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Sustainable Intensification Opportunities under Current and Future Cereal Systems of North-West India

ICAR-Central Soil Salinity Research Institute
Cereal Systems Initiative for South Asia
(International Maize & Wheat Improvement Centre)
Karnal- 132 001 (Haryana) INDIA

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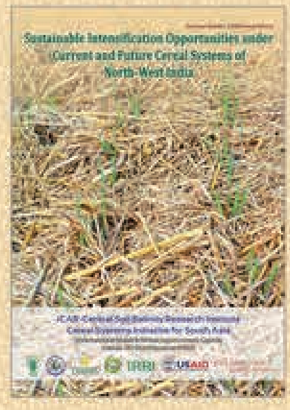

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Foreword

The spread of the rice-wheat system in North-West (NW) India has brought forth several edaphic, environmental, ecological and social implications. Continuous cultivation of rice-wheat system in North-Western Indo-Gangetic plains (IGP) of India has led to an over-exploitation of fresh ground water reserves, poor soil health, low carbon content and multiple nutrient deficiencies. A number of problems have cropped up in the region with the cultivation of rice and wheat in a system mode for the last five decades, threatening the sustainability of the system. Increased cultivation cost, labor shortage and climate change all pose additional threats to the sustainability of this system in NW India. To overcome formidable problems of RW system in North-West India, sustainable intensification on the principles of conservation agriculture (CA) has emerged an important alternative to attain the objectives of improved and sustained productivity, increased profits and food security while preserving and enhancing the natural resource base and the environmental quality in NW India. The CA based agro-technological package, intensified cropping system and holistic farming approach not only saves natural resources but also help in producing more at low costs, improves soil health, promotes timely planting and ensures crop diversification, reduces environment pollution and adverse effects of climate change on agriculture. Implementation of agriculturally diversified systems intensification in NW India may be a productive way to build resilience into agricultural systems for national food security. Sustainable intensification is an important component of the overall strategy for ensuring food security of coming generations in NW India.

I am very happy to see that a group of scientists from ICAR and CGIAR has developed a road map for future cereal systems in North-West India to address the second generation problems of Green Revolution. I am sure that the National Agricultural Research and Extension System (NARES), in partnership with all stakeholders (CGIAR, NGOs, private sector organizations and farmer's societies) will take full advantage of recommendations emerging from the CSISA project (collaborative programme of ICAR, IRRI and CIMMYT). It is also expected that this publication will be immensely helpful to policy planners, administrators, researchers, extension workers, farmers, stakeholders and other users for efficient management of soil, water and other resources for sustainable crop production while preserving the natural resources and quality of environment for betterment of livelihoods in North-West India. I take this opportunity to congratulate the authors as well as the collaborating institutions CIMMYT, IRRI, CSSRI and CSISA for bringing out this valuable publication timely.

Date : May 11, 2015
Place : New Delhi

(Alok Kumar Sikka)

MANPREET-763

Contents

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1. Introduction

Rice (*Oryza sativa* L.) and wheat (*Triticum aestivum* L.) are the world's most important cereal crops, contributing about 45% of the digestible energy and 30% of total protein in the human diet, besides supplying feeds to livestock, substantially. Rice and wheat are now grown in sequence on the same land year after year on an area of over 26 M ha of South and East Asia to meet the growing food demand of a rapidly expanding human population. Rice-wheat (RW) cropping system occupies about 13.5 M ha in the Indo-Gangetic Plains (IGP) of India, Bangladesh, Nepal and Pakistan and it is one of the major agricultural production systems, which is a source of livelihood, employment and income for over 150 million rural and urban poor and thus is very important to the food security of South Asia. The slowdown in yield growth mainly affected wheat and rice, with annual growth rates falling below 1% in recent years and staying well below annual population growth for the past decade or more. Therefore, the South Asian agriculture is currently facing twin challenges of resource fatigue and decelerating productivity growth of cereal crops. Also, there exist large yield gaps more particularly *'management yield gaps'* ranging from 14 to 47% in wheat, 18 to 70% in rice and 36 to 77% in maize, respectively.

Rice-wheat cropping system of north-west (NW) India is fundamental to India's food security as its plays a leading role in contributing food grains for the whole nation. In India alone, RW system occupies about 10.5 M ha and contributes about 40% of the country's total food grain basket. With the adoption of high yielding varieties, higher application of inputs of plant nutrition, irrigation water and improved crop management practices, the productivity of RW system in the region was remarkably increased and had ushered into *Green Revolution* primarily in North-Western India. RW system has played a significant role in increasing food grain production since *Green Revolution* period for achieving food security of the region. However, these gains were accompanied by widespread problems of resource degradation, which now pose a serious challenge to the continued ability of the region to meet the food demand of an ever increasing population. In recent years, RW system has witnessed a significant slowdown in the yield growth rate. The sustainability of this important cropping system is at risk due to second-generation problems (ground water depletion at faster rate, soil salinization, poor quality underground water, low fertility status, multiple nutrient deficiencies, imbalanced use of fertilizers and inadequate system diversity). The current approach of RW production is now known to be ecologically intrusive and economically and environmentally unsustainable which is further aggravated with the fast changing climate in the region.

The new challenges demand high priority to efficient resource use and conservation to ensure continuance of earlier gains of Green Revolution leading to the sustainability of the RW production system in long run to meet the emerging needs. Evidence from various production environments suggests that conservation agriculture (CA) based management can have both immediate and long term benefits of reduced production costs, reduced erosion, stabilized crop yield, improved water productivity, adaptation to climatic variability and improved soil health and ecosystem services, respectively. CA based sustainable intensification acquires special significance in this region because of the ecological and environmental problems and strain on natural resources associated with the post Green Revolution era, and difficulty in sustaining growth in output and income.

2. Production system constraints in NW India

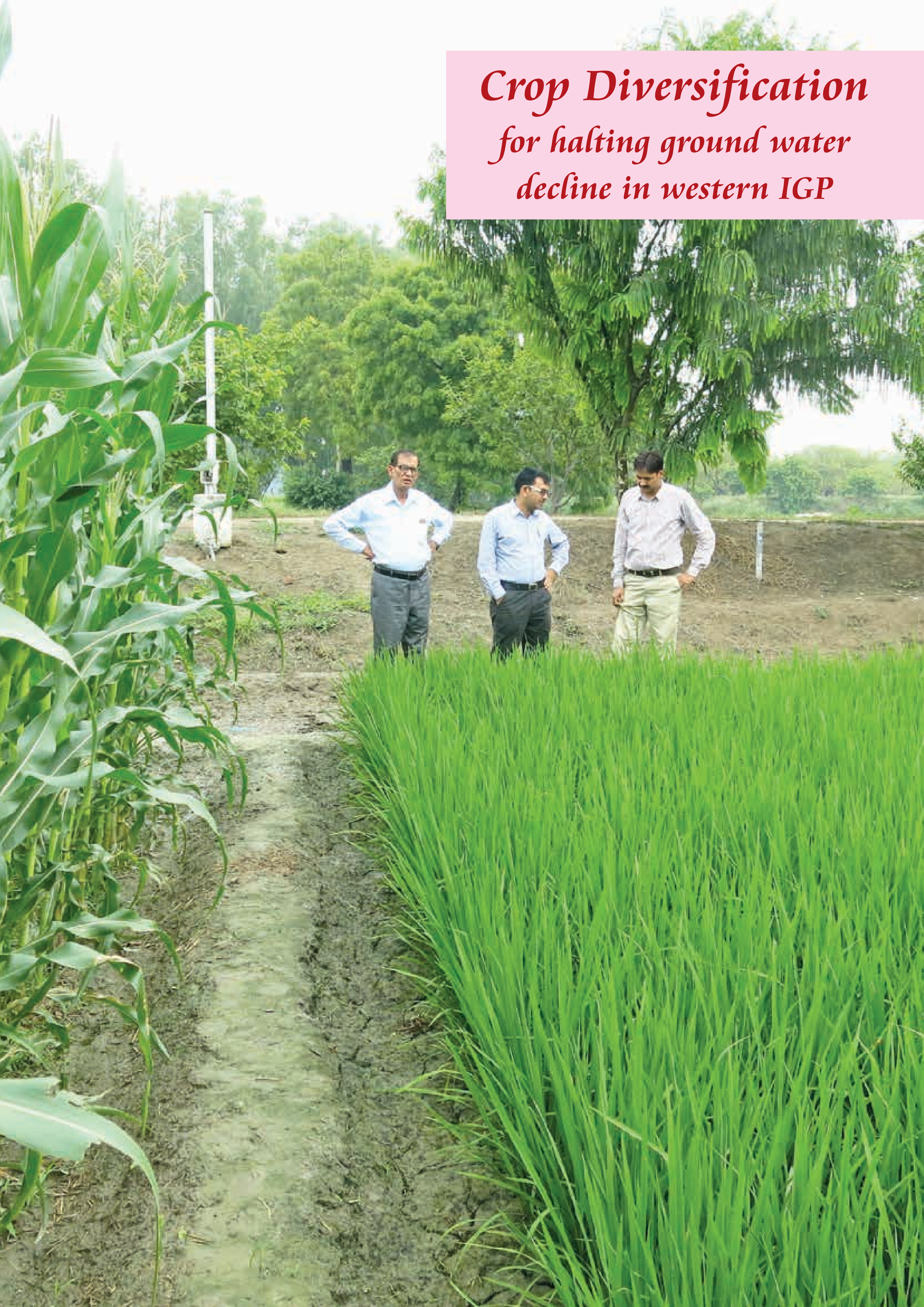
In recent past, the multiple challenges associated with plow based conventional production practices in RW system including declining factor productivity, shrinking farm profits due to increasing energy and labor costs, emerging crisis for irrigation water and recent challenges of changing climates are leading to a major threat to food security. It will be further exacerbated by the projected threats to agriculture due to the consequences of natural resources degradation and projected climate change effects. Depletion of underground water, declining fertility status associated with multiple nutrient deficiencies, increased concentration of GHGs in the atmosphere owing to large scale burning of rice and wheat residues are some of the end results of this farming system.

I. Emerging climatic variability

Indian subcontinent is at high risk, because of the climate change leading to weather variability, crop season shifting, temperature alterations and precipitation patterns which ultimately affect different aspects of crop production and agricultural ecosystem. Such effects have made changes in nutrient cycling and soil moisture, as well as shifts in weed flora, pest occurrences and plant diseases, all of which have great influence on crop production and ultimately food security. The IPCC has projected a rise in temperature from 0.5 to 1.2 ^{o}C by 2020 and from 0.88 to 3.16 ^{o}C by 2050 in the South Asia region due to an increase in the concentration of green house gases (GHGs) (CO_2, CH_4 and N_2O). Increases in temperature reduce crop duration, increase crop respiration and reduce crop yield, besides affecting survival and distribution of pest populations. Nutrient mineralization also get hastened by increase in evaporation. The projected increase in temperature would decrease the growth duration and yield of both the crops (rice and wheat). Crop models (WTGROWS and INFOCROP) have also predicted a decline in rice productivity by 0.75 t ha^{-1} with a 2 ^{o}C rise in mean air temperature. In a simulation study, an increase in temperature by 2 ^{o}C led to a 10-20% decrease in grain yield of both rice and wheat.

Climate change, which could have negative consequences for agricultural production has generated a desire to build resilience into agricultural systems. Crop diversification and sustainable intensification can improve resilience in various ways: by using improved CA based management practices and resilient system under future climate scenarios. Agriculture plays an important role in mitigating the GHG emission. There is a need to address climate change through adaptation strategies and mitigation potential aimed at reducing GHGs and

Crop Diversification
for halting ground water decline in western IGP



increase removal of CO_2 from the atmosphere. Tillage results in large decline in soil organic carbon due to significant flush of CO_2 and perturbs the soil system causing a shift in the gaseous equilibrium by releasing CO_2 to the atmosphere. As CA involves practices such as zero or minimal mechanical disturbance, crop residues retention, permanent organic soil cover, diversified crop rotations, precise placement of agro chemicals, in field traffic control etc. resulting in GHG mitigation and more carbon sequestration in soil. Different cropping systems yield different amounts of soil carbon.

