

Conservation Agriculture in Maize Systems



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PREFACE

The search for profitable and sustainable farming methods has become crucial in the constantly changing world of agriculture. The need to feed a growing global population while preserving the delicate balance of our environment presents an unprecedented challenge for agriculture worldwide. Contemporary challenges agriculture is facing nowadays are characterized by diminishing factor productivity, stagnant crop yields, deteriorating soil health, declining groundwater levels, diminishing farm profits, and escalating environmental degradation. These problems find their roots in the monoculture-intensive conventional farming systems that have prevailed for decades.

Today, Indian agriculture faces a critical juncture - how to bolster high-quality food production for a burgeoning populace while safeguarding the health of our soils and environment. This dilemma begs the question: where will future strides in productivity originate? Will germplasm enhancements mimic the successes of the past four decades?

The answer lies in embracing innovative natural resource management practices that augment input efficiency in irrigated semi-arid and sub-humid regions and boost productivity in rainfed agroecosystems. Enter the era of Conservation Agriculture (CA), spearheaded by cutting-edge technologies such as CA-based Resource Conservation Technologies (RCTs), underpinned by single-cross maize hybrid technology. These innovations hold the promise of elevating crop productivity, enhancing farm profitability, and championing sustainability.

In this pursuit, agriculture systems must readily adopt novel technologies that harness untapped sources of production growth while ensuring environmental stewardship. Hence, the focus on sustainability and CA within intensive production systems has grown exponentially. Since the mid-1990s, researchers have committed their energies to develop, refine, expedite, and advocate for the widespread adoption of CA technologies in India, ushering in a veritable 'revolution in tillage techniques.'

Conservation agriculture, founded on the three cardinal principles of minimal soil disturbance, maintenance of permanent soil cover, and judicious crop rotations, strives to deliver sustainable and profitable agriculture, ultimately improving the lives of farmers. Its applicability spans farms of all scales and various agroecological systems, offering a lifeline to smallholder farmers grappling with labor shortages. CA harmonizes productive agricultural output with ecological sustainability and has demonstrated its success across diverse agro-ecological zones and farming systems.

Research on CA in maize systems has paved the path for the creation of successful cropping systems that are resource-efficient and adapted to various agroecologies, such as maize-wheat-mungbean and maize-mustard-mungbean.

"Conservation Agriculture in Maize Systems" offers a comprehensive exploration of these innovative farming practices and their implications. It delves into the intricacies of CA, its principles, and its manifold benefits for both farmers and the environment. This bulletin aims to serve as a guiding beacon for farmers, researchers, and policymakers, illuminating the path toward sustainable and productive agriculture in maize systems. It is our aim that the knowledge presented here will encourage and guide everyone involved in the agriculture industry as they work together to create a more sustainable future.

Authors

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INTRODUCTION

Presently, the declining water table in some of the highly productive areas of western IGP and Peninsular India is alarming and has led to the creation of more dark zones. This has become a matter of concern for the present rice-wheat in IGP and rice-rice in Peninsular India. The technological development and policy support in rice and wheat have ensured their bumper production in India. However, their limited industrial utility besides food purposes makes these crops dependent on policy support and thus there is not much possibility of their further expansion. At present, rice and wheat are overproduced in India to ensure food self-sufficiency due to the enhanced adoption of these crops in irrigated ecologies with suitable cultivars. However, these crops have limited industrial potential compared to crops like maize and thus later is considered as a future crop. It is also a lesser water-requiring crop which has higher demand in the market as it is mostly (>85%) used for industrial purposes. This crop also has a lot of export potential as major importers of it (China, Indonesia, and Japan) are near India. Almost all South Asian countries also import maize and thus we have a good opportunity to earn forex along with water saving by producing this market-driven crop through diversification. Hence, the replacement of existing water-guzzling, low profitable cropping system with resource-efficient maize-based cropping system like maize-wheat in IGP and rice-maize in Peninsular India is a need of the hour.

Soil sickness, fading organic carbon and decreasing input use efficiency are the major challenges for the sustainability of modern agriculture. It is further aggravated by the fast-changing climatic conditions having aberrant weather conditions, which pose a serious threat to the sustainability of farming in the world and India in particular. The excessive tillage operation enhances the production cost and carbon oxidation and thus causes economic and soil health losses. Conservation agriculture (CA) based crop management practices are found effective for mitigating the effects of climate change due to lesser greenhouse gas emissions compared to the conventional agriculture system. These practices were also found to be effective for adaptation of the climate change effect due to favorable changes in soil health and microclimate modification.

In this scenario, if alternate cropping systems like maize-wheat or rice-maize in newer ecologies and traditional maize-based cropping like maize-mustard or maize-chickpea or maize-oat or maize alone practiced with CA-based best bet management practices could lead to overall sustainability with lesser environmental footprints and improved soil health. Therefore, in this bulletin, we discussed CA in maize systems for



sustainability in traditional and newer ecologies. CA is the set of practices based on three cardinal principles of minimal soil disturbance, retention of residue as soil cover and profitable sustainable crop rotation. The key elements of CA have a direct and indirect bearing on the nutrient supply/availability of soil, which are described below:

Principles of CA

A. Minimal mechanical soil disturbance: The mechanical disturbance of the soil is completely avoided except for sowing purposes and sowing implement, or process must open the soil minimally. Mechanical weeding is also to be avoided in CA and uprooting is to be practiced. The key benefits of this practice are as follows:

- ✦ It allows the residue to remain over the soil surface which is a key for the success of CA.
- ✦ Moderates/decreases organic-matter oxidation and enhances soil carbon sequestration.
- ✦ Limits re-exposure of weed seeds and their germination.
- ✦ Optimizes proportions of respiration gases in the rooting zone.
- ✦ Retention of the biopores as natural ways for water infiltration after the decay of roots.
- ✦ This also decreases the movement and spread of weed propagules from one place to another in the field, specifically perennial weeds.
- ✦ Mycorrhizal networks established in the soil thrive without experiencing mechanical losses, thereby improving plants' ability to access water and nutrients beyond their immediate foraging zones.

B. Permanent covering of sufficient organic matter over the soil surface: The minimal 30% coverage of the residue over the soil surface gives a natural environment in the agro-ecosystems. The use of live mulch and crop residue retention on soil surface through special mulch tillage techniques is an important component of CA. In situ, mulch formed by the residue of a dead or chemically killed cover crop left in place is generally becoming an integral component of mulch tillage techniques that provide a favorable microclimate for crop growth and development and avoid extremes. Evaporation loss from the maize crop field can be arrested by covering the soil with organic farm waste like straw or retention of crop residues. As there is competitive use of maize residue in the livestock mixed production system of semi-arid areas and rising issues of stray cattle in fallow season, live mulch crops like cowpea, Sesbania, sunnhemp, greengram, blackgram, etc. can be sown under zero-tillage (ZT) for mulching purposes. However, as far as possible, retain a significant portion, particularly the lower one-third, of crop residue in the field. This residue should primarily be kept in an upright, anchored position to facilitate crop sowing and promote increased soil biological activity. The advantages of mulching in CA are as follows:



- ✦ Residue/live mulch acts as a layer for protecting soil moisture losses caused by evaporation specifically at early crop growth stages and at later stages as well.
- ✦ Mulching smothers weeds owing to their lesser germination and reduced growth and thus helps in weed control in crops.
- ✦ Better soil moisture condition enhances soil nutrient availability and uptake for crops.
- ✦ Reducing soil erosion by indirect impact of raindrops and other form of erosion by providing land coverage and obstruction for water movement.
- ✦ Buffering against the severe impact of solar radiation due to moderation of microclimate
- ✦ Residue mulch helps regulate soil temperature by lowering it during periods of high temperature stress and raising it during instances of low temperature stress. (Fig. 1).
- ✦ Reduced evaporation leads to less salt accumulation on soil surface and thus helps in reducing salinity.
- ✦ Residue acts as a food substrate for soil organisms and thus enhances soil biological wealth.
- ✦ Residue also enhances surface and underground soil faunal (macro, meso and micro) activity that helps in enhancing natural enemies of pests and diseases.
- ✦ The biopore developed by residue and biological activities facilitate water movement by increased hydraulic conductivity and infiltration rate.

