# System Based Conservation Agriculture

Vinod Kumar Singh
B. Gangwar

WESTVILLE

# System Based Conservation Agriculture

**Vinod Kumar Singh**
**B. Gangwar**

WESTVILLE

**Westville Publishing House**
New Delhi

V.K. Singh and B. Gangwar (2018). System Based Conservation Agriculture, Westville Publishing House, New Delhi. pp 272.



ISBN 978-93-83491-88-9



Published by Mrinal Goel, Westville Publishing House
47, B-5, Paschim Vihar, New Delhi–110 063, India
Tel: 011-25284742, Fax: 011-25267469
Email: westville_2002@yahoo.co.in
Website: www.westvillepublishing.com
Printed in New Delhi

रानी लक्ष्मी बाई केन्द्रीय कृषि विश्वविद्यालय
ग्वालियर रोड, झांसी 284 003 (उत्तर प्रदेश) भारत
**Rani Lakshmi Bai Central Agricultural University**
Gwalior Road, Jhansi 284 003 (U.P.) India

डॉ अरविन्द कुमार
कुलपति
**Dr Arvind Kumar**
Vice-Chancellor

Phone : 0510-2730777
Telefax : 0510-2730555
E-mail : vcrlbcau@gmail.com
Website : www.rlbcau.ac.in

# 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 diversified 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 initial help extended in compilation of different chapters by Dr. K.K. Singh, Assistant Director General (Farm Machinery and Power), ICAR, New Delhi is duly acknowledged.

The help extended by Dr. Anil K. Choudhary, Drs. Kapila Shekhawat (Senior Scientist, Agronomy), Pravin Kumar Upadhyay, 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.

**Vinod Kumar Singh**
**B. Gangwar**

# Contents

# 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 has made significant contribution towards improving soil organic matters content and nutrient use efficiency in different cropping systems. Dr. Singh developed 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, Fellow International Society for Noni Science, 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, Rajendra Prasad Award (2015), 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 NAAS, Fellow International Society of Noni Science, 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 142 research papers, 186 popular articles, 28 book chapters, 24 books/ manuals, 15 research/extension bulletins and 36 edited publications.

# List of Contributors

| | |
|---|---|
| **A.K. Biswas** | ICAR–Indian Institute of Soil Science, Bhopal-462038, Madhya Pradesh, India |
| **A.K. Patra** | ICAR–Indian Institute of Soil Science, Bhopal-462038, Madhya Pradesh, India |
| **Anchal Dass** | Division of Agronomy, ICAR-Indian Agricultural Research Institute, New Delhi-110012, India |
| **Arvind K. Shukla** | ICAR–Indian Institute of Soil Science, Bhopal-462038, Madhya Pradesh, India |
| **B. Gangwar** | Indian Institute of Farming Systems Research, Modipuram-250110, UP, India |
| **B.S. Dwivedi** | ICAR–Indian Agricultural Research Institute, New Delhi-110012, India |
| **C. Prakash** | ICAR–Indian Institute of Soil Science, Bhopal-462038, Madhya Pradesh, India |
| **D. Mahala S.** | ICAR–Indian Agricultural Research Institute, New Delhi-110012, India |
| **Debarati Bhaduri** | ICAR–National Rice Research Institute, Cuttack-753006, Odisha |
| **H.S. Jat** | International Maize and Wheat Improvement Centre (CIMMYT), Central Soil salinity Research Institute, Karnal-132001, Haryana, India |
| **Harbir Singh** | ICAR–Indian Institute of Farming Systems Research, Modipuram, Meerut-250110 U.P., India |
| **J. Somasundaram** | ICAR–Indian Institute of Soil Science, Bhopal-462038, Madhya Pradesh, India |
| **J.P. Singh** | Indian Institute of Farming Systems Research, Modipuram, Meerut-250110 U.P., India |
| **K.K. Singh** | Indian Council of Agricultural Research, New Delhi-110012, India |
| **Kamta Prasad** | ICAR–Indian Institute of Farming Systems Research, Modipuram, Meerut-250110, U.P., India |
| **Kapila Shekhawat** | ICAR–Indian Agricultural Research Institute, New Delhi-110012, India |