II. Ground water depletion

Large scale adoption of RW system in this region have caused rapid expansion of the tube well network in the NW-IGP leading to extensive groundwater pumping for irrigation of these crops. Rice is sown in puddled soil and requires large amount of irrigation water (>200 cm ha^{-1}) resulting in ground water depletion in NW India at a speedy rate. Since the early 1970s, there has been a steady increase in the depth to the groundwater due to the over exploitation in most of the RW area of NW (Punjab, Haryana and Western Uttar Pradesh) India. The groundwater table in this region has gone down at the rate of about 0.50 m yr^{-1} during 1993-2003. However, in some areas of NW-IGP, the water table is now being depleted at more alarming pace. By 2009, 103 out of 138 administrative blocks in Punjab and 55 out of 108 blocks in Haryana were already reported overexploited.

III. Ecological degradation

The continuous cultivation of rice-wheat cropping system for almost five decades in NW India has set in the processes of degradation in the natural resources *viz.* water, soil, climate and biodiversity. The various forms of resource degradation due to the RW production system are: loss of organic matter; mining of soil nutrients; build-up of biotic (weeds, diseases and pests) and abiotic (waterlogging, salinity and sodicity) stresses. Flora and fauna diversity which is very much required for ecosystem stability is also negatively affected by the continuous cultivation of RW system in the region. Apart from these, the labor charges continue to increase, high prices of inputs with low factor productivity make the RW production system less profitable and unsustainable that forces the farmers to migrate from villages to urban areas and may also compel them to sell their agricultural lands.

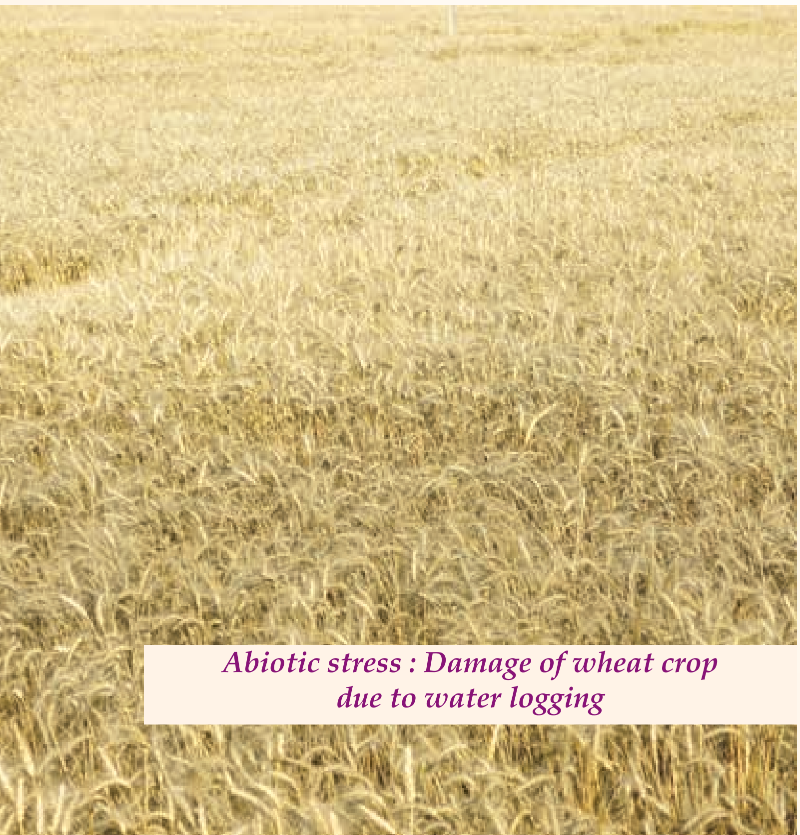
IV. Monoculture

In NW India, to remove the barriers of monoculture (RW system), crop diversification from rice to alternate remunerative crops is required to overcome the second generation problems of this system. Diversification would help accomplishing sustained soil fertility, crop productivity and thereby boosting farmer's income. Maize has the potential to be as productive and profitable as rice, with up to 90% less irrigation water requirement. Less pumping of fresh groundwater would build-up less salt in the soil profile as salinity increases with water table depth. It would be helpful prevent productive lands to turn in to saline lands besides sustaining agricultural growth and productivity in this region. Inclusion of other crops like pigeonpea, soybean, mungbean etc. also act as a means of supplying N through biological nitrogen fixation to the system.

Conventional cropping (Rice-Wheat) system of IGP

V. Biotic and abiotic stresses

Green revolution in the country improved the productivity of cereal crops but at the same time *Phalaris minor* was also got introduced in wheat crop. Presently, *Phalaris* has developed strong resistance to the commonly used herbicides and farmers have shifted to new and more expensive herbicides. Continuous cultivation of RW system have also led to the decline in soil organic matter and multiple nutrient (major- N, P, K, and S; minor- Zn, Fe,



Abiotic stress : Damage of wheat crop due to water logging

Biotic stress : Phalaris minor in wheat and Mn) deficiencies due to their overmining from soils. Excessive pumping of fresh water aquifer have also increased salinity and sodicity problems leading to impaired physical and biological environment; the soil and plant growth is adversely affected. As in Punjab, the salinity of the groundwater increases with depth. The rate of salinization of the aquifer can therefore be slowed by management practices that minimize the amount of irrigation water applied to crops. On one side, excessive pumping lead to declining fresh water aquifer zones, while on another side inadequate drainage is causing waterlogging and salinity problems. Socio-economic and agricultural problems are also interrelated and tend to be concentrated in areas.

VI. Poor management of residues

In North-west India, combine harvesting of rice and wheat is now a common practice leaving large amount (> 6 t ha^{-1}) of crop residues in the fields. In most of the region, to clear the fields for the timely sowing of wheat, majority of the paddy straw is burnt *in-situ* by the farmers causing environmental pollution and loss of plant nutrients and organic matter. Burning of residues emits a significant amount of GHGs. For example, 70, 7 and 0.7 % of carbon present in rice straw is emitted as CO_2, CO and CH_4, respectively, while 2.1% of N in straw is emitted as N_2O upon burning. The main reasons for burning crop residues in field include lack of awareness, unavailability of turbo seeder, use of combines without spreader, mindset of farmers and high cost in removing residues.

Residue burning in Indian IGP

Burning of crop residues lead to loss of plant nutrients (all amount of C, 80% of N, 25% of P, 50% of S and 20% of K) and having adverse impacts on soil physico-chemical and biological properties. About 25-40% of the N, 30-40% of the P, 70-85% of the K, and 40-50% of the S absorbed by rice and wheat crop were retained in residues. At harvest, rice straw contains about 5-8 kg N, 0.7-1.2 kg P, 12-17 kg K and 0.5-1 kg S per ton while one ton of wheat residue contains about 4-5 kg N, 0.7-0.9 kg P, and 9-11 kg K nutrients on dry weight basis. Residue retention have the potential to become primary source of organic matter (as C constitutes about 40% of the total dry biomass), besides enriching soil and providing favorable micro climate for stability of agricultural ecosystems.

VII. Labor shortages and Energy prices

Labor shortages during the crucial period of crop production *viz*., sowing/transplanting and harvesting has become the major challenge before the farmers of NW India. It has happened mainly because of lesser migration of agricultural labor year after year from the eastern part of the country. In such a dismal scenario, CA may be one of the ways to sustain the farmer's livelihood and national food security. The resource requirements of different crops are different as it depends on the genetic potential and their interaction with the environmental indices. Rice is a C_3 plant having less photosynthetic efficiency, high energy requirement and lower yield potential than maize, being a C_4 plant. The resource requirement of both the crops varies with soil and climatic conditions and resource availability. Conventional-till rice requires at least five times more fuel than direct seeded rice (DSR) and ZT maize. To overcome the ill-effects of puddling on soil structure and to reduce drudgery of rice planting without yield penalty, a suitable method of rice seeding (dry/wet direct seeded rice; DSR) is very much essential on the larger area. CA based sustainable intensification/crop diversification is one of the options to cope up labor shortages and energy consumption.

Manual transplanting of rice

VIII. Cost of production

The RW system is labor, water and energy intensive. The key drivers for adoption of CA by farmers are dwindling labor availability and higher cost incurred on diesel and electricity. The problem is further aggravated with deterioration of soil health and emerging challenges of climate change. Timely availability of agriculture labor is a major hurdle in the production of transplanted rice in NW India. Puddling in rice not only disturbs the soil structure, soil compaction, and suboptimal permeability in subsurface layer but also increase the cultivation cost by many folds. The youth in NW India are not showing much interest in agriculture because of that the demand for labor will increase manifolds in near future. There is a need to explore the ways and means by which farmers could reduce the cost of production to make this business profitable.

3. Conservation agriculture (CA)

Scientific efforts made in the past to improve soil, air and water quality through conventional management practices have not yielded tangible results to halt their degradation trend. This, therefore, calls for an urgent need to reorient the present ways of practicing agriculture to those that can improve resource (water, labor and energy) use efficiency by advanced crop management technologies, while maintaining the natural resource base. Resource conservation based agriculture has emerged as a new paradigm to achieve goals of sustainable agricultural production and food security. CA may represent a key solution for enhancing crop productivity and safeguarding the environment through prudent and efficient resource use in Indian IGP. CA is a system based management optimization involving a paradigm shift from intensive tillage to zero or reduced tillage with economically viable crop rotation that

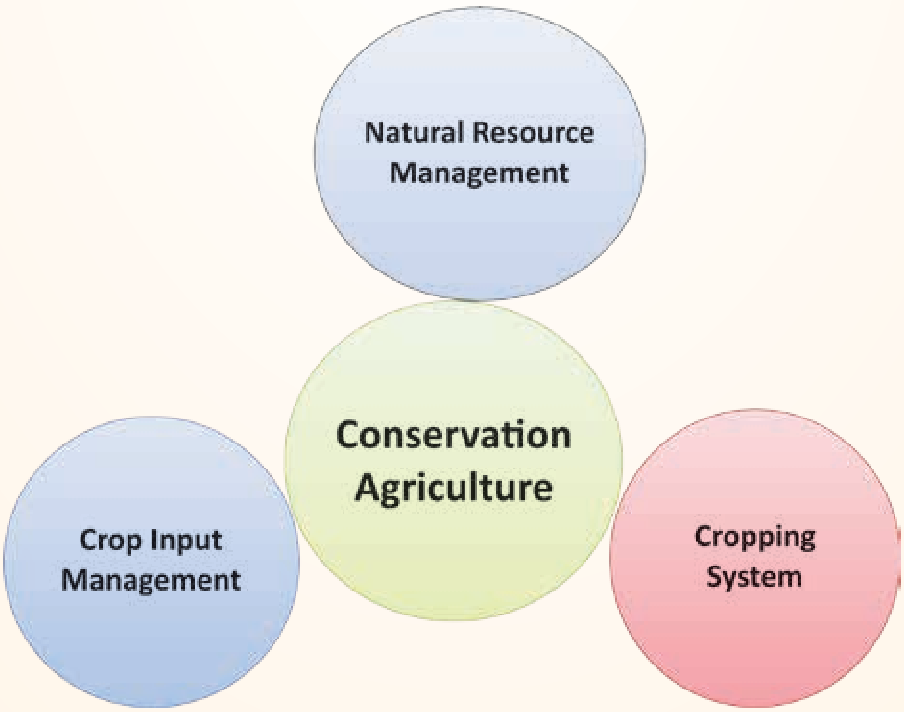


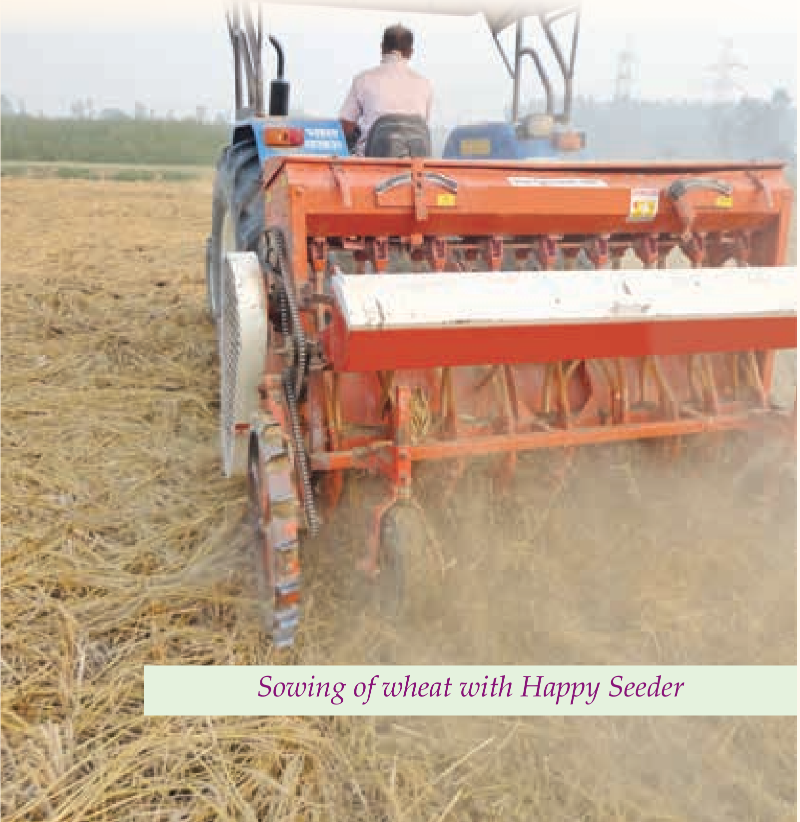
Fig. 1. Components of Conservation agriculture

complement residue retention. Over the past four decades or so, internationally, rapid strides have been made to evolve and spread resource conservation technologies like zero-tillage (ZT), crop establishment, efficient input (water, nutrients, residue etc.) management, suitable crop rotations which enhance conservation of water and nutrients. CA can be defined as an approach to managing agro-ecosystems for improved and sustained productivity, enhanced profits and food security while preserving and enhancing the quality of resource base and the environment.