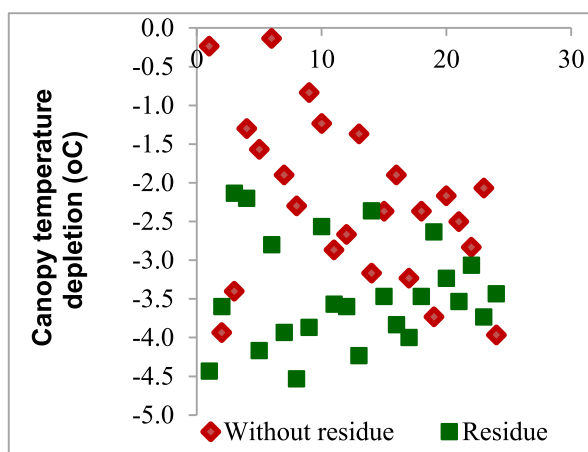


Fig. 1. Effect of crop residue application on canopy temperature depletion in maize after 10 days dry spell. (Source: IIMR Annual Report 2015-16)



C. Profitable sustainable crop rotation: Under CA, it is essential to implement profitable and sustainable crop rotations. These rotations should ideally include legumes and a variety of diversified crops to ensure the success of CA practices. Market-oriented profitable crops must also be integrated into the sustainable crop rotation plan within CA. The benefits of crop rotation in this context are manifold:

- ✦ Reduced crop-associated weeds: Crop rotation helps mitigate the problem of crop-associated or parasitic weeds, resulting in more effective weed management.
- ✦ Pest population control: Crop rotation disrupts the life cycles of pests, reducing their population buildup. It also encourages parasitization and predation due to the inclusion of non-host crops in the rotation.
- ✦ Disease prevention: Crop rotation disrupts the life cycles of diseases, decreases disease propagules, and limits their spread by incorporating non-host crops and promoting parasitism.
- ✦ Biological nitrogen (N) fixation: Legumes in the rotation contribute to biological N fixation, reducing the need for external N inputs and associated costs.
- ✦ Nutrient transfer: Crop rotation facilitates the transfer of nutrients, such as N to cereals (via biological N fixation) and phosphorus to legumes (via siderophores and rhizodeposition) in mixed or sequential cropping systems.
- ✦ Uniform nutrient extraction and recycling: Crop rotation ensures nutrient extraction and recycling at various soil depths, preventing excessive mining from any particular soil depth.
- ✦ Enhanced productivity and profitability: Effective crop rotation enhances crop productivity and overall profitability.
- ✦ Soil health improvement: The rotation of crops with different rooting patterns leads to the addition of organic matter at all soil depths, contributing to overall soil health improvement.
- ✦ Efficient nutrient transfer: Differential rooting patterns within crop rotations facilitate efficient nutrient recycling and transfer among soil layers.



★ Advantages of CA

For the widespread adoption of any technology, stakeholders are interested in the potential advantages they can reap from its adoption. CA is a technology that offers numerous visible and invisible benefits compared to conventional agricultural practices. The benefits of CA can be categorized as economic, agronomic, and environmental:

- ★ **A. Economic benefits:** CA has a positive impact on labor distribution during the production cycle and, more importantly, reduces labor requirements, particularly beneficial for farmers in regions who rely on family labor. The three major economic benefits of CA adoption are as follows:
 - ★ Cost reduction: CA reduces costs such as fuel, machinery operation and maintenance, as well as labor costs for these operations.
 - ★ Increased net returns: CA leads to higher net returns in crop production due to reduced costs and increased output.
 - ★ Improved input efficiency: CA enhances input efficiency by achieving higher output with lower input.
- ★ **B. Agronomic benefits:** The continuous addition of crop residues increases soil organic matter (SOM) content, initially in the top layer but extending to deeper layers over time. Organic matter is vital for soil health and crop productivity. CA adoption results in improved soil productivity through:
 - ★ Increased organic matter: Higher SOM content improves soil fertility, leading to better soil health and crop productivity.
 - ★ Enhanced in-situ soil water conservation: CA conserves soil water, improving water and nutrient mobilization.
 - ★ Improved soil structure: CA leads to better soil structure, reduced penetration resistance, eliminates plough pans, and provides a better rooting zone for increased nutrient and water absorption and reduced crop lodging.
- ★ **C. Environmental and Social Benefits:** CA protects the soil and the environment, making agriculture more sustainable. Key environmental and social benefits of CA adoption include:
 - ★ In-situ rainwater harvesting and reduced soil erosion: Crop residues on the soil surface reduce the splashing effect of raindrops, allowing for higher infiltration and reduced runoff and erosion.



- ✦ Residue as a physical barrier: Crop residues act as a physical barrier, decreasing water and wind speed over the land surface, reducing soil moisture evaporation and soil particle movement.
- ✦ Improved water harvesting and storage: Greater infiltration reduces flooding, recharges groundwater, and revitalizes dried-up springs.
- ✦ Reduced reservoir siltation: Reduced soil erosion indirectly lowers maintenance costs for drinking water treatment, dams, and hydroelectric power plants.
- ✦ Reduced agrochemical pollution: CA improves runoff and groundwater quality by retaining harmful agrochemicals, which degrade through photo and biological oxidation/degradation.
- ✦ Reduced green house gases (GHGs) emissions in crop production: CA leads to improved air quality by reducing aerosols, dust particles, and greenhouse gas emissions, particularly carbon dioxide.
- ✦ Biodiversity enhancement: CA enhances biodiversity by promoting soil microbes and friendly faunal diversity.
- ✦ Carbon sequestration: CA systems, with high crop residue addition and no tillage, sequester more carbon in the soil, helping reduce greenhouse gas emissions and combat global warming's impacts.

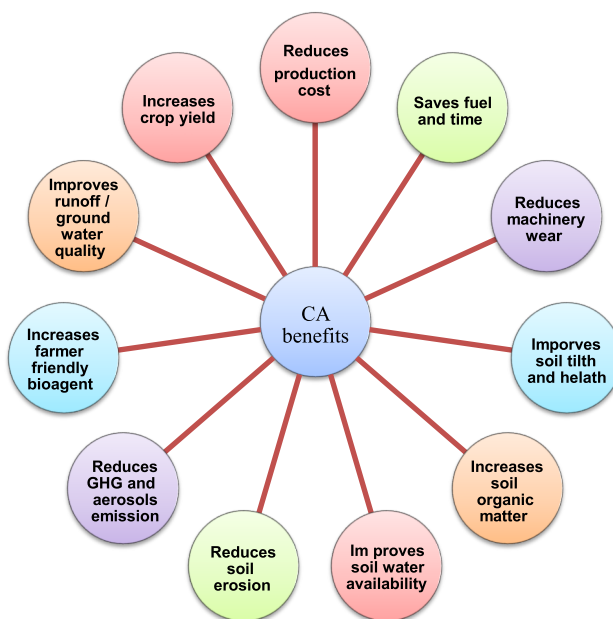


Fig. 2. The CA benefits.



Adoption of CA in the world

The CA approach has been adopted across 181 million hectares in 78 countries, accounting for 12.5% of the world's cropped area (Table 1).

Table 1. Progress of area under CA in the world.