| | |
|---|---|
| **Kaushik Majumdar** | International Plant Nutrition Institute, Asia, Africa, and Middle East, Gurgaon-122001, Haryana, India |
| **M. Shamim** | ICAR–Indian Institute of Farming Systems Research, Modipuram-250110, U.P., India |
| **M.C. Meena** | ICAR–Indian Agricultural Research Institute, New Delhi-110012, India |
| **M.L. Jat** | International Maize and Wheat Improvement Centre (CIMMYT), NASC Complex, New Delhi-110 012, India |
| **N. Nadarajan** | ICAR-Indian Institute of Pulses Research, Kanpur-208024, U.P., India |
| **N. Ravisankar** | ICAR–Indian Institute of Farming Systems Research, Modipuram, Meerut-250110, U.P., India |
| **N.K. Jat** | ICAR–Central Arid Zone Research Institute Jodhpur-342003, Rajasthan, India |
| **N.K. Sinha** | ICAR–Indian Institute of Soil Science, Bhopal-462038, Madhya Pradesh, India |
| **Narendra Kumar** | Indian Institute of Pulses Research, Kanpur-208024, U.P., India |
| **Neetu Sharma** | Sher-e-Kashmir, University of Agriculture Science and Technology, Jammu-180001, India |
| **P.K. Tiwari** | ICAR–Indian Institute of Soil Science, Bhopal-462038, Madhya Pradesh, India |
| **P.K. Upadhyay** | ICAR–IndianAgricultural Research Institute, New Delhi-110012, India |
| **Peeyush Sharma** | Sher-e-Kashmir, University of Agriculture Science and Technology, Jammu-180001, India |
| **R.K. Jat** | Borlaug Institute for South Asia (BISA), Pusa, Samastipur-848101, Bihar, India |
| **R.K. Sharma** | ICAR–Indian Institute of Wheat and Barley Research, Karnal-132001, Haryana, India |
| **R.P. Mishra** | ICAR–Indian Institute of Farming Systems Research, Meerut-250110, U.P., India |
| **R.S. Chaudhary** | ICAR–Indian Institute of Soil Science, Bhopal-462038, Madhya Pradesh, India |
| **R.S. Chhokar** | ICAR–Indian Institute of Wheat and Barley Research, Karnal-132001, Haryana, India |
| **R.S. Yadav** | ICAR–Indian Institute of Farming Systems Research, Modipuram, Meerut-250110, U.P., India |
| **Raj Singh** | Division of Agronomy, ICAR-Indian Agricultural Research Institute, New Delhi-110012, India |

| | |
|---|---|
| **Ranjan Laik** | Dr. Rajendra Prasad Central Agricultural University, Pusa, Samastipur, Bihar-848125, India |
| **S. Kumar** | ICAR–Indian Institute of Farming Systems Research, Modipuram, Meerut-250110, U.P., India |
| **S.K. Singh** | Rani Lakshmi Bai Central Agricultural University, Jhansi-284001, U.P. India |
| **S.P. Singh** | Director Extension, Narendra Dev University of Agriculture and Technology, Faizabad-224001, U.P., India |
| **S.S. Rathore** | Division of Agronomy, ICAR-Indian Agricultural Research Institute, New Delhi-110012, India |
| **T. Satyanarayana** | International Plant Nutrition Institute, South Asia Programme, Gurgaon-122016, Haryana, India |
| **Tapan J. Purakayastha** | ICAR–Indian Agricultural Research Institute, New Delhi-110012, India |
| **V.K. Singh** | ICAR–IndianAgricultural Research Institute, New Delhi-110012, India |
| **V.P. Choudhary** | ICAR–Indian Institute of Farming Systems Research, Modipuram-250110, U.P., India |
| **Vikas Abrol** | Sher-e-Kashmir, University of Agriculture Science and Technology, Jammu-180001, India |
| **Yadvinder Singh** | Punjab Agricultural University, Ludhiana-141004, Punjab, India |