In NW India, due to rising concerns related to groundwater depletion, increasing cost of cultivation, scarcity of labor and energy, soil and ecological deterioration, poor management of crop residues leading to their burning and climate change, there is increased interest among researchers, policy makers and administrators to find out the options with CA to overcome problems associated with RW system. To keep pace with changing climate, declining resources and growing food demand, South Asia's farmers will have to produce more food from fewer resources while sustaining environmental quality.

I. CA principles

CA refers to a set of agricultural practices involving three basic principles of proven scientific soundness. These include (i) continuous minimum mechanical soil disturbance; (ii) permanent organic (crop residues or cover crops) soil cover; and (iii) diversified, efficient and economically viable crop sequences. These principles are very specific to prevailing agro-climatic conditions, bio-physical and socio-economic conditions of the farmers. Selection of cropping system, crop establishment, residue retention and their management practices may vary as per the situations prevailing under different agro-ecosystems. Sustainability of conventional agriculture, declining profit, labor shortages, degradation of natural resources with expected climate change are the force behind the adoption of CA based on above said three principles.



Sowing of wheat with Happy Seeder

Seedling emergence of wheat under zero tillage

II. Area

ZT is currently practiced in around 155 m ha (10.9 % of crop land) worldwide in more than 50 countries, however CA is practiced in 124 M ha and the area is expanding rapidly. Argentina, Australia, Brazil, Canada and America constitute more than 90% of area under CA. Most widely adopted resource conserving technology in the Indo-Gangetic Plains (IGP) of South Asia particularly in India has been ZT wheat after rice. In South Asia, conservation agriculture is practiced in around 3 M ha, however, in India, it is around 1.5 M ha which comes mostly under Indian IGP. Zero-till establishment of wheat after rice is now practiced in over 2 million ha in India. ZT with residue retention technology in RW system has been reported to help in adapting wheat to terminal heat effects which is an emerging concern globally in view of climate change. Therefore, crop diversification with maize is now required to combat the ground water depletion in RW system in Punjab and Haryana.

III. Benefits

The CA based management practices have various potential benefits such as (i) richer resources-natural resource conservation; (ii) food security- sustained and enhanced productivity; (iii) climate adaptation- better resilient to climate extremes and GHGs emissions. In India, the CA based crop management technologies have been developed and deployed in irrigated production systems and ecologies. But until recent past, the major focus of the technology development has remained on zero-tillage, crop establishment and to some extent on residue management within primary domains of IGP. CA should be biophysically and socio-economically sustainable under different typologies to expand into newer areas. CA based management technologies have proved to produce more at less costs, reduce environmental footprints, promote conjunctive use of organics (avoid residue burning), improve soil health and promote timely planting of winter crops to address the issues of terminal heat stress in the region. Retention of crop residues on soil surface as mulch provides multiple benefits including soil moisture conservation, suppression of weeds, improvement in soil organic C and ultimately overall soil health.

4. CA initiative in NW India

In NW India, on-farm testing of zero-till drill was started with the introduction of inverted T opener on Pantnagar zero-till drill during mid 1990's and got momentum with the establishment of Rice-Wheat Consortium (RWC) in 1994 as a NARS-CG eco-regional initiative. RWC program was a combination of natural resource management and production (extension) in a defined geographical area. The aim of RWC was to efficiently improve the productivity and sustainability of RW systems of South Asia and by conserving natural resources leading to improved livelihoods. A basket of resource conserving technologies (RCTs) were developed and made available to farmers like ZT, bed planting, laser leveling, dry seeding etc. in NW India. During 1996-99, the commercial manufacturing of ZT drill was

Farm Mechanization
for system intensification

started by National Agro Industries, Ludhiana. After 1999, large scale demonstrations and research on RCTs was initiated by CCSHAU, Hisar and DWR, Karnal, Haryana. During the first decade of the 21st century, systematic studies commenced to harness the full benefit of conservation agriculture in irrigated ecosystem of NW India in a collaborative mode with ICAR, NARES and CGIAR institutes like CIMMYT, IRRI etc. During this period, several CA based component technologies have been developed and evaluated in farmers' fields. These include resource conserving tillage (e.g. ZT) and efficient crop establishment (CE) methods (e.g. drill seeding) in both rice and wheat to address the issue of deteriorating soil health, declining water availability, labor shortage, crop establishment methods and the turnaround time between rice and wheat.

Time and again, the response from science to problems in agriculture, generally focused on single resource conserving technologies. These technologies reduce pressure on natural resources that often can only slow down but not reverse the long-term trends of declining resource base and yields. In South Asia, Cereal systems initiative for South Asia (CSISA) was initiated in the year 2009 with the aim of sustaining food security in the region. In this programme, major focus was on system based CA management practices with precise nutrient and water management. Use of ZT methods in RW system, allows them to intensify by introducing an additional crop of mungbean in prevailing crop sequence.

Now, CA has emerged as an alternative to reconcile our short term needs of achieving enhanced productivity within the framework of long term sustainability goals. Recent research efforts in IGP of India have attempted to identify the best genotypes and to refine the crop management technologies that are more resource efficient, improve production and income, and reduce GHGs emission compared to the conventional practices. Since 2012, CA is increasingly being promoted as Climate Smart Agricultural Practice (CSAP) under climate smart villages (CSV) of CGIAR Research program on climate change, agriculture and food security (CCAFS), implemented by CIMMYT and NARES and also as sustainable intensification opportunities under WHEAT (CRP 3.1) and MAIZE (CRP 3.2) programs with the aim of sustaining food security, making adaptation to climate change and enhancing the mitigation potential of cropping systems for GHGs. It also offers an opportunity for arresting and reversing the downward spiral of resource degradation, thereby, making agriculture more resource use efficient, competitive and sustainable.

5. Rationale

RW system is most crucial in NW India with respect to Right to Food Bill and where majority of the population is vegetarian. Recently the sustainability of the conventional RW system, especially in northwest IGP is at risk because of resource degradation, declining factor productivity and shrinking farm profitability under current farming scenario of Indian agriculture which is well documented. These problems vary not only with spatial and temporal dimensions, but also with managerial capabilities of the individual farmer. The

ZT in wheat has been widely adopted in RW system in the NW-IGP and had a significant positive impact on wheat productivity, profitability, and resource-use efficiency. However, unlike wheat, rice continues to be widely grown by conventional practice of transplanting after puddling.

Therefore, to harness the full benefits of ZT, which otherwise are lost by doing puddling in rice or burning of residue, possibility of growing both rice and wheat under ZT with residue retention on soil surface as mulch needs to be explored. This will require further intensification but that has to come through ecological intensification (EI) based on system approach rather than single-technology-centric approach, following the principle of CA. In future, along with shifting from resource and cost intensive conventional tillage and CE methods to resource efficient conservation tillage and CE methods, we may have to shift from rice-wheat system to other cereal-based systems to adapt to future drivers of agricultural change. Diversification of rice with maize could be one possible alternative under extreme labor and water scarce scenario. Looking to the second generation problems of RW system in NW India, there is a need to develop and evaluate the technologies as per the defined domain and socio-economic situation while taking in account the food security, resource efficiency, soil health, biodiversity and environmental quality.

6. Cereal Systems Initiative for South Asia (CSISA) Project

CSISA project was launched in 2009 to improve cereal productivity and farm income in four countries of South Asia (India, Nepal, Bangladesh and Pakistan) to remove the persistence of massive poverty in this part of the continent. This program is funded by Bill & Melinda Gates Foundation (BMGF) and U.S. Agency for International Development (USAID) and run by 5 CGIAR institutes *viz*., CIMMYT, IRRI, ILRI, IFPRI and World Fish. CSISA provides an overall strategy and a new umbrella for contributing cutting edge science and innovative technologies for accelerating short and long term cereal production growth in South Asia's grain baskets through a value chain approach. It builds on technologies developed and lessons learnt from the Rice-Wheat Consortium (RWC), Irrigated Rice Research Consortium (IRRC), and many other investments in agricultural R&D by both public and private sectors. CSISA project was started with 3 major objectives *viz*. 1) reverse the decline in annual cereal yield growth; 2) reduce hunger and malnutrition; 3) increase farm income and security. Research platforms were establsihed to undertake/conduct basic researches on conservation agriculture to develop technologies for out scaling to end users.

7. CSISA at CSSRI

A comprehensive research program on CSISA was designed, initiated and established on farm scale production level at CSSRI experimental research platform, Karnal with the aims to devise strategies to reorient rice-wheat cropping system in Indo-Gangetic Plains keeping into consideration the declining yields, deteriorating natural resources, climatic changes besides water, labor and energy shortages being faced by the present day agriculture. Further objective is to design next generation of cereal systems that are highly productive, resource efficient, sustainable, and adapted to the expected changes in environmental and socio-economic drivers (e.g. yield, resource use, impact of new technologies on crop, soil, and environmental health). During first phase (2009-12), research was conducted by NARES partners in collaboration with IRRI, whereas in second phase (2012-15), CIMMYT is the collaborating partner. Keeping the program objectives in mind, near-production scale long-term experimental platform was designed to optimize cropping systems to current and future drivers of agricultural change in the region and assess the performance of different agricultural systems (scenarios) with respect to crop productivity, water and energy use, economic returns and soil quality at CSSRI, Karnal.

Overview of CSISA experimental site (RP II) at CSSRI, Karnal

8. Research approach

I. Site characterization

CSISA experimental research platform is located at the ICAR-Central Soil Salinity Research Institute (CSSRI), Karnal, Haryana, India (29°70′N latitude and 76°96′E longitude). The climate of the area is semi-arid, with an average annual rainfall of 700 mm (75–80% of which is received during June to September), minimum temperature of 0–4°C in January, maximum temperature of 41–44°C in June, and relative humidity of 50–90% throughout the year. The reclaimed alkali soil of the experimental field was loam in texture, low in organic carbon with alkaline pH. Before start of the experiment, EM survey was conducted to see the variability between and within plots. The soil characteristics of the experimental site are given in Table 1.

Table 1. Initial soil characteristics (0-15 cm soil depth) of CSISA Research Platform site

Soil properties	Mean
Clay (%)	27.48
Silt (%)	43.52
Sand (%)	29.00
pH (1:2 soil:water)	8.00
EC (dS m^{-1}) (1:2 soil:water)	0.37
Total carbon (%)	0.56
Available P (mg kg^{-1})	5.74
Exchangeable K (mg kg^{-1})	130
Total N (%)	0.06

II. Experimental details

A production scale long-term cropping systems trial adapted to four different scenarios was established in 2009. After laser land levelling, experimental area was divided into 12 permanent plots of 2000 m^2 each. A general crop of puddled transplanted rice (uniformity/gradient crop) was grown in all the plots during July-October 2009 to record variability and to exhaust the nutrients to keep same level of available nutrients. Four scenario treatments varying in cropping system, tillage, crop establishment, varieties, residue management, nutrient management and water management were evaluated for four years during 2009-13. All scenarios were organized in a randomized complete block design replicated thrice having farm-scale plots, each of size 2000 m^2. Details relating to different scenarios are described in Table 2.