Sr. No.	Country	CA area in 2008-09 (‘000 ha)	CA area in 2013-14 (‘000 ha)	CA area in 2015/16 (‘000 ha)
1	USA	26,500.00	35,613.00	43,204.00
2	Brazil	25,502.00	31,811.00	32,000.00
3	Argentina	19,711.00	29,181.00	31,028.00
4	Canada	13,481.00	18,313.00	19,936.00
5	Australia	12,000.00	17,695.00	22,299.00
6	Paraguay	2400.00	3000.00	3000.00
7	Kazakhstan	1300.00	2000.00	2500.00
8	China	1330.00	6670.00	9000.00
9	Bolivia	706.00	706.00*	2000.00
10	Uruguay	655.10	1072.00	1260.00
11	Spain	650.00	792.00	900.00
12	South Africa	368.00	368.00*	439.00
13	Germany	354.00	200.00	146.00
14	Venezuela	300.00	300.00*	300.00#
15	France	200.00	200.00*	300.00
16	Finland	200.00	200.00	200.00
17	Chile	180.00	180.00*	180.00#
18	New Zealand	162.00	162.00*	366.00
19	Colombia	102.00	127.00	127.00#
20	Ukraine	100.00	700.00	700.00#
21	Italy	80.00	380.00	283.92
22	Zambia	40.00	200.00	316.00
23	Kenya	33.10*	33.10	33.10#
24	United Kingdom	24.00	150.00	362.00
25	Portugal	25.00	32.00	32.00#
26	Mexico	22.80	41.00	41.00#
27	Zimbabwe	15.00	90.00	100.00
28	Slovakia	10.00	35.00	35.00#
29	Sudan	10.00	10.00*	10.00#
30	Mozambique	9.00	152.00	289.00
31	Switzerland	9.00	17.00	17.00#
32	Hungary	8.00	5.00	5.00#
33	Tunisia	6.00	8.00	12.00
34	Morocco	4.00	4.00	10.50
35	Lesotho	0.13	2.00	2.00
36	Ireland	0.10	0.20	0.20
37	Russia	-	4500.00	5000.00
38	India	-	1500.00	1500.00#
Total		106,505.23	156,738.96	180,438.64

*2013/14 values taken from 2008/09; #2025/16 values taken from 2013/14; Source: 2008/09 and 2013/14 estimates.



At the farm level, the primary driving factors behind its adoption include cost savings, flexibility in planting times, reduced water requirements, and favorable government support. To potentially enhance the productivity of the IGP in a sustainable manner, CA needs to be effectively integrated into the existing agricultural system (Jat et al., 2016). However, in India, CA adoption remains limited, with only 1.5 million hectares currently under CA practices, primarily due to its targeted implementation within a restricted number of cropping systems.

Why CA is needed in Indian Agriculture?

- ✦ Due to intensive production system,
- ✦ Excess withdrawal of tube well water for irrigation,
- ✦ Residue removal and burning,
- ✦ Degradation of soil structure due to excess puddling in rice,
- ✦ Depletion of SOM,
- ✦ Nutrient imbalance,
- ✦ Soil salinity and sodicity,
- ✦ Specialization of pest problem due to monoculture,
- ✦ Small farm sizes with each farm operating as integrating farming system, and
- ✦ In certain situations, where tillage operations caused delay in sowing and add to the cost of production.

In India, the prevailing limitations on the natural resource base, combined with the intensive cropping systems and excessive use of external inputs, are leading to the degradation of soil, water, and genetic resources. In the face of declining water tables and the degradation of natural resources, as well as the market-driven modernization of agriculture in peri-urban areas, maize is emerging as a viable alternative for crop diversification. The development of high-yielding maize varieties, hybrids, and resource-efficient production techniques has made maize a promising crop in terms of farm profitability when compared to rice or wheat. Maize is a versatile crop that can be cultivated across India, adapting to diverse soil types, seasons, and climatic conditions, which has resulted in the creation of various maize-based cropping systems. The shift from traditional crops and cropping sequences to maize-based systems is gaining significance in response to the changing resource landscape in contemporary farming. In peri-urban areas, maize-based high-value intercropping systems are also gaining



importance due to market-driven agricultural practices. Furthermore, maize is compatible with several other crops with different growth habits, leading to the development of various intercropping systems.

Today, the primary challenge in Indian agriculture is to increase the production of high-quality food for a growing population while preserving soil health and environmental quality. This raises the question: where will future productivity gains come from? Will germplasm improvement research replicate the progress of the past four decades?

It appears that future productivity growth in intensively cultivated systems will come from the adoption of improved natural resource management practices designed to enhance input efficiency in irrigated semi-arid and sub-humid tropics and increase productivity in rainfed agroecosystems. Consequently, the major challenge for researchers in the future will be to develop alternative systems that yield more with less water and energy, while also improving farm profitability and sustainability. These are precisely the areas where single-cross maize hybrid technology, combined with advanced natural resource management practices like CA-based resource conservation technologies (RCTs), plays a crucial role in boosting crop productivity and farm profitability.

This underscores the need for agriculture systems to incorporate new technologies that can tap into new sources of production growth while ensuring sustainability. Hence, there is a growing emphasis on issues of sustainability and CA in intensive production systems. Since the mid-1990s, researchers have made significant efforts to develop, refine, accelerate, and promote the adoption of CA technologies in India, leading to a 'revolution in tillage techniques.'

Conservation agriculture aims to achieve sustainable and profitable agriculture, ultimately improving the livelihoods of farmers by adhering to three core principles: minimal soil disturbance, maintaining permanent soil cover, and implementing crop rotations. CA has enormous potential for farms of all sizes and various agroecological systems, with a particular urgency for smallholder farmers facing labor shortages. It represents a way to combine profitable agricultural production with environmental sustainability, and its success has been demonstrated across diverse agro-ecological zones and farming systems.

The benefits of retaining crop residue on the soil surface are well-documented, including reduced soil erosion from water or wind, improved water infiltration,



enhanced soil water storage efficiency, reduced labor, fuel, and machinery costs, improved soil quality, increased SOM, better water and air quality, and increased biodiversity and wildlife habitat.

Why maize for CA?

a) Technology available

- ✦ High yielding single cross hybrid (7-10 t/ha)
- ✦ Efficient weed management
 - ✓ Application of Atrazine 50% WP @ 800 g/acre in 400 litre water within 0-3 days of crop sowing.
 - ✓ Apply herbicide when there is sufficient moisture in the soil.
 - ✓ Do not disturb the soil after herbicide application.
 - ✓ Apply Tembotrione 42% SC @ 115 ml/acre or Topramezone 33.6% SC @ 30 g/acre or 2,4-D Amine 58% SL @ 350 ml/acre as post emergence herbicide at 20-35 days after sowing.

✦ b) Machinery from sowing to harvesting

✦ c) Increased internal maize demand:

- ✦ Expansion of poultry, feed, starch and dairy industries
- ✦ Specialty corn: baby corn and sweet corn in urban sprawl
- ✦ Green fodder & silage for dairy industries

d) Export potential: low transport and production cost

Among the various maize-based cropping systems, maize-wheat ranks first and is the third most important cropping system in India, following rice-wheat and rice-rice. It covers an area of 1.8 million hectares and contributes approximately 3% to India's food grain production. Studies conducted under the All India Coordinated Research Project (AICRP) on Cropping Systems have revealed that, when compared to existing cropping systems, maize-based cropping systems exhibit superior water and resource utilization across different soil and climate conditions. Research on CA in maize systems has led to the development of resource-efficient and profitable cropping systems, such as maize-wheat-mungbean and maize-mustard-mungbean for the IGP region, and others tailored to various agro-ecologies (refer to Table 2).



Table 2. The CA based maize system for various agro-ecologies in India.

Agro-climatic region	Potential CA-based cropping system
Western Himalayan Region	Maize-wheat
	Maize-oat
Eastern Himalayan Region	Summer rice/maize-mustard
	Maize-maize-legumes
	Maize-french bean
	Maize-mustard
Lower Gangetic Plain region	Autumn rice-maize
	Jute-maize
Middle /Upper Gangetic Plain region	Maize-wheat-mungbean
Trans Gangetic Plain region	Maize-mustard-mungbean
	Maize-chickpea
Eastern plateau and hills region	Maize-wheat
	Maize-chickpea
Central plateau and hills region	Maize-wheat
	Maize-chickpea
Southern plateau and hills region	Rice-maize
	Maize-chickpea
East coast plain and hills region	Rice-maize-urdbean
West coast plain and hills region	Maize-pulses
	Rice-maize
Gujarat plains and hills region	Maize-wheat
	Maize-mustard
Western dry region	Maize-mustard
	Maize-chickpea
Island region	Rice-maize

(Source Jat et al., 2020, Maize Seminar)



Maize-wheat-mungbean: an efficient cropping system

- ✦ Advancing wheat planting
- ✦ Increased wheat duration
- ✦ Lesser water requirement to wheat
- ✦ Reduced terminal heat stress
- ✦ Enhanced wheat yield
- ✦ Timely planting of third crop of summer mungbean
- ✦ Increased mungbean yield
- ✦ Three crops with lesser water than rice

✦ Maize-mustard-mungbean: More efficient MMM system

- ✦ Advancing mustard planting
- ✦ Increased mustard duration
- ✦ Reduced aphid infestation
- ✦ Enhanced mustard yield
- ✦ Timely planting of longer duration summer mungbean
- ✦ Increased mungbean yield
- ✦ Three crops with much lesser water than rice



Wheat and chickpea crops under ZT in maize system.