# 1

# 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 and pesticides) and increased mechanization. The approach of 'more inputs- more output' is generally ecologically intrusive as well as economically and environmentally unsustainable, has led to sub-optimal factor productivities and yield levels that are difficult and expensive to maintain over the 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 as 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 management practices, 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, 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 $21^{st}$ 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. 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 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 heat stress, reduces weed infestation. | x x | x x | x x | x x x |
| Micro irrigation system | Increases water and nutrient use efficiency, | x x | x | x x x | x x x |

(Contd.)

| *Climate smart practices* | *Potential benefits relative to conventional practices* | *FS* | *CR* | *A* | *M* |
|---|---|---|---|---|---|
| | reduces GHG emissions, increased productivity | | | | |
| Agroforestry | Sequester carbon in the soil and prevent soil erosion, enhancing biodiversity, improve the ecosystem | x | - | xxx | xxx |
| 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 | xx | xxx | 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. 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 $20^{th}$ 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 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 20$^{th}$ 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 warming 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, bed planting and drip irrigation substantially save irrigation water without any reduction in grain yield and improves 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 applied 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 generally burns 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. Happy seeder sown wheat 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 conventional 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.

### 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

**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

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 are 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 litre 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 interaction. 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 for designing cultivars for good crop stand establishment under CA environment and use genotype x management interactions. Studies show that performance of 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 are 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.

## References

Behera UK, Sharma AR, Mahapatra IC. 2007. Crop diversification for efficient resource management in India: Problems, prospects and policy. *Journal of Sustainable Agriculture* 30, 97-127.

Bijay-Singh, Shan YH, Johnson-Beebout SE, Yadvinder-Singh, Buresh RJ. 2008. Crop residue management for lowland rice-based cropping systems in Asia. *Advances in Agronomy* 98, 118–199.

Bouman BAM, Tuong TP. 2001. Field water management to save water and increase its productivity in irrigated lowland rice. *Agricultural Water Management* 49, 11–30.

Camp CR .1998. Sub-surface drip irrigations: A view. *Transactions of the American Society of Agricultural Engineers* 45, 1353-1367.

Chauhan BS, Singh RG, Mahajan G. 2012. Ecology and management of weeds under conservation agriculture: a review. *Crop Protection* 38, 57–65.

Chauhan DS, Sharma RK, Tripathi SC, Kharub AS and Chhokar RS. 2000. Wheat cultivation after rice-a paradigm shift in tillage technology. *Indian Farming* 50(6), 21-22, 38.

Corsi S, Friedrich T, Kassam A, Pisante M, Sa Jd M. 2012. Soil Organic Carbon Accumulation and Greenhouse Gas Emission Reductions from Conservation Agriculture: A literature review. Plant Production and Protection Division. Food and Agriculture Organization of the United Nations, Rome, 2012. *Integrated Crop Management* 16-2012: 89 pp.

Das TK, Bhattacharyya R, Sudhishri S, Sharma AR, Saharawat YS, Bandyopadhyay KK, Sepat S, Bana RS. 2014. Conservation agriculture in an irrigated cotton–wheat system of the western Indo-Gangetic Plains: Crop and water productivity and economic profitability. *Field Crops Research* 158, 24–33.

Erenstein O, Farooq U, Malik, RK, Sharif M. 2008. On-farm impacts of zero tillage wheat in South Asia's rice-wheat systems. *Field Crops Research* 105, 240-252.

Fageria NK. 2007. Yield physiology of rice. *Journal of Plant Nutrition* 30, 843–879.

Anonymous. 2014. Food and Agriculture Organization. What is Conservation Agriculture? FAO CA website http://www.fao.org/ag/ca/1a.html)

Anonymous. 2015. Food and Agriculture Organization. AQUASTAT Main Database, Food and Agriculture Organization of the United Nations (FAO). Website accessed on [26/09/2015 12:26]

Gupta RK, Seth A. 2007. A review of resource conservation technologies for sustainable management of the rice-wheat system cropping systems of the Indo-Gangetic Plains. *Crop Protection* 26, 436-447.