Table 2. Description of scenarios using a wide range of indicators

Particulars	Scenario 1	Scenario 2	Scenario 3	Scenario 4
Drivers of agricultural change	Business as usual (current farmers' practice)	Increasing productivity and income by intensification and best management practices (integrated crop and resource management) (partial CA based system)	System designed to deal with water, labor, and energy scarcity and degrading soil health (complete CA based systems)	Futuristic, intensive and diversified cropping systems to deal with resource use and optimization (complete CA based systems)
Cropping system	Rice-wheat	Rice-wheat-mungbean	Rice-wheat-mungbean	Maize-wheat-mungbean
Crop establishment method	Rice- transplanting Wheat- broadcast	Rice- transplanting Wheat- drill seeding Mungbean- drill/ relay broadcast	Rice- drill seeding Wheat- drill seeding Mungbean- drill/ relay broadcasted	Maize- drill seeding Wheat- drill seeding Mungbean- drill/ relay broadcasted
Tillage	Conventional till	Conventional/ Zero-till Rice- CT-TPR/ puddling Wheat- zero-till Mungbean- zero-till	Zero-till Rice- zero-till Wheat- zero-till Mungbean- zero-till	Zero-till Maize- zero-till Wheat- zero-till Mungbean- zero-till
Varieties	Rice- Pusa 44 Wheat- PBW 343/ DBW 17/ HD 2967	Rice- Arize 6444 Wheat- DBW 17/ HD 2967 Mungbean- SML 668	Rice- Arize 6129 Wheat- DBW 17/ HD 2967 Mungbean- SML 668	Maize- NK 6240/ DKC 9125 Wheat- DBW 17/ HD 2967 Mungbean- SML 668
Residue management	All residue removed	Partial rice and wheat residue (anchored) retained in first 2 years and after that full rice residue retained; and full mungbean residues incorporated during puddling in rice season	Full (100%) rice and mungbean and partial (anchored) wheat residue retained on soil surface	Full (100%) residue retained in first 2 years and partial (65%) residue (below cobs) retained in next 2 years and partial (anchored) wheat and mungbean residue retained on soil surface

Nutrient management	Rice: Basal: 125 kg DAP ha^{-1} and 25 kg zinc sulphate ha^{-1}; Top dressing: 330 kg urea ha^{-1} was applied in three equal splits at early establishment (7-10 DAT), active tillering (21-25 DAT), and at panicle initiation stage (45-50 DAT). Wheat: Basal: 125 kg ha^{-1} DAP at sowing; Top dressing: urea was applied in two splits manually @ 150 and 125 kg ha^{-1} at first and second irrigation coinciding with crown root initiation (CRI) and maximum tillering	Rice: Basal: 125 kg DAP ha^{-1}, 100 kg MOP ha^{-1}, and 25 kg zinc sulphate ha^{-1} Top dressing: 280 kg urea ha^{-1} was applied in three equal splits at early establishment (7-10 DAT), active tillering(21-25 DAT), and at panicle initiation stage (45-50 DAT). Wheat: Basal: 200 kg ha^{-1} NPK (12:32:16) was drilled at sowing; Top dressing: urea was applied in 2 splits manually @ at 150 and 125 kg ha^{-1} at first and second irrigation No fertilizer application	Rice: Basal: 200 kg NPK (12:32:16) was drilled at sowing + 50 kg MOP ha^{-1}. 25 kg Zinc sulphate ha^{-1} applied 7-10 DAS Urea top dressing: 300 kg urea ha^{-1} was applied in 3 splits @ 50 kg ha^{-1}at early (15 DAS) and @ 125 kg ha^{-1} each at active tillering (25 DAS) and at panicle initiation (45-55 DAS) Wheat: Basal: 200 kg ha^{-1} NPK (12:32:16) was drilled at sowing; Top dressing: urea was applied in 2 splits manually @ at 150 and 125 kg ha^{-1} at first and second irrigation	Maize: Basal: 200kg NPK drilled at sowing + 65 kg MOP Urea top dressing: 325 kg urea ha^{-1} applied in 3 splits @ 125 kg ha^{-1} each at 20 and 45 DAS and @ 75 kg ha^{-1} at tasseling/silking stage Wheat: Basal: 200 kg ha^{-1} NPK (12:32:16) was drilled at sowing; Top dressing: urea was applied in 2 splits manually @ at 150 and 125 kg ha^{-1} at first and second irrigation
Water management	Rice: Continuous flooding of 5 cm depth for one month, followed by irrigation applied at hair-line crack Wheat: On critical growth stages	Rice: Continuous flooding of 5 cm depth for first 15-20 days after transplanting 'fb' irrigation at -40 to -50 kPa matric potential at 15 cm depth till 1-wk before flowering 'fb' irrigation at -15 to -20 kPa Wheat: On critical growth stages Mungbean: On need basis	Rice: Kept soil wet for first 20 days 'fb' irrigation at -20 to -30 kPa matric potential Wheat: On critical growth stages (CRI, tillering, jointing, flowering, milk, & grain filling) Mungbean: On need basis	Maize: On need basis Wheat: On critical growth stages Mungbean: On need basis
Crop management	Farmers' practice	Best management	Best management	Best management

Scenario 1 (Business-as-usual): This scenario was based on farmer's practices in which rice was grown by transplanting in puddled soil, whereas wheat was sown by broadcasting and/ or line sowing method in conventionally-tilled fields. About 30 to 35 days old rice seedlings were randomly transplanted manually. Farmers generally burn rice residues *in situ* before wheat sowing; these were removed from experimental plots before land preparation for wheat sowing as burning is legislatively banned in Punjab and Haryana.

Rice-wheat cropping system

Scenario 2 (Partial CA): This scenario was designed to increase productivity and income through intensification and best management practices. Instead of rice-wheat in scenario 1, rice-wheat-mungbean was the rotation in this scenario (Table 2). Wheat was drilled in ZT plots with partially anchored rice stubbles; mungbean, was drilled/relayed in ZT plots after wheat harvest in partially anchored wheat stubbles, followed by puddled transplanted rice, where mungbean residue was fully incorporated into soil during soil churning. After two years onwards, full (100%) residue of rice were retained.

Rice-wheat-mungbean cropping system

Scenario 3 (Full CA): This scenario was designed to deal with increasing scarcity of water, labor, and energy. In this scenario, the cropping system was similar to scenario 2 (rice-wheat-mungbean) but all the crops were grown under ZT. Wheat was drilled in full rice residues; mungbean was drilled/relayed as per the situation prevailed; and rice was direct drill seeded in partially anchored wheat stubbles of about 10-15 cm height and in mungbean residue after killing it with paraquat, a non-selective herbicide.

Rice-wheat-mungbean cropping system

<u>Scenario 4 (Full CA for future)</u>: This scenario was designed to identify futuristic and diversified cereal based cropping system as an alternative to rice-wheat to deal with the same issues as in the scenario 3 (Table 2). In this scenario, maize-wheat-mungbean rotation was followed. All the crops in rotation were grown under ZT as in scenario 3. Residue management of wheat and mungbean were similar to scenario 3, however, 65% of total maize residue (portion below the cob) was retained on the soil surface after harvesting the above cob portion.

Maize-wheat-mungbean cropping system

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III. Soil sampling and analysis

Before imposing the experimental treatments (after cover crop harvest), baseline soil samples were collected from 0-15 cm soil depth. For soil sampling, each plot was divided into four grids (10-m x 50-m). Within each grid, soil was collected from 4 locations and it was composited depth wise. Collected soil samples were analyzed for different soil parameters as per the standard procedures.

Soil sampling for bulk density

IV. Crop management

The crop management including land preparation, seed rate, sowing time, seed treatment, fertilizer management, water management, and pest management for rice, wheat and maize under different scenarios was done as per the standard recommendations. Wheat was broadcasted manually or drilled in conventionally tilled plots in scenario 1, whereas, rice was manually transplanted in scenarios 1 and 2, and was drill seeded in scenario 3 using Turbo seeder. Rest of the crops were sown using Turbo seeder and using a separate box with inclined plate seed metering system. The mungbean pods were manually picked followed by application of paraquat (500 g ai ha^{-1}), a non-selective herbicide to sow the next rice crop.

V. Residue management

Residues were managed under different scenarios using Turbo seeder. Turbo seeder worked very well upto a residue load of 10 t ha^{-1}. After wheat harvest, all the loose residues were removed and only wheat stubbles were retained on the soil surface in all scenarios except in scenario 1 where the entire residue (loose + anchored) was removed from the plots. In scenario 2, 3 and 4, residues were maintained as per the details given in Table 2.

Turbo seeder in action for wheat sowing

Crop residues recycled in four scenarios varied in amounts and depends upon the biomass produced in a particular year. Scenario 1 had received no crop residue. On the other hand, scenarios 2, 3, and 4 had been received a total of 48, 56 and 66 t ha^{-1} crop residues, respectively, during the last four years. In scenario 2, 26 t ha^{-1} of anchored and loose rice stubble and 8 t ha^{-1} anchored wheat stubbles were retained on soil surface at the time of wheat and mungbean sowing, respectively, during the last 4 years, while 13 t ha^{-1} of mungbean residue was incorporated into the soil during puddling. In scenario 3, full rice (32 t ha^{-1}) and mungbean residues (14 t ha^{-1}), and anchored wheat stubbles (10 t ha^{-1}) were retained on the soil surface. In scenario 4, full maize residue (43 t ha^{-1}), in addition to 9 t ha^{-1} anchored wheat stubbles, and full mungbean residues (14 t ha^{-1}) were retained on the soil surface.

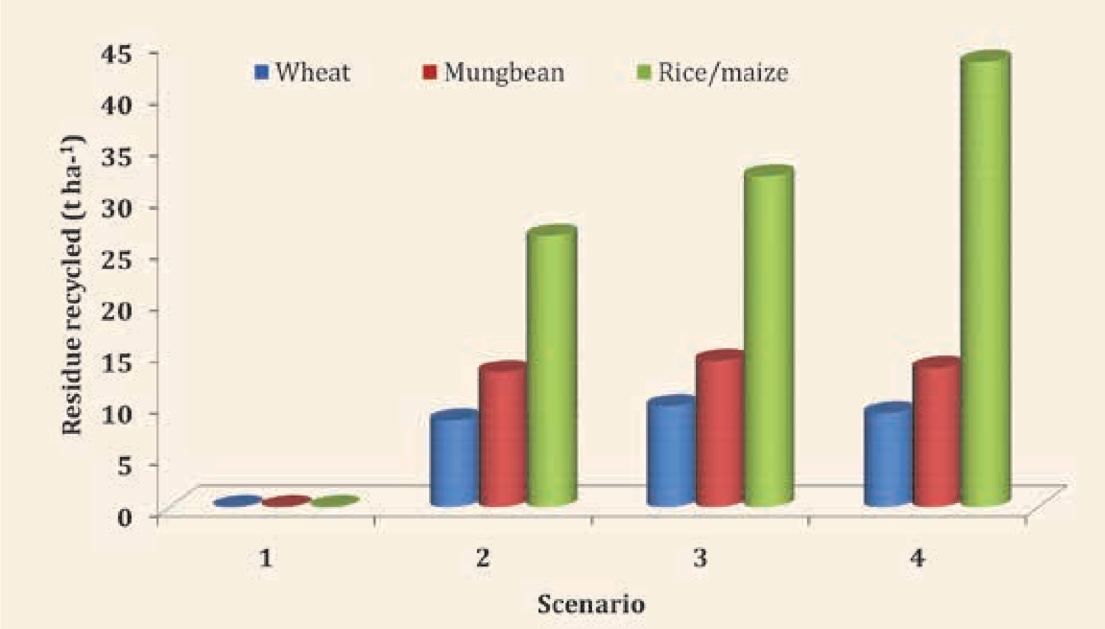

Fig.2. *Crop residue recycled in different scenarios*

VI. Water management

For precise water application and measurements at each plot, 6 inch polyvinyl chloride (PVC) pipe line (Jain Irrigations, Jalgaon, India) was installed in sub-surface (90 cm) having provision of outlets at centre of the plot face. To avoid any water loss within and between irrigation intervals, a non-return valve (NRV) was fixed with underground pipeline at tubewell delivery outlet link. Each outlet was provided with an air tight butter fly valve to avoid any loss of water due to leakage. For measurement of irrigation water during each irrigation, water meter reading was recorded at the start and end of irrigation. Irrespective of treatment and crop, the flooding depth of water at each irrigation was maintained at around 5±2 cm. The amount of water was quantified in mm ha^{-1} using equation given below:

$$\text{Volume of irrigation water} = \frac{\text{Final water meter reading-Initial water meter reading}}{2000} \times 10000$$

$$\text{Irrigation water (mm ha}^{-1}\text{)} = \frac{\text{Volume of irrigation water (Kilolitre ha}^{-1}\text{)}}{10}$$

1 ha mm irrigation depth = 10 kilolitre = 10,000 litre =10 m^3

To monitor soil matric potential, gauge type soil tensiometers (IRROMETER) were installed at 15-cm and 30-cm depth in all the plots immediately after crop sowing. During rice/maize season (*kharif*), irrigation water was applied based on tensiometer reading. However, during wheat season (*rabi*), water was applied based on tensiometer reading as well as on critical wheat growth stages.