Maize is one of the fastest-growing crops in India due to increased maize demand for remunerative prices and the availability of the best technologies for easier and higher production. The crop area of maize has now reached close to 10 m ha and the upcoming areas as well as traditional areas if targeted with CA will be sustainable and more profitable. Hence, we enumerated the potential of CA in maize systems with special reference to India in this paper for improving profitability and soil health for sustainable crop production.

Hence, conservation tillage practices, such as zero and minimum tillage and permanent beds, may offset the production cost and other constraints associated with land preparation. The farmers in India are yet to grow maize-based cropping systems with CA technology packages, though it is a common practice in many Western countries. Bed planting of maize helps in proper plant establishment, increases input efficiency, increases yields, and opens avenues for a double no-till system. Adoption of no-till practice helps in timely seeding either of the crops in sequence, hence leads to increase in productivity.

However, the major bottleneck in large-scale adoption appears more toward socio-economical and policy related rather than technical. It has also been experienced that dissemination of these technologies are more complex because managing CA based cropping system is a round the year activity rather demonstrating a simple technology e.g., seeds of a new variety or a pesticide or a herbicide. The main reasons for slow adoption are:

- ✦ Lack of trained human resources on CA as till now CA is not in the course curriculum of the State Agriculture Universities.
- ✦ Traditional mindset problem not only with farmers but also of the researchers and extension agents and they mainly have a belief of business as usual.
- ✦ Lack of appropriate policies that support quality machinery and open access to quality machinery on subsidies as limited vendors have been authorized for subsidies. There exists policy mismatch as well.
- ✦ Lack of local artisans, machinery manufacturers in different states for repairing and spares.
- ✦ Lack of availability of certain herbicides and knowledge about their proper use.
- ✦ Lack of regional system-based information on long term basis.



- ✦ Initial field appearance without tillage and in presence of residues is disliked by farmers.
- ✦ There are limited efforts on long-term system-based research on CA for generating information for location/region/ecology specific fine tuning in the technologies before rolling them out by the extension machinery for wide scale adoption by the farmers.

Practicing CA on field

1. Practicing CA on field: Crop establishment and Machinery

Pre-requisite for CA

a) Chiselling: Continuous cultivation of puddled rice can lead to the development of a compacted subsoil layer, commonly referred to as a hard pan. Therefore, chiseling/sub-soiling of rice system soil before start of maize cultivation is very essential to break plough pan. Chisel plough helps in break up soil compaction, improve soil structure for sustainable maize cultivation.



Chisel plough



b) Laser land leveller

Traditionally levelled farmers field have 5-15 cm undulation in general within the field, which often result in poor seedling germination, seedling mortality due to water logging and uneven initial crop growth. Laser land levelling improves crop establishment by facilitating planters for uniform seeding depths. Laser land levelling also enables the farmer to apply water and nutrients uniformly facilitating a uniform crop stand and maturity through improved nutrient-water interactions. Therefore, laser land-levelling is a pre-requisite technology and rather an entry point for permanent ZT or permanent beds through improved water and crop management. It requires initial high investment on equipment cost so the small and marginal farmers can go for custom hiring of this technology.



Advantages of laser land levelling

- ✦ Reduced weed problems and improved weed control efficiency
- ✦ Improved efficiency of applied fertilisers and herbicides
- ✦ Approximately 35-45 % saving in irrigation water
- ✦ Reduction in salinity problems
- ✦ Uniformed crop maturity
- ✦ Improved crop establishment
- ✦ Approximately 4-5 % increase in cultivable area
- ✦ Easy farm operation due to uniform tilth
- ✦ Increase crop yields by 10%

Methods of planting under CA

a) Zero-tillage planting

The zero-till planting is a specialized component technology for conservation tillage that minimizes disruption to both the soil and surface residues. It is consisting of a single-tractor operation by using specially designed seed cum fertilizer drill that operates without any prior field operations. The surface residues of such a



system are of critical importance for soil and water conservation. Weed control is generally achieved with herbicides or in some cases with crop rotation. No-tillage systems eliminate all pre-planting mechanical seedbed preparation except for the opening of a narrow (2-3 cm wide) strip or small hole in the ground for seed placement to ensure adequate seed/soil contact.

b) Permanent bed planting

In bed planting 67 cm wide beds (37 cm ridge and 30 cm furrow) are prepared with the help of bed planter. Bed planter with incline plate seed mattering system can precisely place the maize seed at required depth of 3-4 cm. After preparing the fresh beds during first year these beds can be maintained as permanent beds for subsequent year while retaining crop residue. If necessary, these beds can be reshaped after each crop harvest. On permanent beds punch planter can be used to plant maize. One line of maize on each bed is desirable when sole crop of maize is planted keeping seed to seed spacing of 20 cm. optimum plant density (30,000-35,000/acre) should be maintained to tap potentials of hybrids.

Permanent bed for maize offers several advantages such as prevents delays in sowing, minimize fuel and labour costs, demands low draft power, well- suited for coarse textured soils, improves soil health and quality, reduces erosion and conserves soil moisture, improves water use efficiency (15-20%) and crop yield. During periods of heavy rains, temporary water lodged conditions can adversely affect the growth of maize crop. In bed planting that temporary water lodged conditions can be avoided by draining out excess water in furrows and better infiltration and aeration than conventional till (CT) condition. It was observed that standing water persists for longer time in CT due to surface crust formation or soil compaction. In contrast, ZT offers a higher infiltration rate due to natural soil aggregation which is helpful in avoiding the onset of anaerobic conditions resulting from water lodging. Zero till or permanent beds have better availability of water for maize especially in residue retained conditions.

Permanent beds conserve moisture during prolonged dry spell in water-scarce areas for sustained moisture supply for crop and act as a drainage channel in high rain fall/waterlogged areas. Additionally, they provide better microclimate for plant growth and root development. Following prerequisites should be kept in mind during making permanent beds and planting on them:

- ✦ Prepare ridges in East-West direction



- ✦ Plant crop on side of ridge
- ✦ Maintain row to row spacing at 60-75 cm and plant to plant spacing at 20 cm
- ✦ Ensure proper plant spacing for easy movement in field, rouging and removal of tassels

Advantages of ridge and furrow sowing

- ✦ Conserve moisture in water deficit areas
- ✦ Provide conserve moisture for the crop during prolonged dry spell
- ✦ Provide microclimate for better plant growth and better root development
- ✦ Prolong availability of moisture to sustain plant life

CA machinery

Planting machinery: Presence of plant residue and firm soil prevent conventional seed drill to function under no-till conditions. Surface lying crop residues affect furrow opening and closing, and the uniformity of seeding depth. The accumulated residues after combine harvesting often block tine furrow openers and create hairpinning issue when disc furrow openers are used. Hence, zero till planting machineries need effective residue management mechanisms to clear planting paths ahead of furrow opening. Several such mechanisms are commercially available and have variable performance depending upon the specific conditions under which they are used. Broadly, these mechanisms are designed to: (1) Chop the residue ahead and along planting paths, (2) Push residues sideways (in-between furrow openers) ahead of furrow opening, (3) Lift the residue and throw it back on the soil after the seed has been placed and covered. As against conventional planting machineries, the no-till planters are built heavier, need modified furrow openers and additional attachment of residue management system and consume more power to carry much more weight. The CA machineries generally uses two types of furrow opener viz., inverted 'T' type and double disc type.