Gupta RK,Yadvinder-Singh, Ladha JK, Bijay-Singh, Singh J, Singh G, Pathak H. 2007. Yield and phosphorus transformations in a rice-wheat system with crop residue and phosphorus management. *Soil Science Society of American Journal* 71, 1500-1507

Hira GS. 2009. Water management in northern states and the food security of India. *Journal of Crop Improvement* 23, 136-157.

Hobbs PR, Gupta RK. 2003. Resource conserving technologies for wheat in rice–wheat systems. In *Improving the productivity and sustainability of rice–wheat systems: issues and impact*, vol.65 (Eds JK Ladha, J Hill, RK Gupta, J. Duxbury and RJ Buresh), paper 7, ASA special publications, pp. 149–171. Madison, WI: ASA.

Jat HS, Singh G, Singh R, Choudhary M., Gathala MK, Jat ML, Sharma DK. 2015. Management influence on maize–wheat system performance, water productivity and soil biology. *Soil Use and Management* 31(4), 534-543.

Jat ML, Saharawat YS, Gupta R. 2011. Conservation agriculture in cereal systems of South Asia: Nutrient management perspectives. *Karnataka Journal of Agriculture Sciences* 24, 100-105.

Jat ML. 2014. Climate smart villages in Haryana, India. *Technical Bulletin*, CIMMYT-CCAFS, August 2014. pp 1-12.

Jat ML, Singh RG, Saharawat YS, Gathala MK, Kumar V, Sidhu HS, Gupta Raj. 2009. Innovations through conservation agriculture: progress and prospects of participatory approach in the Indo-Gangetic plains. In: Pub Lead Papers, *4th World Congress on Conservation Agriculture*, 4-7 February, 2009, New Delhi India. P. 60-64.

Kang S, Shi W, Zhang J. 2000. An improved water-use efficiency for maize grown under regulated deficit irrigation. *Field Crops Research* 67, 207–214.

Kassam A, Friedrich T, Derpsch R. Kienzle J. 2015. Overview of the Worldwide Spread of Conservation Agriculture. *Field Actions Science Reports*, Vol. 8 2015, (http://factsreports.revues.org/3966)

Kharrou MK, Er-Raki S, Chehbouni A, Duchemin B, Simonneaux V, Michel Le, Ouzine L, Jarlan J. 2011. Water use efficiency and yield of winter wheat under different irrigation regimes in a semi-arid region. *Agricultural Sciences* 2, 273-282.

Kumar K, Goh KM. 2000. Crop residues and management practices: Effects on soil quality, soil nitrogen dynamics, crop yields, and nitrogen recovery. *Advances in Agronomy* 68, 197-319

Kumar V, Ladha JK. 2011. Direct seeded rice: Recent development and future research needs. *Advances in Agronomy* 111, 297-413.

Laik R, Sharma S, Idris M, Singh AK, Singh SS, Bhatt BP, Saharawat Y, Humphreys E, Ladha JK. 2014. Integration of conservation agriculture with best management practices for improving system performance of the rice–wheat rotation in the Eastern Indo-Gangetic Plains of India. *Agriculture, Ecosystem and Environment* 195, 68–82.

Ladha JK, Pathak D, Yadav RL. 2003. How extensive are yield declines in long term rice wheat experiments in Asia? *Field Crops Research* 81, 159-180.

Ladha JK, Kumar V, Alam MM, Sharma S, Gathala M, Chandana P, Saharawat YS, Balasubramanian V. 2009. Integrating crop and resource management technologies for enhanced productivity, profitability, and sustainability of the rice-wheat system in South Asia. In: Ladha JK ,Yadvinder-Singh and D. Hardy (Eds.) *Integrated crop and resource management in rice-wheat system of South Asia*. Los Banos, Phillipines, pp. 69-108.

Ladha JK, Pathak H, Padre AT, Dave D, Gupta RK. 2003. Productivity trends in intensive rice-wheat cropping systems in Asia. P.45-76. *In*: J.K. Ladha *et al*. (ed.) *Improving the productivity and sustainability of rice-wheat systems: issues and impacts*. ASA Spec. Publ. 65. ASA, CSSA, and SSA, Madison, WI.