Irrometer for measuring soil matric potential

VII. Nutrient management

In rice and wheat crops, the fertilizers were given as per the dose mentioned in Table 2. Fertilizers were applied in the form of NPK complex fertilizers, DAP, Urea, Zinc and Iron sulphate to meet the nutrient demand of the crops. P and K fertilizers were applied as basal and N both as basal and top dressed at different growth stages of the different crops (Table 2). No fertilizer was applied in mungbean crop. Rice, wheat and maize crops were sown using Turbo seeder with a fertilizer box for fertilizer drilling and separate seed box with inclined plate seed metering system for seeding.

VIII. Energy budgeting

The energy output of different cropping sequences were calculated on the basis of equivalent values given by Mittal and Dhawan (1988) and other workers and expressed as total energy (MJ ha^{-1}).

IX. Crop harvest and yield

At maturity, wheat was harvested either by combine or with reaper and binder machine (BCS India Pvt. Ltd., Ludhiana) at about 15-20 cm above ground level in all the scenarios except scenario 1 where wheat was harvested from ground level. Similarly, rice was harvested and threshed either manually or with the help of combine. Maize plots were harvested manually and threshed using maize sheller. Grain of rice, wheat and maize contained about 14, 12 and 14 % of moisture, respectively. Mungbean yields were estimated by harvesting entire plot. For comparing total system productivity, all non-rice crops in the systems were converted into rice equivalent yield. However, for different scenarios, maize yield of scenario 4 was converted into rice equivalent yield (t ha^{-1}).

$$\text{Rice equivalent yield} = \frac{\text{Crop yield (q ha}^{-1}\text{) x Minimum support price of crop (Rs. q}^{-1}\text{)}}{\text{Minimum support price of rice (Rs. q}^{-1}\text{)}}$$

9. Research achievements

A set of CA based cropping system management scenarios were compared with business as usual i.e. farmer management scenario in the region to address the issues of deteriorating natural resources, plateauing yields, water, labor and energy shortages and emerging challenges of climatic aberrations being faced by the farmers.

I. Crop productivity

Productivity of different crops and cropping systems differed significantly in different scenarios (Fig. 3). Zero-till wheat in scenarios 2, 3, and 4 yielded higher than conventionally-till wheat by 6, 15 and 16%, respectively, compared to scenario 1 (5.1 t ha^{-1}). The yield of

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rice was higher by 14% in scenario 2 over scenario 1, while in scenario 3, it was at par with scenario 1. Rice equivalent of maize (maize yield- 8.3 t ha^{-1}) in scenario 4 was recorded to be 10 % higher than scenario 1 (7.0 t ha^{-1}).

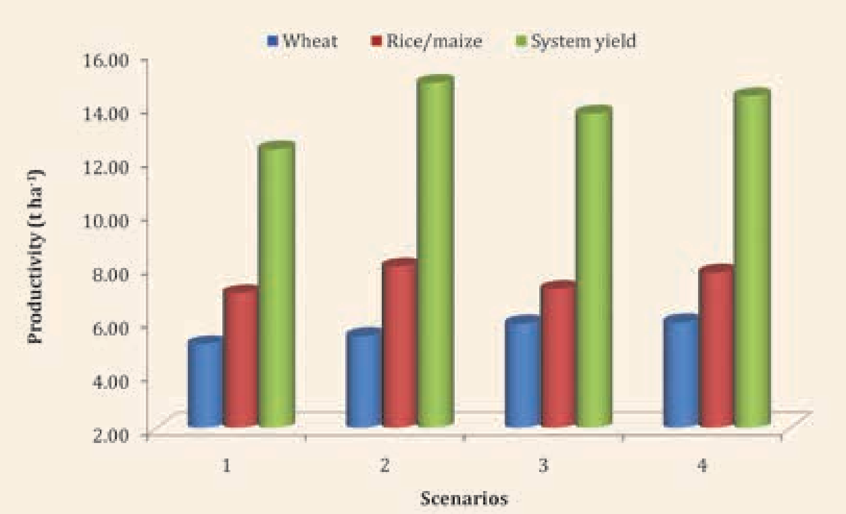


Fig.3. *System productivity under different scenarios*

Rice equivalent system productivity varied among different scenarios. The rice equivalent system productivity was highest in Scenario 2, 3 and 4 by 20, 11 and 14%, respectively, in comparison to scenario 1 (12.4 t ha^{-1}). Further, the rice equivalent system productivity in scenario 3 and 4 didn't differ amongst themselves. Scenario 1 recorded lowest system productivity of 13.0 t ha^{-1}. CA based scenarios demonstrated higher system productivity during the last 4 years on an average basis.

II. Irrigation water

In wheat, four years average irrigation water application varied from 379 to 431 mm in different scenarios. However, there was not much variation between scenario 1 and 2 and scenario 3 and 4 with respect to each other (Fig. 4). Irrigation water application followed the trend as: scenario 1 > 2 > 3 > 4.

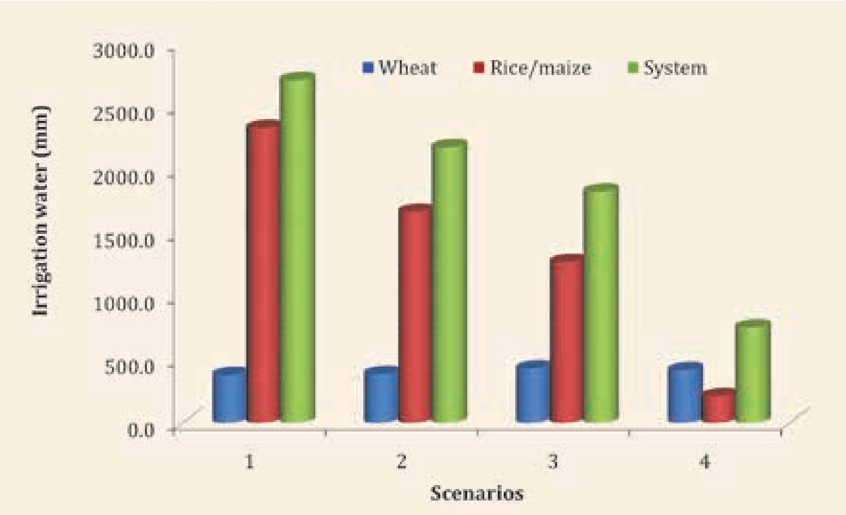


Fig.4. *Irrigation water application in different scenarios*

In rice/maize, four years average irrigation water application was highest in scenario 1 (2332 mm ha^{-1}) followed by scenario 2 (1669 mm ha^{-1}) and 3 (1271 mm ha^{-1}) and it was lowest in scenario 4 (212 mm ha^{-1}). However, on system basis, irrigation water application varied significantly amongst scenarios and followed the trend: scenario 1 > scenario 2 > scenario 3 > scenario 4. Highest water requirement in scenario 1 (2710 mm ha^{-1}) and least consumption in scenario 4 (754 mm ha^{-1}) were reported in different years.

Saving in irrigation water

In scenario 4, where maize was grown instead of rice, irrigation water (four years average) saving was 91% compared to scenario 1. Similar irrigation water saving in scenarios 2 and 3 was around 45 and 28 % respectively (Fig. 5). Further, irrigation water application, at system level, in different scenarios also followed the same trend as of irrigation water during *kharif* season with savings of 20, 33 and 72% irrigation water in scenarios 2, 3, and 4, respectively, compared to scenario 1.

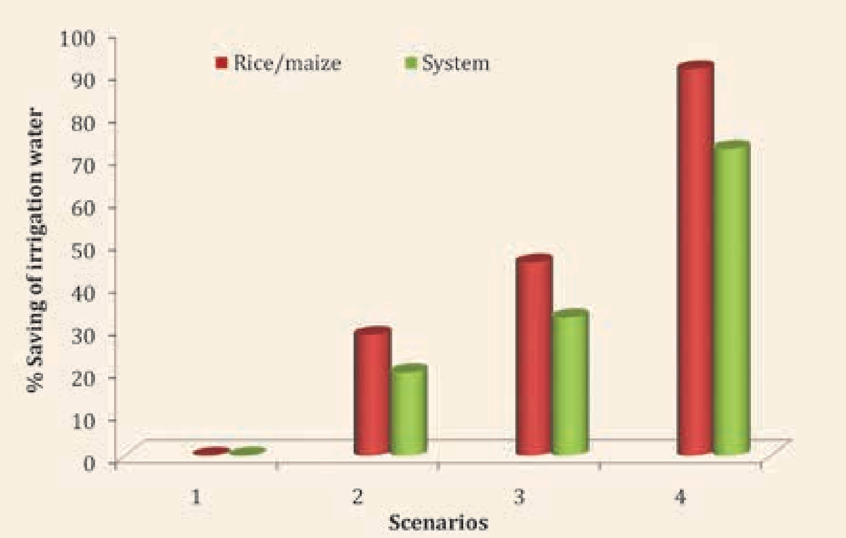


Fig.5. *Saving of irrigation water in different scenarios*

The irrigation water application in transplanted rice, where water was managed by alternate wetting and drying method (scenario 2) was 28% lower as compared to scenario 1 in which water was applied as per the farmer's practice where fields were continuously flooded for most of the growing period.

III. Energy requirement

The best management practice proved to be the most energy efficient as compared to the farmers practice (scenario 1) under CA based management system. The energy usage in different scenarios varied amongst themselves over the different years. Energy requirement for wheat and rice/maize ranged from 20172 to 24729 and 16019 to 51084 MJ ha^{-1}, respectively (Fig. 6). Regarding the overall system energy requirement, the futuristic scenario proved to be the most energy (40551 MJ ha^{-1}) efficient, while the farmers practice (75812 MJ ha^{-1}) showed higher energy requirement.

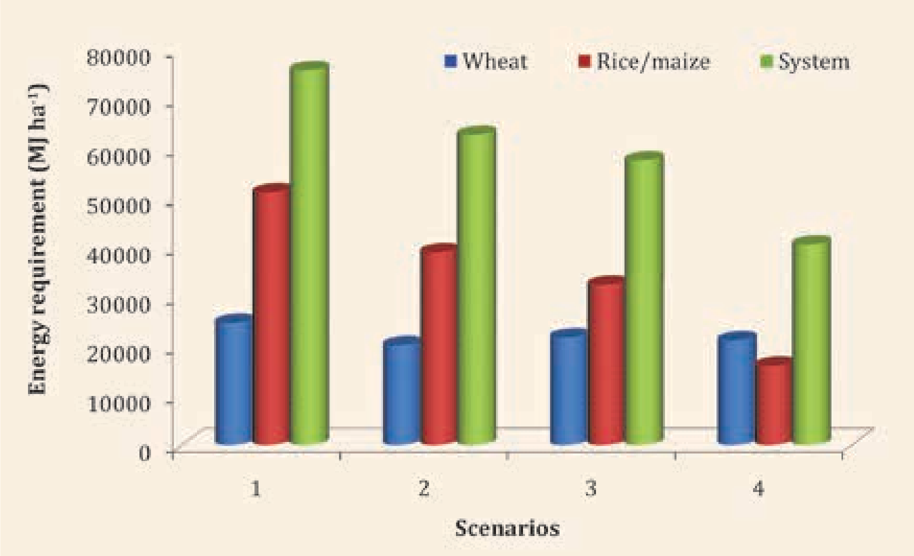


Fig.6. *Energy requirement in different scenarios*

Saving in energy requirement

In scenarios 2, 3 and 4, wheat was sown under ZT conditions and the savings in energy requirement ranged from 12-18% compared to scenario 1 (Fig. 7). However, in rice/maize, similar energy saving in scenarios 2, 3 and 4 was 24, 37 and 69 % than that of scenario 1. While observing energy saving in system mode, the futuristic scenario (scenario 4) proved to be the most efficient with energy saving of 47 %, followed by scenario 3 and 2 with energy saving of 24 and 17 %, respectively, compared to scenario 1.