Inverted 'T' type furrow opener: Conventional seed drill generally has seed and fertilizer boxes, wide shovel type furrow openers, seed metering device, seed and fertilizer delivery tubes and seed depth control wheels. While zero-till ferti-seed drill has all these components except that the wide furrow openers are replaced with chisel or "inverted T" type openers to place seeds and fertilizers in narrow slits with minimal soil disturbance. To facilitate seeding into loose residues, double disc type furrow openers and star-wheel (dibble) type openers can also be used with the existing zero-till seed-cum-ferti-drill. Farmers are doing planking after seeding to cover seeds planted with the conventional seed drills. Zero-till seed-cum-ferti-drill planted crop does not require planking. In fact, zero-till performance of rabi season crops improves if seeds are not covered/planked. As the dew factor received in significant amounts that facilitates germination in rabi crops.



Double disc type furrow opener: This is one of the second-generation machines having double disc-coulters fitted in place of tynes to place the seed and fertilizer into the loose residues. The problem being faced with this machine is that being lightweight it fails to cut through the loose residues and the seed and fertilizer is dropped on the top of it, part of which reaches on the soil surface. For proper germination after seeding irrigation is required immediately. This machine may efficiently work up to a residue load of about 4 to 5 tonnes/ha.

A) Zero till multi-crop planter: These planters are similar to conventional seed drills except that the wide furrow openers are replaced with chisel or "inverted T" type openers to place seeds and fertilizers in narrow slits with minimal soil disturbance. Zero-till planters are capable of sowing crops directly in standing stubbles of previous crops. If loose straw of previous crop is lying on the soil surface, it must be collected aside



before seeding to avoid interruption in the seeding operation and uniformly broadcast it after seeding to serve as mulch. This machinery can plant small as well as large seeded crops. The inclined plate seed metering system enables the planters to plant different crops with precise rate and spacing using the same planter which does not exist in fluted roller metering drills. Hence, the same multi-crop planter can be used for planting different crops by simply changing the inclined plates.

B) Combo Happy Seeder: The Combo Happy Seeder was made by fusing a straw



cutter and no-till seed drill into a single light weighted compact unit. The straw cutter has flails mounted on a PTO-driven rotor that chops anchored residues, lifts and discharges the chopped straw through a chute opening behind the seeder and onto drilled seed rows. This planter is having few issues like high power requirement (>33.6 kW), heavy weight (630 kg)

and choking of the machine under heavy straw loads ($>7-8$ Mg ha⁻¹), thick mulch cover on sown rows and poor crop emergence under heavy residue load. Beside these the planter also leaves one unsown row adjacent to the field boundary due to the rear position of the ground wheel.

C) Turbo Happy Seeder: This is an improved version of Combo Happy Seeder and can perform well in heavy straw loads with lower energy requirement. This machine is equipped with J-shaped flails mounted on a PTO-driven rotating shaft (rotational speed: 1000-1300 rpm) that chop residues in front of furrow openers, and feed the residues past and in-between the furrow openers result in much less straw deposition on the seed rows. The Turbo model does not have a chute and the flails sweep past each sowing tyne twice per rotation, clearing the residues away and enabling the tynes to pass freely through the residues. The inclined plate seed metering systems allows the planter for direct drilling of different small and coarse grain crops with change in inclined plates and gear in accordance with the optimal geometry of different crops. The Turbo Happy Seeder is considered to have a high-power requirement (>33.6 kW), relatively low operating capacity and heavy weight; poor maneuverability and significant vibration. The improved version of Turbo Happy Seeder has less power requirements (15 % less



than earlier version) and lesser overall weight (506 kg), improved fuel efficiency, coupled with maneuverability and enhanced ground wheel traction. Turbo happy seeder doesn't work when residue is wet



Turbo happy seeder



D) Punch planter/Star wheel: A punch planter employs ground engaging parts for punching a hole in the soil and then drops a seed in the hole, cover it and firm the soil around it. A well-designed punch planter plants seeds equidistantly at uniform depth and remain unclogged by residue and/or dirt. This planter is suitable for small and marginal farmers due to

its low cost and easy handling. It disturbs minimum amount of soil and offers precision seed spacing. The planter works under low residue load of up to 3 tonnes/ha.

E) CA machineries for small holder:

Jab planter: The planter delivers seed and fertilizer through separate sharp beaks which are closed on entering the soil and opened at planting depth.



Jab planter



Single row zero till seed drill: The single row zero till seed drill is comprised of seed and fertilizer boxes and inverted T-type furrow opener, driving wheel and depth control wheel. It places seed and fertilizer with minimum soil disturbance under residue load.



Single row zero till seed drill

Mini tractor drawn powered disc drills: It comprises two discs either offset or of different diameters and the leading disc which deflect residue, cut through residue and form a V-shaped slot in the soil. Metered seed and fertilizer can be fed into the gap between the discs via suitable tubing.



Two wheel tractors operated zero till seed drill.

Rolling jab planter: It comprises twin rotating off-set inclined star wheels which come together to penetrate the surface mulch and deliver the seed before opening to receive the subsequent seed.



Rolling jab planter





Farmer innovations for zero till maize crop establishment

2. Practicing CA on field: Nutrient Management

Nutrient management involves the efficient utilization of plant nutrients to enhance productivity while safeguarding the environment. The key to achieving optimal crop yield lies in applying nutrients at the right time, in the right place, using the correct rate and sources. Inadequate nutrient application can limit crop yields, while excessive application not only escalates cultivation costs but also poses environmental risks. So, the key principle behind nutrient management is balancing soil nutrient inputs with crop requirements.

For CA nutrient management is an important aspect for crop productivity and for the adoption of CA by farmers. The three pillars or principles of CA have direct and indirect bearing on the nutrient availability/supplying capacity of soil and in various combinations aim at establishing and sustaining healthy soil systems.



A) Minimum mechanical soil disturbance

- ✦ Provides optimum porous soil structure for movement of gases in the rooting-zone
- ✦ Moderates organic matter oxidation thus nutrient release through mineralization
- ✦ Modifies soil porosity for increased water movement, retention and release at all scales
- ✦ Limits re-exposure of weed seeds and their germination

B) Permanent covering of sufficient organic matter over the soil surface

- ✦ Buffering against severe impact of solar radiation and rainfall
- ✦ A substrate for soil organisms' activity
- ✦ Raised cation-exchange capacity for nutrient capture, retention and slow-release
- ✦ Smothering of weeds

C) Cropping sequences and rotations which include legumes

- ✦ Minimal build-up of populations of pest species, through life cycle disruption
- ✦ Biological N-fixation in appropriate conditions, limiting external costs
- ✦ Prolonged slow release of such N from complex organic molecules derived from soil organisms
- ✦ Range of species, for direct harvest and/or fodder
- ✦ Soil improvement by organic-matter addition

All three principals in various combination help in increase in SOM content which in turn leads to several benefits, including improved soil nutrient storage capacity, nutrient availability, biological activity, soil structure and resistance to erosion. However, soil nutrient supplies and cycling are enhanced by the biochemical decomposition of organic crop residues at the soil surface that are also vital for feeding the soil microbes, but it is also advisable to apply higher basal dose of N during initial years of CA for better crop due to immobilization of applied mineral N in residue decomposition process. Nonetheless, long-term experiments have indicated an



increased release of nutrients owing to microbial activity and nutrient recycling.

Increased SOM at the soil surface in CA improves nutrient-use efficiency (NUE) as it reduces soil erosion and prevents nutrient loss from the field. Nutrient loss may be minimized due to reduced runoff and the appropriate use of deep-rooting cover crops that recycle nutrients leached from the topsoil. Similarly, crop residues can increase plant availability of phosphorus and its efficiency in no-tillage systems.

In CA, much of the N needs of primary food crops can be achieved by planting N-fixing legume species, other plant essential nutrients often must be supplemented by additional chemical and/or organic fertilizer inputs. In general, soil fertility is built up over time under CA, and fewer fertilizer amendments are required to achieve optimal yields over time.

There are several questions about nutrient management in permanent bed planted crops. When nutrients are applied uniformly before the beds are made, some amounts of nutrients are left in furrows and can remain unutilized. When applied on the beds, the nutrients will remain on the surface and there could be a problem of reduced availability, especially for less mobile nutrients such as phosphorus. Over the years accumulation of phosphorus in surface soil layer may reduce the availability of other nutrients such as Zn. If applied in furrows, a part of nutrients such as N can be lost by leaching (Prasad, 2011).