Maclean JL, Dawe DC, Hardy B, Hettel GP. 2002. Rice almanac. Los Ban˜ os, Philippines: International Rice Research Institute, 1–10.

Matson PA, R Naylor, Ortiz-Monasterio. 1998. Integration of environmental, agronomic, and economic aspects of fertilizer management. *Science* 280, 112 – 114.

Nurbekov A, Akramkhanov A, Lamers J, Kassam A, Friedrich T, Gupta R, Muminjanov H, Karabayev M, Sydyk D, Turok J and Bekenov M. 2014. Conservation Agriculture in Central Asia. *In*: Jat R, Kanwar S, Kassam A. (eds). *Conservation Agriculture: Global Prospects and Challenges*. pp.223-247. CABI, Wallingford.

Ortiz-Monasterio I, Wassmann R, Govaerts B, Hosen Y, Katayanagi N, Verhulst N. 2010. 'Greenhouse gas mitigation in the main cereal systems: rice, wheat and maize'. *In*: Reynolds, M.P. (ed.) *Climate Change and Crop Production*. CABI, Oxfordshire, UK, pp. 151-176.

Pathak H, Saharawat YS, Gathala M, Ladha JK. 2011. Impact of resource-conserving technologies on productivity and greenhouse gas emission in rice-wheat system. *Greenhouse Gas Science and Technology* 1, 261-277.

Piggin C, Haddad A, Khalil Y, Loss S, Pala M. 2015. Effects of tillage and time of sowing bread wheat, chickpea, barley and lentil grown in rotation in rainfed systems in Syria. *Field Crops Research* 173, 57-67.

Ponnamperuma FN. 1984. Straw as a Source of Nutrients for Wet-Land Rice, In Organic Matter and Rice, Banta, S. and Mendoza, C.V. (Eds.), IRRI, Los Banos, Philippines, p. 117–136.

Powlson DS, Stirling CM, Jat ML, Gerard BG, Palm CA, Sanchez PA, Cassman KG. 2014. Limited potential of no-till agriculture for climate change mitigation. *Nature Climate Change* 4, 678-683.

Saharawat YS, Ladha JK, Pathak H, Gathala M, Chaudhary N, Jat ML. 2012. Simulation of resource-conserving technologies on productivity, income and greenhouse gas emission in rice-wheat system. *Journal of Soil Science and Environmental Management* 3(1), 9-22.

Sapkota Tek B, Kaushik M, Jat ML, Kumar A, Bishnoi DK, McDonald AJ, Pampolino M. 2014. Precision nutrient management in conservation agriculture based wheat production of Northwest India: profitability, nutrient use efficiency and environmental footprint. *Field Crops Research* 155, 233–244.

Sharma DK, Jat HS. 2014. Sustainable intensification of cereal based cropping systems in north-west India. *In*: National Symposium on "Agricultural diversification for sustainable livelihood and environmental security" Nov. 18-20, 2015, Ludhiana, Punjab. pp. 8-10.

Sharma PK, Bhushan L, Ladha JK, Naresh RK, Gupta RK, Balasubramanian BV, Bouman BAM. 2002. Crop-water relations in rice-wheat cropping under different tillage systems and water-management practices in a marginally sodic, medium-textured soil. In: B. A. M. Bouman, H. Hengsdijk, B. Hardy, P. S. Bindraban, T. P. Toung, and J. K. Ladha (Eds.), *Water-Wise Rice Production*. Proceedings of the International Workshop on Water-Wise Rice Production (pp. 223-e235). Los Banõs, Philippines: International Rice Research Institute.

Sharma RK, Chhokar RS and Chauhan DS. 2004. Zero-tillage technology in rice-wheat system- retrospect and prospects. *Indian Farming* 54 (4), 12-17.

Sharma RK, Tripathi SC, Kharub AS, Chhokar RS, Mongia AD, Jag Shoran, Chauhan DS, Nagarajan S. 2005. A decade of research on zero tillage and crop establishment. Directorate of Wheat Research, Karnal- 132 001, Haryana. *Research bulletin No. 18*.