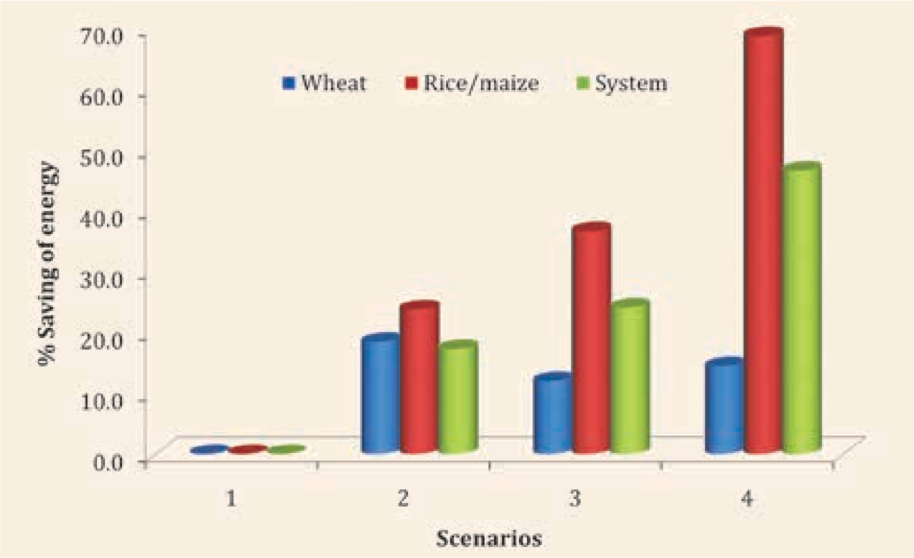


Fig.7. *Saving of energy in different scenarios*

IV. Fertilizer saving

In NW India, 10-12 tonnes grain yield is generally recorded from rice-wheat cropping system, each year. Farmers resort to imbalanced fertilizer use by adding more urea than the recommended dose as both crops are more responsive to N. This practice results in higher mining of nutrients from the soils and also exceeds the rate of replenishment in the system. Nutrient depletion in soils adversely affects soil quality and reduces factor productivity, crop yield and consequently poses a potential threat to food security and socio-ecological instability. These changes not only inhibit vegetative growth, but reduce the presence of valuable biota and the overall biodiversity in the soil. CA has proven potential of converting soils from sources to sinks of atmospheric C as evidenced by many studies in the rainfed ecosystem. In general, soil carbon sequestration by adoption of CA practices is marginal during the first quarter of decade. In CA, permanent crop residue mulch retention, combined with ZT could be the best management practice for soil organic matter (SOM) restoration which helps in saving of N fertilizers after few years of establishment. At CSISA platform, broadcasting of urea was practiced as per requirement of crop based on observation made by Green Seeker at 70 days of crop growth and first 2 applications was made as mentioned in Table 2 and thus a saving of urea by 10-15% was observed with full CA practices (scenario 3 and 4) in wheat crop after 3 years of experimentation. If scenario 3 (Dry DSR-ZT Wheat-ZT mungbean) is practiced in Haryana where RW system is being followed (1.2 M ha), we can save 0.7-1.1 M bags of urea every year.

Mungbean as a catch crop

V. Economic returns

Net returns of cropping system differed significantly in different scenarios (Fig. 8). Scenario 4 yielded highest net returns (US$ 1234) on last 4 years average basis. Further, scenario 4, 3 and 2 recorded higher returns (four years average basis) by 32, 29 and 17% respectively than farmers' practice (scenario 1). The higher returns clearly reflect the cumulative effects of improved management practices, especially the reduction in labor and tillage, and higher yields.

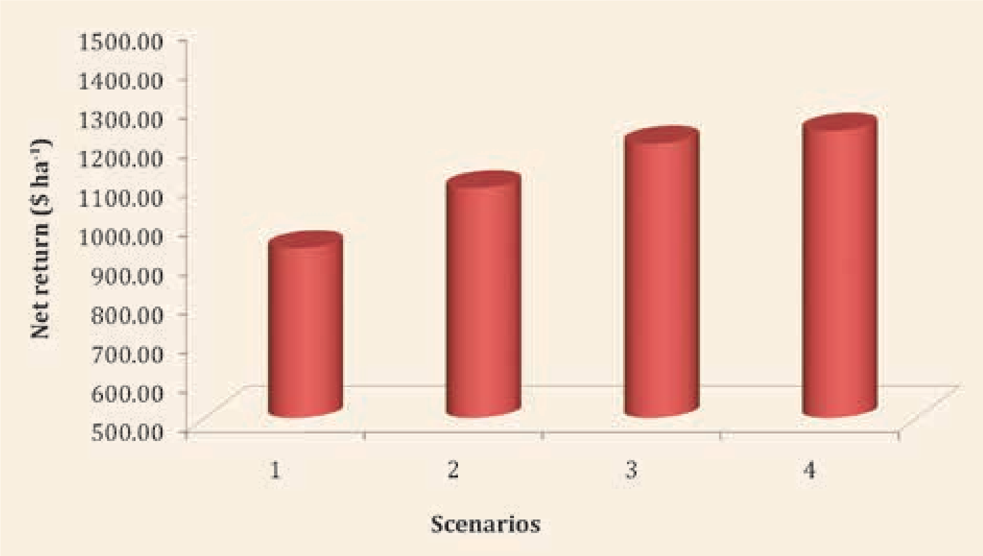


Fig.8. *Net returns in different scenarios*

VI. Soil quality

a. Soil organic carbon (SOC)

In scenario 2, 3, and 4, a total of 48, 56 and 66 t ha^{-1} crop residues, respectively, has been recycled in last 4 years (2009-13), however, all crop residues were removed in scenario 1. This much amount of crop residues under different CA based scenarios led to changes in SOC content of soil.

Improvement in soil health by adopting conservation agriculture

The initial SOC at 0-15 cm soil depth was 0.45% at the beginning of the experiment and after 4 years it was found same in scenario 1. However, SOC content, after four years of experimentation increased by 22, 67 and 71% in scenario 2, 3, and 4, respectively, compared to scenario 1. The SOC content under different scenarios at 0-15 cm soil depth after four years of CA practices is presented in Fig. 9.

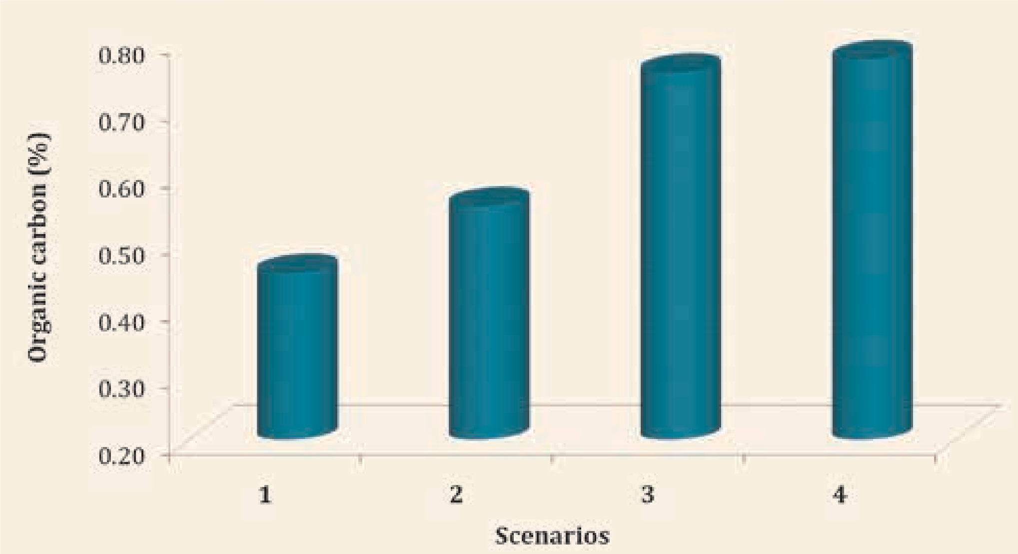


Fig.9. *Soil organic carbon in different scenarios at 0-15 cm depth*

b. Macro (N, P and K) nutrients

The availability of primary macro nutrients such as N, P and K varied under different CA based practices (Fig. 10). Scenario 3 and 4 recorded higher available N content at upper surface soil layer (0-15 cm) as compared to scenario 1 (117 kg ha^{-1}). The N content was increased by 13% in scenario 2 and by almost 24% in scenario 3 and 4 compared to farmers practice during last 4 years.

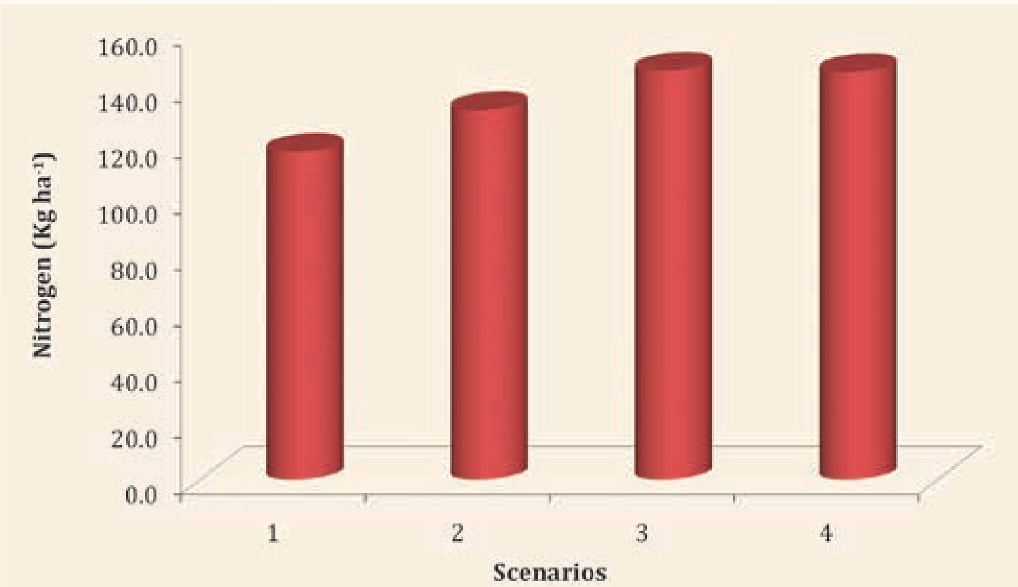


Fig.10. *Available N content in soil under different scenarios at 0-15 cm depth*


S. LIMIT PLOT SEED DRILL

CA-based practices particularly conservation tillage and residue retention played a major role on nutrient content and their availability. Available P content also varied in different scenarios. Highest available P was observed under scenario 3 (21.6 kg ha^{-1}) and was 38% higher than scenario 1. Further, scenario 4 recorded 25% higher P content in surface layer, compared to scenario 1 (15.7 kg ha^{-1}). Scenario 1 and 2 showed lower and almost equal P content (Fig. 11).