It is only prudent that new fertilizer recommendations should be able to mimic significant effect of residue retention vis-a-vis incorporation of organics having differential soil moisture and thermal regimes. Therefore, the paradigm shift from tilled to no-till CA systems require a serious thrust on nutrient management research to improve soil and crop productivity and environmental quality. Carefully planned experiments are needed to develop the nutrient (primary, secondary and micro) management practices for different CA based technologies in various maize based cropping systems in India.

Precision Nutrient management in the context of CA

The layering of CA-based management practices with precision nutrient prescriptions using site-specific nutrient management (SSNM) based decision support tools offers a new management paradigm for scaling up of the MW system in north-west India (Parihar et al., 2017). The adoption of conservation tillage (ZT/PB) practices with improved nutrient management (SSNM/Ad-hoc) could be a viable option for achieving



higher productivity, water and energy-use efficiency and profitability in MWMb system. Significantly higher pooled bio-energetic yields (22-35%), net returns (31-38%) and water-use efficiency (30-35%) were observed in SSNM/Ad-hoc plots compared with FFP (farmers fertilizer practices) (Parihar et al. 2017, 2017a). The application of the 33% basal N followed by green seeker guided N application (33+GS) in maize significantly increased the grain yield of kharif maize by 6.9% over the traditional three splits recommended N application (IIMR, 2019).

Neem coated urea (NCU) has been found suitable to increase N use efficiency and profitability in CA-based maize systems (Jat et al., 2019a, 2019b, 2019c). Field experiments were conducted to evaluate the relative performance of NCU vis-à-vis ordinary prilled urea applied to maize, wheat and mustard. The application of NCU at recommended rate (150 kg N/ha) produced significantly higher maize grain yield (7.0 %); NCU @ 120 kg N/ha resulted in significantly higher wheat grain yield (12.3%) and NCU @ 90 kg N/ha resulted in significantly higher mustard seed yield (2.4%) than the yield obtained with ordinary urea on a coarse-textured sandy loam soil. The higher grain yield with the application of NCU over ordinary urea was accompanied by a spectacular increase in N use efficiencies.

3. Practicing CA on field: Weed Management

Weed flora of maize based cropping systems

In general, weed flora varied between the two nearest fields due to differentiated management practices as well as cropping and herbicide use history. *Cyperus rotundus*, *Bracharia reptans*, *Dactyloctenium aegyptium*, *Digera arvensis*, *Digitaria ciliaris*, *Cucumis* spp. are the dominant weed flora of maize during rainy season (Table 3). The weed pressure during winter season is comparatively less than that appears during rainy season, the major winter season maize weeds are *Cyperus rotundus*, *Cannabis sativa*, *Anagallis arvensis* and *Chenopodium album*. Weeds cause huge yield losses in maize especially during rainy season. Hand weeding is the most popular weed control method among the farmers. It is a highly labor-intensive, time-consuming, drudgery and costly operation. Weather conditions greatly impact the feasibility of hand weeding. Rainfall, wet soil, or extreme heat can hinder the effectiveness of manual weeding, causing delays and reducing its efficiency. A shortage of labor during the peak transplanting season often leads to delays in weeding operations, increasing labor cost and escalating cost of production are the other issues in manual weeding. Therefore, farmers need



effective and economical alternative weed management strategies

a) Pre-plant weed management

Stale seed bed with pre-plant herbicides is one of the important technique to control perennial and annual weeds in maize, and in particular in ZT. Application of pre-sowing irrigation facilitate weeds to germinate that can be killed by use of non-selective herbicides. For germinated annual weeds, apply either Paraquat or Glyphosate @ 1000 g a.i./ha. For perennial weeds, Glyphosate at the same rate of 1000 g a.i./ha is recommended. Tank mixture of glyphosate and 2,4-D is a better strategy to control troublesome weed i.e. *Cyperus rotundus*. It is advised that use clean water for Glyphosate spray @ 150L/ha and use multi-nozzle boom for better efficacy.

b) Pre-emergence weed control in CA

In a pre-emergence weed management strategy, the objective is to eliminate germinating weeds to prevent early-stage competition with crops. Tank mix application of Atrazine 50% WP (1000 g a.i./ha), Pendamethalin (1000 g a.i. /ha), Atrazine +Pendamethalin (500 g a.i. each/ha) or Alachlor + Atrazine (1250g+ 375g a.i./ha) found effective in controlling annual weeds in summer maize.

c) Post emergence weed management in CA

There are good options for post emergence weed control in maize due to availability of selective herbicides. Atrazine 50% WP @ 1000 g a.i./ha at 20-30 DAS also serves as a selective herbicide for maize. In addition, a targeted application of Paraquat dichloride 24% SL between maize rows using a covering material (hood) can be an effective method for controlling annual weeds. Apply Tembotrione 42% SC @ 115 ml/acre or Topramezone 33.6% SC @ 30 g/acre for control of all types of weed or 2,4-D Amine 58% SL @ 350 ml/acre as post emergence herbicide to control broad leaved weeds at 20-35 days after sowing in maize (Table 4). Simultaneous planting of mungbean as over crop on both sides of maize row on beds appeared effective in controlling complex weed flora.



Table 3. Major weed spectrum in maize based cropping systems

Botanical name	Cropping systems and seasons	
	Kharif season	Winter season
Grassy weeds		
<i>Brancharia reptans</i>	M-W, R-M	
<i>Cynodon dactylon</i>	M-W	M-W
<i>Dactyloctenium aegyptium</i>	M-W	
<i>Digitaria ciliaris</i>	M-W, M-P+M, M-P	
<i>Echinochloa colonum</i>	M-W	
<i>Eleusine indica</i>	M-W	
<i>Eragostis tenella</i>	R- M	
<i>Panicum repens</i>	R- M	
Broad leaf weeds		
<i>Anagallis arvensis</i>		M-W, M-P+M, M-P
<i>Cannabis sativa</i>		M-W, M-P+M, M-P
<i>Celosia argentea</i>	M-W	
<i>Cirsium arvense</i>		M-W
<i>Caesulia axillaris</i>	R- M, M-W	
<i>Chenopodium album</i>		M-W, M-P+M, M-P
<i>Commelina bengalensis</i>	M-W, R- M,	
<i>Cucumis spp</i>	R- M, M-W	
<i>Digera arvensis</i>	R-M, M-W	
<i>Eclipta alba</i>	M-W,	
<i>Euphorbia hirta</i>	M-W	
<i>Launaea nudicaulis</i>		M-W
<i>Melilotus indica</i>		M-W
<i>Phyllanthus niruri</i>	M-W	
<i>Physalis minima</i>	R-M	
<i>Parthenium hysterophorus</i>		M-W
<i>Solanum nigrum</i>		M-W
Sedges		
<i>Cyperus iria</i>	R- M, M-W	
<i>Cyperus deformis</i>	R- M, M-W	
<i>Cyperus rotundus</i>	M-W, R-M, M-P+M, M-M	M-W, M-P+M, M-P
<i>Fimbristylis milicea</i>	R-W/ M	

R= rice, W= wheat, P= potato, M= maize, PP= pigeonpea , L = lentil, F= Fallow,
C=Chickpea

(Source: Jat et al., 2014, Fresher's Training manual)



Table 4. Herbicides recommended for use in maize in India as of April 2022.