Sidhu HS, Singh M, Yadvinder-Singh, Blackwell J, Lohan SK, Humphreys E, Jat ML, Singh V, Singh S. 2015. Development and evaluation of the Turbo Happy Seeder for sowing wheat into heavy rice residues in NW India. *Field Crops Research* 184, 201-212.

Singh VK, Yadvinder-Singh, Dwivedi BS, Singh SK, Majumdar K, Jat ML, Mishra RP, Rani M. 2016. Soil physical properties, yield trends and economics after five years of conservation agriculture based rice-maize system in north-western India. *Soil and Tillage Research* 155, 133–148.

Sivakumar MVK, Stefanski R. 2011. Climate Change in South Asia, In: Lal, R., Sivakumar, M.V.K., Faiz, S.M.A., Rahman, A.H.M.M., Islam, K.R. (Eds.), *Climate Change and Food Security in South Asia*. Springer Science+Business Media B.V, pp. 13–28.

Verhulst N, Nelissen V, Jespers N, Haven H, Sayre KD, Raes D, Deckers J, Govaerts B. 2011. 'Soil water content, rainfall use efficiency and maize yield and its stability as affected by tillage practice and crop residue management in the rainfed semi-arid highlands of Mexico'. *Plant and Soil* 344, 73-85.

Von Westarp S, Sietan Chieng b, Hans Schreier. 2004. A comparison between low-cost drip irrigation, conventional drip irrigation, and hand watering in Nepal. *Agricultural Water Management* 64, 143–160.

Wassmann R, Jagadish SVK, Sumfleth K, Pathak H, Howell G, Ismail A, Serraj R, Redoña E, Singh RK, Heuer S. 2009. Regional vulnerability of rice production in Asia to climate change impacts and scope for adaptation. *Advances in Agronomy* 102, 91-133.

Yadvinder-Singh, Bijay-Singh, Timsina J. 2005. Crop residue management for nutrient cycling and improving soil productivity in rice-based cropping systems in the tropics. *Advances in Agronomy* 85, 269–407.

Yadvinder-Singh, Manpreet-Singh, Sidhu HS, Khanna PK, Kapoor S, Jain AK, Singh AK, Sidhu GK, Avtar-Singh, Chaudhary DP, Minhas PS. 2010. Options for Effective Utilization of Crop Residues. *Research Bulletin* 3/2010. Punjab Agricultural University, Ludhiana, India, pp. 32.


The present publication deals with the scope and significance of refinement, adoption and dissemination of conservation agriculture (CA) in Indian *vis-à-vis* global context. Through this book, an attempt has been made to help readers to gain a precise understanding of the role of mechanization and the necessity for suitable modifications in the existing machinery for efficient residue recycling, crop establishment, optimized nutrient and water use, and weed management. Highlighting the collective work of various CA researchers, this reference book helps to understand the aspects like dynamics of macro and micro-nutrients along with the desired management alterations as per the CA principles. For the wider adoption of CA, location-specific crop diversification suited for different soil types has also been discussed in the book. The approaches like integrated farming system and organic farming in conjunction with CA principles for enhanced resource recycling, sustained livelihood in long-term perspective has been documented in the book. The impact of CA on soil quality, technologies designed for adaptation/mitigation for climate vulnerability, economics and system sustainability has been the focal point in the present book.

*. . . This book is a perfect compilation of consorted efforts of various researches 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 . . .*

***– Dr Arvind Kumar***
*Vice-Chancellor*
*Rani Laxmi Bai Central Agricultural University, Jhansi*

***Readership:*** Researchers working on conservation agronomy, soil science, soil physics, environmental sciences, farm machinery and power, agricultural economics and extension. Undergraduate, post graduate students of different natural resource management disciplines in SAUs, all the stake holders including policy makers, state agriculture development departments involved in agricultural production in general and conservation agriculture in particular.

WESTVILLE

**Westville Publishing House**
47, B-5, Paschim Vihar, New Delhi – 110063
Tel: 011-25284742 Telefax: 011-45521968
Email: westville_2002@yahoo.co.in
Website: www.westvillepublishing.com

978-93-83491-88-9
9 789383 491889
₹ 2500 US$ 75