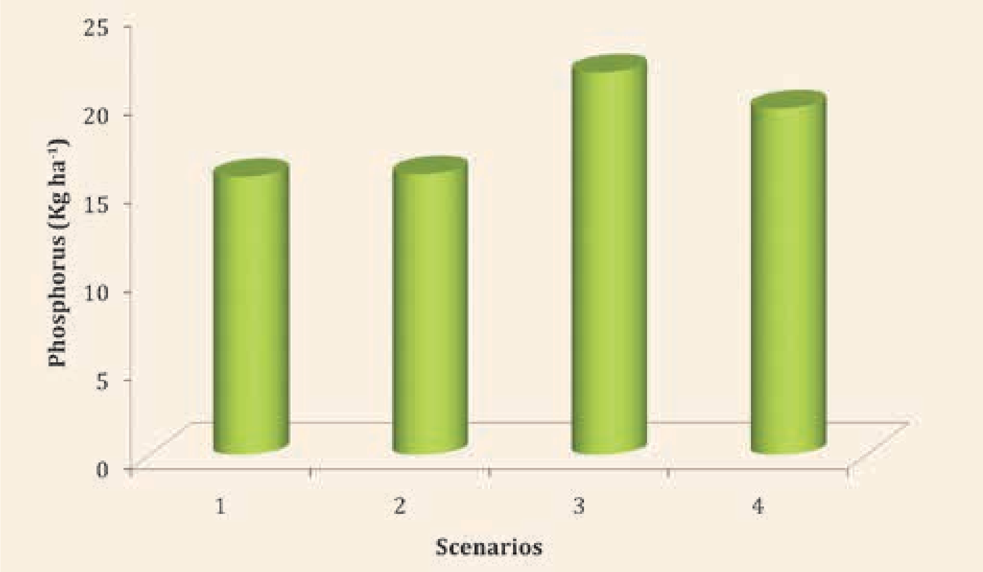


Fig.11. *Available P content in soil under different scenarios at 0-15 cm depth*

The highest quantity of available K was recorded under scenario 4 (318 kg ha^{-1}) followed by scenario 3, whereas scenario 1 and 2 (179 kg ha^{-1}) reported at par and lower available K at 0-15 cm depth (Fig. 12). Scenario 4 and 3 showed higher K content by 73 and 29% compared to scenario 1. There was no difference between K content in scenario 1 and 2 during the last 4 years.

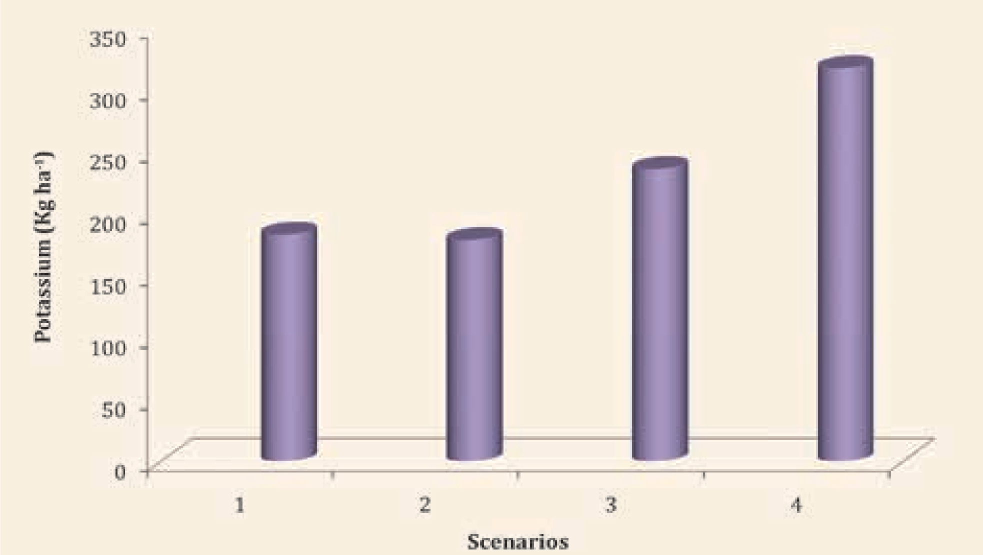


Fig.12. *Available K content in soil under different scenarios at 0-15 cm depth*

c. Micro-nutrients

The micronutrient content in soil is also influenced by the CA practices like macro nutrients. Amongst different scenarios, highest Zn content was observed in scenario 3 (9.15 mg kg^{-1}), followed by scenario 2. Zn content is scenario 4 was almost at par with scenario 2. (Fig. 13). Scenario 1 recorded lowest Zn values amongst different scenarios. Compared to scenario 1, Zn content increased by 36, 48 and 34% in scenario 2, 3 and 4 respectively, in the upper soil layer (0-15 cm). Further, Cu content was almost similar in scenario 1 and 3 (2.7 mg kg^{-1}), whereas it was higher by 10% in scenario 2, compared to scenario 1.

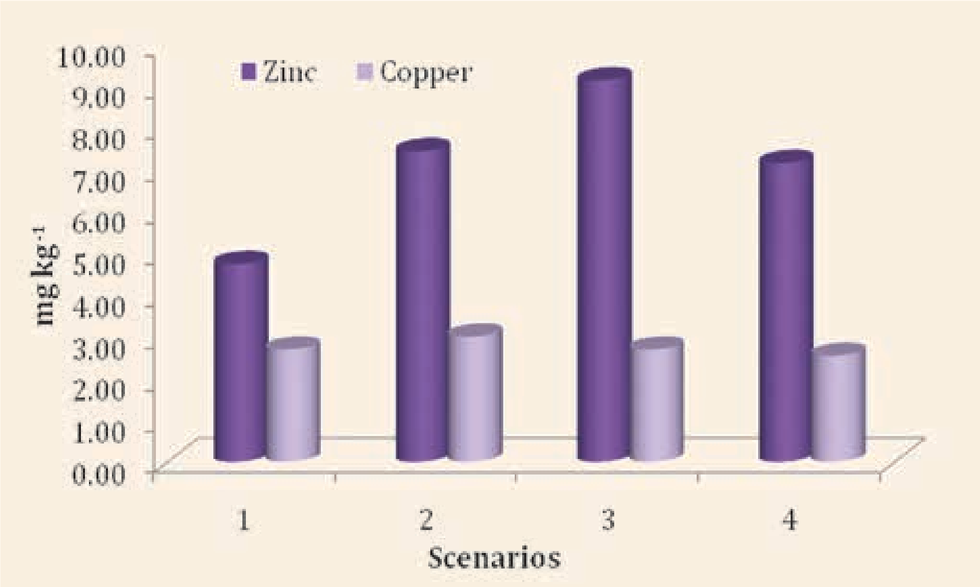


Fig.13. *Zn and Cu content in soil under different scenarios at 0-15 cm depth*

Amongst different scenarios, highest Fe content was recorded in scenario 2 (149 mg kg^{-1}) and lowest in scenario 4 (88 mg kg^{-1}), after four years of experimentation (Fig. 14). Fe content in scenario 3 was at par with scenario 1. However, it increased by 11% in scenario 2 compared to scenario 1. Further, Mn content in scenario 3 (99 mg kg^{-1}) also increased by 18% compared to scenario 1.

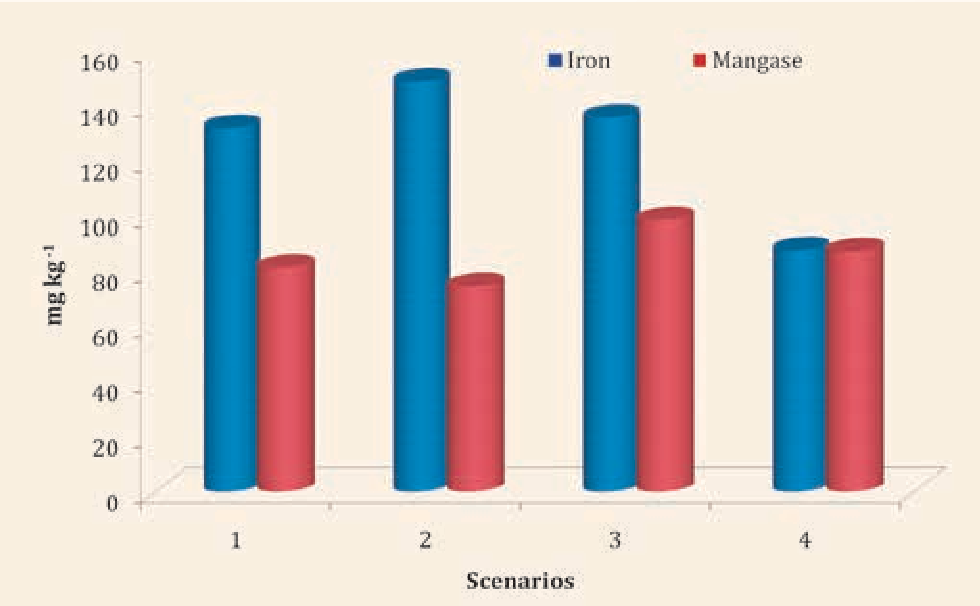


Fig.14. *Fe and Mn content in soil under different scenarios*

d. Microbial diversity

CA based management practices significantly affect microbial population in different scenarios at 0-15 cm soil depth. Microbial diversity was studied after 4 years of experimentation. Microbial counts related to fungal (11.7 c.f.u $\times 10^3 g^{-1}$ soil), bacterial (16.9 c.f.u $\times 10^5 g^{-1}$ soil) and actinomycetes (8.4 c.f.u $\times 10^5 g^{-1}$ soil) were higher in scenario 4 compared to scenario 1 (Fig. 15). Microbial population followed the trend: scenario 1 < scenario3 < scenario 2 < scenario 4.

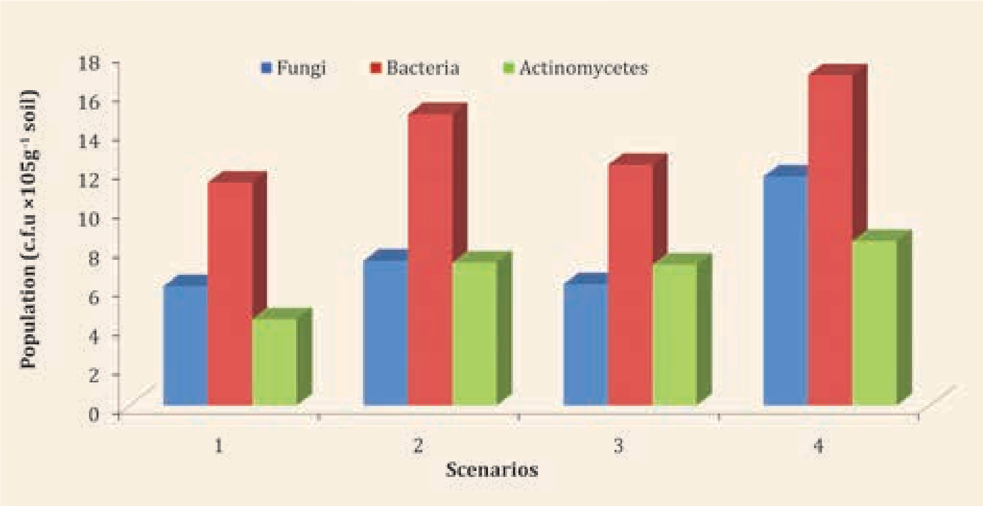
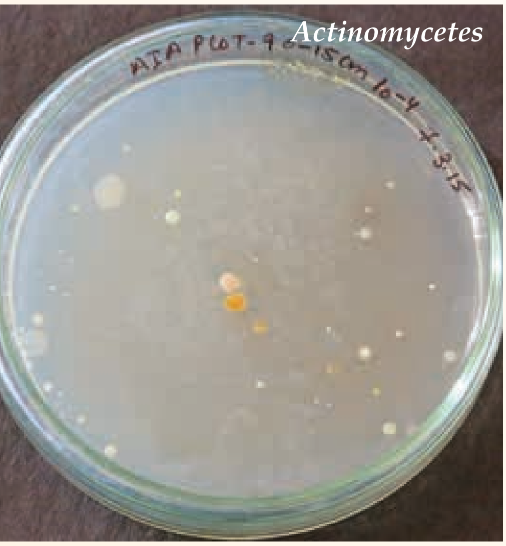


Fig.15. *Microbial count in soil under different scenarios at 0-15 cm depth*

Most abundant lignocellulosic fungi recorded were *Aspergillus flavus*, *Aspergillus terreus*, *Aspergillus niger*, *Alternaria alternate*, *Fusarium oxysporum*, *Penicillium oxalicum*, *Penicillium janthinellum*, *Cladosporium cladosporoides* etc. These fungi dominated in the CA based management practices. These are also known to help in fast mobilization of nutrients upon residue decomposition. As per metagenomics results, CA based Maize-wheat-mungbean system (Scenario 4) showed highest number of saprophytic fungi (Fig. 16). As per the observation, diversification of RWCS in IGP will improve the number of lignocellulose decomposing fungi.