Herbicides	Dose/ha		Dilution in water (L/ha)
	a.i	Formulation (g/ml)/%	
Pre-emergence (0-2 DAS)			
Atrazine 50% WP	0.5-1 kg	1-2 kg	500-700
Pyroxasulfone 85% w/w WG	127.5 g	150g	500
Post-emergence (20-30 DAS)			
2,4-D Dimethyl Amine salt 58% SL	0.5 kg	0.86g	400-500
2,4-D Ethyl Ester 38 % EC (having 2,4-D acid 34 % w/w)	0.9 kg	2.65 L	400-450
Halosulfuron Methyl 75% WG	67.5 g	90	375
Paraquat dichloride 24% SL [pre-plant (minimum tillage) before sowing]	0.2-0.5 kg	0.8-2.0 L	500
Paraquat dichloride 24% SL (Post-emergence directed inter row application at 2-3 leaf stage of weeds)	0.2-0.5 kg	0.8-2.0 L	500
Tembotrione 34.4% SC	120 g	286ml	500
Topramezone 336 g/l w/v SC	25.2 to 33.6 g a.i./ha + MSO adjuvant @ 2 ml/L of water	75 to 100 ml + MSO adjuvant @ 2 ml/L of Water	375
Mesotrione 2.27% w/w + Atrazine 22.7% w/w SC	875 g	3500	500


Fig. 3. Effective pre and post emergence herbicide-based weed management in maize under CA.


d) Non-seasonal weed control

The weed seed bank tends to expand due to neglected weed management during the non-growing season. It's essential to address this issue by uprooting weeds before they have the chance to set seed. Alternatively, non-selective herbicides like Paraquat dichloride 24% SL or Glyphosate can be applied at @ 1000 g a.i./ha to effectively control weeds before they set seed.

e) Preventive measures for weed management in CA

No seed setting to be allowed for weed at any stage of the crop in initial years of CA adoption.

4. Practicing CA on field: Water Management

In contrast to CT RW rotation which consumed 1889 mm ha⁻¹ irrigation water (2-yr mean), CA with sub-surface drip irrigation system saved 58.4 and 95.5% irrigation water in rice-wheat and maize-wheat rotations, respectively.

Precision water management in CA

CA with sub-surface drip irrigation in MW systems recorded 5% (2-yr mean) higher profitability (Table 5) with 80% subsidy on installing a sub-surface drip irrigation system and similar profitability without subsidy scenario compared with their respective flood irrigated CA-based systems (Jat et al., 2019). This CA with drip irrigation in maize-wheat system improved energy productivity by 169% and partial factor productivity of N by 49.6% respectively compared to conventional rice-wheat system (Table 6). The sub-surface drip irrigation system saved the fertilizer N by 20% under CA systems.



Table 5. Grain yield, cost of cultivation with (80%) and without subsidy on SDI system and net returns under different scenarios

Scenario	Grain yield (Mg ha ⁻¹)				Cost of cultivation (USD ha ⁻¹)		Net returns (USD ha ⁻¹)	
	Rice eq.	Wheat	Mung	System	Rice/ Maize	System	Rice/ Maize	System
Rice-Wheat-Fallow CT-CT	7.51 ^{ab}	5.47 ^c	-NA-	13.40 ^b	687 ^a	1359 ^a	979 ^b	1807 ^c
Rice-Wheat-Mungbean CT-ZT-ZT	7.39 ^b	5.72 ^{bc}	0.50 ^a	15.08 ^a	655 ^a	1335 ^a	984 ^b	2225 ^b
Rice-Wheat-Mungbean ZT-ZT-ZT	5.88 ^c	6.35 ^{ab}	0.15 ^b	13.19 ^b	600 ^b	1247 ^b	705 ^c	1925 ^c
Maize-Wheat-Mungbean ZT-ZT-ZT	7.12 ^{ab} (7.66) *	6.53 ^{ab}	0.15 ^b	14.62 ^a	568 ^{bc}	1212 ^c	1243 ^a	2482 ^a
Rice-Wheat-Mungbean ZT-ZT-ZT SDI	6.21 ^c	6.79 ^a	0.20 ^b	14.12 ^{ab}	526 ^d (642)	1165 ^d (1395)	852 ^{bc} (736)	2184 ^b (1953)
Maize-Wheat-Mungbean ZT-ZT-ZT SDI	7.61 ^a (8.20)	6.38 ^{ab}	0.22 ^b	15.14 ^a	558 ^{cd} (674)	1196 ^{cd} (1426)	1289 ^a (1173)	2547 ^a (2317)

**Figure in parenthesis are actual yield or economics of respective crop i.e., maize.*

Table 6. Irrigation water use and water productivity (WPI), and partial factor productivity on N (PFP_N) under different scenarios

Scenario	Irrigation (mm ha ⁻¹)				WP ₁ (kg grain m ⁻³)	PFP _N (kg grain kg ⁻¹ N applied)
	Rice/ Maize	Wheat	Mung	System	System	System
Rice-Wheat-Fallow CT-CT	1893 ^{ab}	409 ^a	-NA-	2302 ^a	0.59 ^d	41.23 ^c
Rice-Wheat-Mungbean CT-ZT-ZT	1562 ^b	349 ^{ab}	167 ^b	2078 ^{ab}	0.73 ^d	50.27 ^b
Rice-Wheat-Mungbean ZT-ZT-ZT	1420 ^b	357 ^{ab}	183 ^a	1961 ^b	0.67 ^d	42.55 ^c
Maize-Wheat-Mungbean ZT-ZT-ZT	110 ^d	337 ^b	177 ^{ab}	624 ^c	2.37 ^b	44.98 ^c
Rice-Wheat-Mungbean ZT-ZT-ZT SDI	620 ^c	188 ^c	80 ^c	888 ^c	1.59 ^c	56.48 ^a
Maize-Wheat-Mungbean ZT-ZT-ZT SDI	86 ^d	172 ^c	80 ^c	338 ^d	4.50 ^a	58.23 ^a





Fig. 4. Sub-surface drip irrigated maize at CSSRI-CIMMYT platform, Karnal

Impact of CA practices in maize systems on various parameters

a) Soil health and quality

Soil quality is the capacity of the soil to function, and soil health is the continued capacity of soil to function as a vital living system, within ecosystem and land use boundaries, to sustain biological productivity, maintain the quality of air and water environments, and promote plant, animal, and human health. It improved soil physical and biological health (Singh et al., 2015; Parihar et al., 2016, Jat et al., 2019).

Soil biological, physical, and chemical properties get influenced by soil management practices, cropping systems, and weather conditions. CA systems aim at enhancing the soil health. A well-managed healthy soil increases soil water infiltration and storage, and supply of nutrients to plants, microbial diversity, and soil carbon storage. Healthy soils increase the capacity of crops to withstand weather variability including short term extreme precipitation events and intra-seasonal drought without much affecting the yield. SOM is a central soil property that is heavily affected by management and can be



well managed using CA practices. CA based practices decrease mechanical impedance, continuity, stability and size distribution of pores, air-water dynamics and the thermal regime of the soil. Surface retained crop residue provides physical barrier and reduces potential erosion during intense rain events. CA practices also help to enhance or sustain SOM and biodiversity.

CA and soil health in maize systems

A long-term study was conducted to evaluate the tillage practices of ZT, PB and CT in four diversified intensive maize-based crop rotations MWMb, MCS, MMuMb and MMS). In this study, the SOC, physical and biological properties of soil at various depths after 7 years of continuous ZT, PB and CT in diversified maize rotations were analyzed (Parihar et al., 2016a). Compared to CT plots, the soil physical properties like water-stable aggregates (WSA) > 250 mm were 16.1-32.5% higher, and bulk density (BD) and penetration resistance (PR) showed significant ($P < 0.05$) decline (11.0-14.3 and 11.2-12.0%) in ZT and PB plots at 0-15 and 15-30 cm soil layers. The soil organic carbon (SOC) increased by 34.6-35.3% at 0-15 cm, and 23.6-26.5% at 15-30 cm soil depths with conservation agriculture (ZT and PB) based crop establishment techniques over CT.

Similarly, the soil microbial biomass carbon (MBC) under CA-based systems increased by 45-48.9% in 0-30 cm profile depth of a sandy loam (Typic Haplustept) soil. Significant ($P < 0.05$) improvement in soil enzymatic activities i.e., Fluorescein diacetate, dehydrogenase, α -Glucosidase and Alkaline phosphatase were also recorded in the CA-based treatments. Significant ($P < 0.05$) synergistic effects of summer legumes (mungbean and Sesbania) with winter legume/cereal in crop rotations were observed on SOC, WSA, BD, PR and Ksat at 0-15 and 15-30 cm depths. Interaction between tillage and crop rotations were significant ($P < 0.05$) for SOC, physical properties and enzymatic activities. Thus, this long-term study suggests that CA-based crop management with selected diversified maize-based rotations (MCS and MWMb) can be advocated as sustainable intensification strategy in light-textured soils of north-western India and other similar agro-ecologies of South Asia.

