.32	3.46	7.32	0.00

The Table 9 indicated that the total cost of cultivation of wheat was Rs. 9725/ha as against Rs.12608/ha by non adopters. Saving in cost of cultivation and additional income was Rs. 3183/ha. The net return of adopter over not adopter was computed to Rs. 5024/ha.

Table 9. Cost of production and return (Rs/ha) with zero till adopter and non adopter farmers

Farm category	*Cost of production*	*Gross return*	*Net return*
Small	9329	53350	44021
Medium	9443	53821	44378
Large	9307	53663	44356
Total	9425	53895	44470
Non Adopter	12608	52054	39446

4. FUTURE CONCERNS

The resource conservation technologies are practiced in the lack of knowledge to the farming community. There is no blueprint available for resource conservation technologies, as all agro-ecosystems are different. A particularly important gap is the dearth of information on locally adapted cover crops that produces high amounts of biomass under the prevailing conditions. The success or failure of conservation technologies depends greatly on the flexibility and creativity of the practitioners and extension and research services of a region. Trial and error, both by official institutes and the farmers themselves, is often the only reliable source of information. However, resource conservation technologies is gaining momentum rapidly in certain regions, there now exist networks of farmer organizations and groups of interested people who exchange information and experiences on cover crops, tools and equipment and other techniques used in conservation agriculture. Initial nervousness about switching from plough-based farming to zero tillage can be ameliorated by forming farmer groups to exchange ideas and gain knowledge from more experienced practitioners. As resource conservation technologies partly relies on the use of herbicides, at least during the initial stage of adoption, some people worry that adoption of these technologies will increase herbicide use and that in turn will lead to increased contamination of water by herbicides. In fact, experience has shown that herbicide use tends to decline over time as the soil cover practices prevent weed emergence. Technological intervention also needs to be complemented with policy reform to create an enabling environment for sustainable agriculture. This could easily prove even more significant, but implies addressing some of the more thorny policy issues such as the subsidy and taxation schemes that currently undermine the sustainability of rice wheat system (Laxmi *et al.,* 2007).

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