Soil fauna

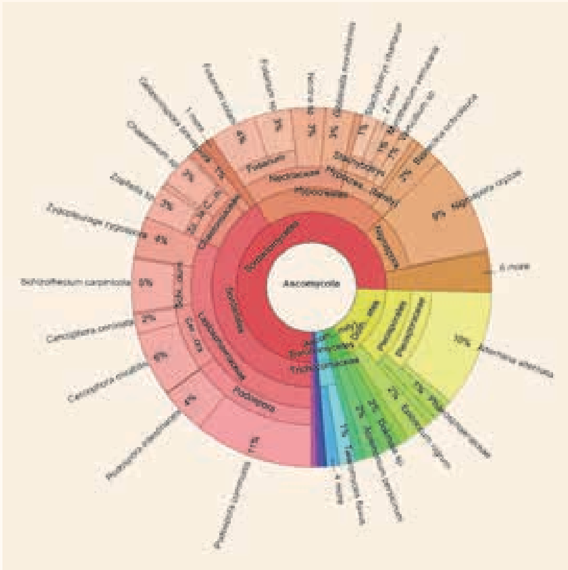


Fig.16. *Microbial diversity in soil under different scenarios at 0-15 cm depth*

VII. Effects on *Phalaris minor*

Phalaris minor is the most troublesome weed of wheat in NW India. This weed is getting resistant to many popular herbicides like Isoproturon and others. CA based management practices provide the solution to control this weed by changing the date of sowing and keeping the residue as mulch on the soil surface. Early sowing of wheat can reduce the *Phalaris* population by 68-80% compared to normal sown (15 November) conditions in NW India. A residue load of 6 t ha^{-1} is required to reduce the *Phalaris* population by 45-75% (Fig. 17). After 3 years of crop rotation in scenario 2 and 3, herbicides in wheat crop were not applied as the weed population had gone negligible. In long term CA based system, herbicide application in wheat crop depends on the residue load, time of sowing and weather conditions.

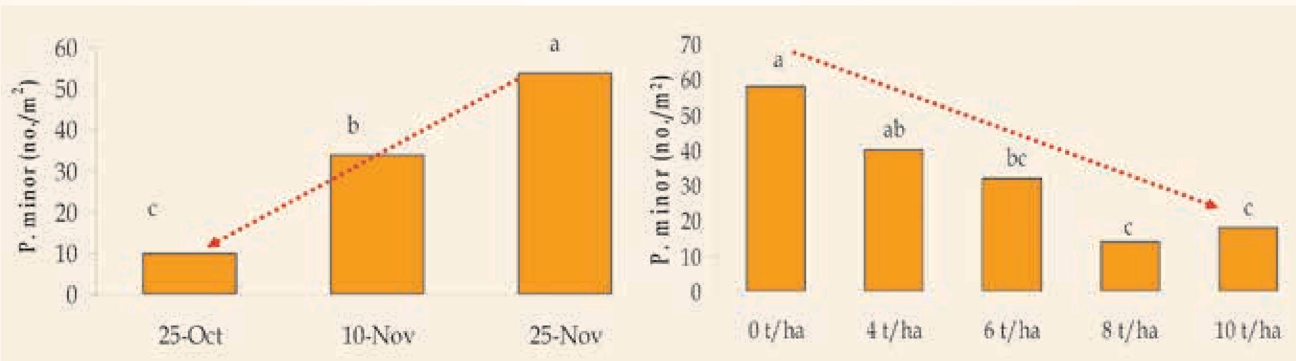


Fig.17. *Effect of date of sowing and residue load on Phalaris population*

To harness the potential of CA technologies, early sowing is required. Sowing in last week of October is very much essential to suppress the weed counts. Both residue retention and early sowing of ZT wheat with CA based management practices can check the weed population up to a great extent. ZT Turbo seeder technology provides a solution to rice residue management and wheat sowing.

Population of Phalaris minor with and without CA in wheat

VIII. Terminal heat effect

Indian Gangetic plains generally experience the terminal heat stress after every 3 to 4 years resulting in a huge loss in productivity. Terminal heat stress in wheat is a major yield limiting factor in the sub-tropical climate of NW India. Heat stress after anthesis, called terminal heat, is the major barrier to achieve the potential yield. During ripening, temperature of >30 ^{0}C cause suppression of current photosynthesis and inhibition of starch synthesis in the endosperm and it moves faster with increasing temperature and cause detrimental effect beyond 34 ^{0}C. At this temperature, grain weight, number and quality get affected like anything. There is an average yield loss of 0.5 to 1.0 t ha^{-1} in wheat, mainly due to lower grain weight, and also grain number when temperature goes beyond its threshold level (34 ^{0}C temperature) during terminal heat year in NW India. It also depends on the canopy temperature and number of terminal heat stress days faced by the crop. Timing, duration and intensity of terminal heat during the month of February-March determine its impact on wheat grain yield in NW India.

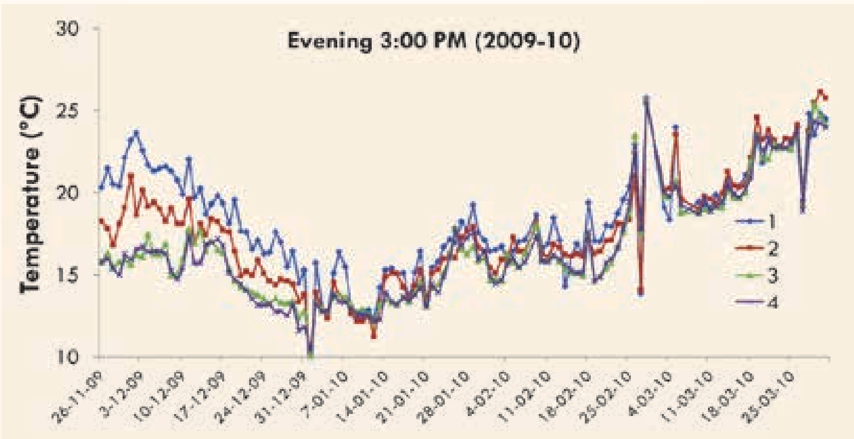


Fig.18. *Evening temperature under different scenarios*

Terminal heat stress can be minimized by developing tolerant genotypes and best-bet management strategies. CA based management strategies in wheat based system can reduce the canopy temperature by 1.5-3.0 ^{0}C depending on the residue retention load and crop genotypes. Moderation in temperature (soil (Fig.18) and canopy) and moisture has direct effect on reducing the deleterious effect of heat on crop productivity up to some extent (10-15%). Time of sowing is another important management strategy in some regions in which CA may also provide the avenue for early sowing of wheat in NW India by 15-20 days (Wheat sowing time: mid-November). Early sowing is very much essential not only to exploit the full potential of CA based management options but also in avoiding the terminal heat stress.

Effect of terminal heat on wheat

Recording of canopy temperature in wheat crop

IX. GHG mitigation potential

Business as usual in RW system not only requires intensive use of resources (labor, water and energy), tillage and crop establishment practices but also emit GHGs in significant amounts. CH_4, N_2O and CO_2 are the most potent GHGs emitted from agricultural fields in significant amounts, depending on the conditions (anaerobic/aerobic) of the soil. CH_4 and N_2O have GWP of 298 and 25 times that of CO_2, respectively. Factors like SOC, tillage, fertilization, moisture, temperature, aeration etc. and their management and magnitude of interaction decides the temporal and spatial variability in GHG emissions. CA is the best-bet management including crop intensification and introduction of new plant type may help in mitigating their potential. The ZT-DSR (scenario 3) showed a reduction in global warming potential (GWP) because of high reduction in CH_4 emissions relative to puddled rice. DSR in scenario3 reduced CH_4 emissions by ~50% compared to farmers' practice of puddled rice. However, diversification of RW system by MW system in scenario 4, reduced GWP by ~20% in comparison to farmers' practice. Use of fuel, electricity and herbicides play a vital role in assessing GWP of different cropping systems.

Collection of GHG in field condition

10. Salient Findings

Four years experimentation have proved that the full CA based crop diversification with maize and double ZT rice-wheat systems is feasible in NW India without any yield penalty. Further, it also leads to higher system productivity over the time with less resource use (water, labor, energy etc.). *Kharif* maize appears to be a suitable alternative and remunerative crop compared to rice to address the critical issues of labor, energy and irrigation water in NW India. CA based best management practices also showed positive effects on soil health which is crucial for long-term sustainability.

- Scenario 2 (CT-TPR- ZT Wheat- ZT Mungbean) recorded 20% higher system productivity compared to other scenarios but with fewer resource savings as compared to full CA based scenarios 3 and 4.
- Scenario 3 (Full CA based: ZT-DSR -ZT Wheat - ZT Mungbean) demonstrated 11% increase in system productivity and 28% higher net returns, with 24% less energy and 34% less irrigation water use, compared to scenario 1 (farmers' practice).
- Replacement of rice with maize in futuristic scenario 4 (ZT Maize- ZT Wheat- ZT Mungbean) registered 14% higher system productivity and 32% higher net returns, besides 47% less energy and 72% less irrigation water use, compared to scenario 1 (farmers' practice).
- SOC content increased by 22, 67 and 71% in scenario 2, 3, and 4, respectively, with different CA management practices, compared to scenario 1.

- CA helped in enriching the soil as evidenced from higher macro-nutrient content in upper soil layer in CA based management scenarios 2, 3 and 4. In general, micronutrient content also increased in all the scenarios, compared to scenario 1. However, Fe content behaved differently.
- Optimum residue load and early sowing not only reduce *Phalaris* weed population, the most troublesome weed of wheat but also moderates soil temperature as well.
- Microbial density increased in all the CA based management systems. Highest microbial diversity was observed under scenario 4 where rice was replaced by maize.
- CA based management strategies were able to beat the terminal heat effect up to some extent through reduction in canopy temperature by 1.5-3.0 ^{0}C in wheat.

11. Conclusion

CA based sustainable intensification options showed positive effects on system productivity and net income along with significantly higher resource (labor, water, energy) use efficiency. Considering system performance parameters (yield, water use, energy use, and economics), maize-wheat-mungbean with CA based management practices (scenario 4) was found to be the best and rice-wheat with conventional tillage based management (scenario 1) as poorest performer, while scenario 2 and 3 were almost at par. Therefore, CA based sustainable intensification approaches may form an important component of the regional strategy for future food security, rural development, enhanced profitability, improved environmental quality and natural resources sustainability. In NW India, CA can work under all typologies and has tremendous potential for area expansion through synergies and convergence in investments in agricultural technologies and institutional arrangements.

12. The way forward: Sustainable intensification and climate smart agriculture (CSA)

Cultivation of RW system in NW India is still confronted with formidable problems of increased cost of cultivation, low return, labor shortage and ill effects of climate change which pose additional threats to farmer's confidence in agriculture. CA 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 deterioration, making agriculture climate smart. Climate Smart Agriculture (CSA) involves a portfolio of interventions (including CA based management) that are chosen to suit the local farming systems and the community's needs to meet the food security, increased adaptive capacity and reduce environmental foot prints.

For widespread adoption of CA based sustainable intensification and CSA options in the region, we have to define the domain of these interventions for different farm typologies considering bio-physical and socio-economic conditions. The interventions are to be chosen


Sustainable intensification of Rice-heat cropping system in IGP

and targeted to suit the local needs. Technical knowledge gap, mindset/perception, availability of sufficient infrastructure, input and output market access and enabling policies still has to put on the ground for accelerated uptake of these technologies. A complete set of system based package should go to the farmers' rather than a commodity centric technology to overcome the ill effects of RW system. Further, convergence among technologies is required to harness the potential benefits of CA in NW India. There is a need to do further research on developing and defining component technologies adapted to CA based sustainable intensification (water, nutrient, weed, pest management, adapted crop varieties, crop-livestock interactions etc) for harnessing the full potential of conservation agriculture.