After 6 years, a significant positive effect of CA practices on SOC content, labile SOC fractions, soil MBC and dehydrogenase activity (Parihar et al., 2018). ZT and PB increased SOC stock (0-30 cm depth) by 7.22-7.23 Mg C ha⁻¹ whereas CT system increased it only by 0.88 Mg C ha⁻¹ as compared to the initial value (Parihar et al., 2018a). Crop rotation and residue management can also affect soil enzyme activity.



Retention of crop residue in PB increased total SOC by 11.5 to 19.5% compared with PB-R, across the soil depths (Jat et al., 2019b).

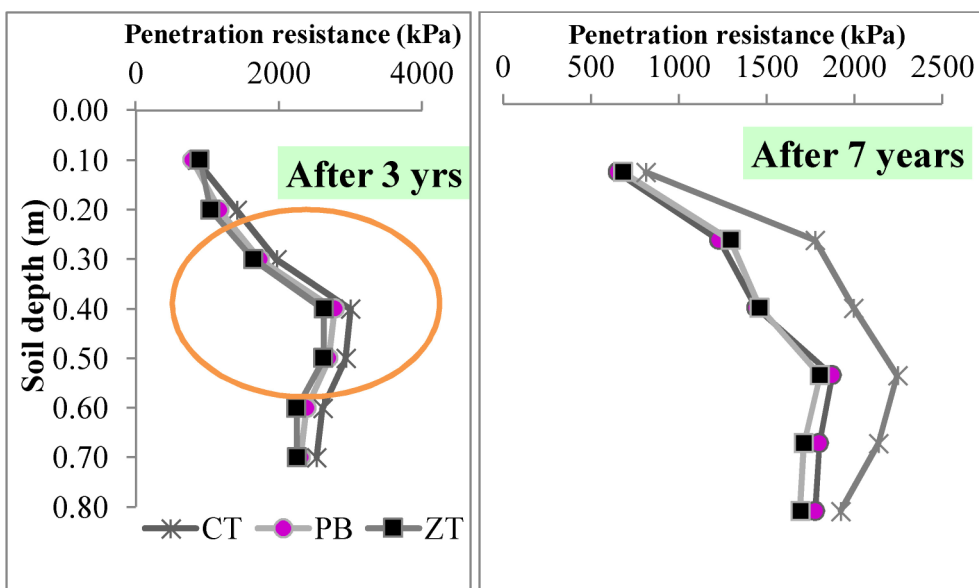


Fig. 5 The change in the penetration resistance in maize systems under CA over the years in sandy loam soils of Delhi.

Soil faunal diversity

Reduced tillage combined with residue retention indirectly defines the species composition of the soil microbial community by improving the retention of soil moisture and modifying the soil temperature. These modifications to the micro-environment influence the biological activity of beneficial micro-organisms in both the crop canopy and the soil.

Soil organisms respond to tillage-induced changes in the soil physical/chemical environment and they, in turn, have an impact on soil physical/chemical conditions, i.e., soil structure, nutrient cycling, and organic matter decomposition. The crop residues at the soil surface under ZT tend to be fungal dominated (Hendrix et al. 1986). Arbuscular mycorrhizal spore number, active hyphal length and glomalin concentration are higher in the topsoil (0-10 cm) under ZT than under mouldboard ploughing (Borie et al., 2006). Simmons and Coleman (2008) attribute the difference in fungal population between zero and CT systems to the ability of an ecosystem to withstand disturbance, where bacterial-dominated systems are more resilient than fungal dominated systems due to the different energy pathway. A reduction in tillage influences different pest species in



different ways, depending on their survival strategies and life cycles (Andersen 1999). Reeleder et al. (2006) found that total mite population was more affected by cover crop than by tillage practice. Termites and ants are predominant in arid and semi-arid regions where earthworms are normally absent or scarce. Management options which favor ants and termites' populations, such as residue mulch and reduced or ZT, have been identified as key factors in improving the topsoil in agro-ecosystems, even in the degraded conditions. Changes in tillage, residue, and rotation practices induce major shifts in the number and composition of soil fauna and flora, including both pests and beneficial organisms.

b) System productivity

CA resulted in 5-10 % higher yield than CT planting. The major reasons behind the yield gains are discussed below:

1. **Timely planting:** In CA, the exclusion of primary and secondary tillage operations accelerates crop planting by 15-20 days. This practice effectively mitigates the risk of exposure to extreme heat or cold during crucial reproductive stages, ensuring that crops thrive in an ideal growth environment throughout their entire life cycle.
2. **Protection against abiotic stresses:** Surface residues serve a dual purpose in agricultural practices. Firstly, they act as a protective layer that reduces soil moisture loss through evaporation. Secondly, they contribute to an increase in soil water holding capacity by boosting the organic carbon content, which is known to possess a water-holding capacity approximately 3-4% higher than regular soil. Consequently, the use of residue mulch effectively prolongs the availability of soil moisture and delays the onset of drought conditions. In the long term, CA techniques contribute to the mitigation of soil compaction (soil hardpan), enhancing the rate of water infiltration, and promoting the formation of soil macro pores, commonly referred to as biopores. These combined effects are instrumental in facilitating the drainage of excess water during heavy rainfall events, thereby safeguarding waterlogging-sensitive crops from the detrimental impact of stagnant surface water. Furthermore, residue mulch plays a crucial role in shielding crops from heat stress. The presence of surface residues assists in maintaining optimal soil moisture levels, which, in turn, contributes to evapotranspiration cooling. As a result, the canopy temperature of crops is reduced, offering protection against heat-related stressors.
3. **Soil health improvement:** All the three components of CA collectively enhance soil physical, chemical, and biological processes, creating an optimal environment for root development, water and nutrient absorption, and various biological activities.



Hence, timely planting, lesser abiotic stress and improved soil environment under CA enhance system yield in a sustainable way. A long-term trial was initiated in maize-wheat system under CA in AICRP on maize (Table 7). The results of the first three years indicated that a notable yield improvement evident in CA-based ZT or PB practices, ranging from 704 to 1860 kg/ha and 486 to 1505 kg/ha, respectively, except in clay loam soil with high rainfall areas in Pantnagar.

Table 7. The productivity of maize-wheat-mungbean system under CA in various agro-ecologies of India.

Tillage practices	System yield (kg/ha; 3 years mean)				
	NWPZ	NWPZ	NWPZ	NEPZ	CWZ
	Clay loam	Loamy	Sandy loam	Sandy loam	Clay loam
ZT+R	8424 ^b	16427 ^a	12657 ^a	11714 ^{ab}	11174 ^a
PB+R	9090 ^b	15969 ^b	12728 ^a	12229 ^a	10443 ^b
CT+R	10874 ^a	15483 ^b	11223 ^b	11010 ^b	9314 ^c
p-value	0.0005	0.0428	0.0117	0.0381	<.0001
Change over CT+R					
ZT+R	-2450	944	1434	704	1860
PB+R	-1784	486	1505	1219	1129

ZTR-Zero till rice, ZTM-Zero till maize, PBR-Rice on permanent beds, PBM-Maize on permanent beds

Various workers in the country researched CA in maize systems intensively. The enhancement in maize yield was significantly higher with the application of the residue by 12.6% over no residue application in CA (IIMR, 2019) which underlies importance of the residue retention in the CA in maize systems. In a 6-year study of CA evaluated the performance of CA-based management practices [permanent bed (PB) and zero tillage (ZT)] and conventional till (CT) for four intensified irrigated maize systems [maize-wheat-mungbean (MWMb), maize-chickpea-Sesbania green manure (MCS), maize-mustard-mungbean (MMuMb) and maize-maize-Sesbania (MMS)]. Significant ($P < 0.05$) tillage and cropping system interactions were observed for system



productivity (Parihar et al., 2016). In the initial two years, higher system productivity (maize equivalent yield) was recorded in PB (8.2-8.5 Mg ha⁻¹), while from third year onwards ZT registered maximum productivity (11.3-12.9 Mg ha⁻¹). Compared to the rice-wheat system, increased system productivity (up to 33%) and profitability (up to 50 %) was observed in CA-based maize-wheat system (IIMR 2019 and 2020).

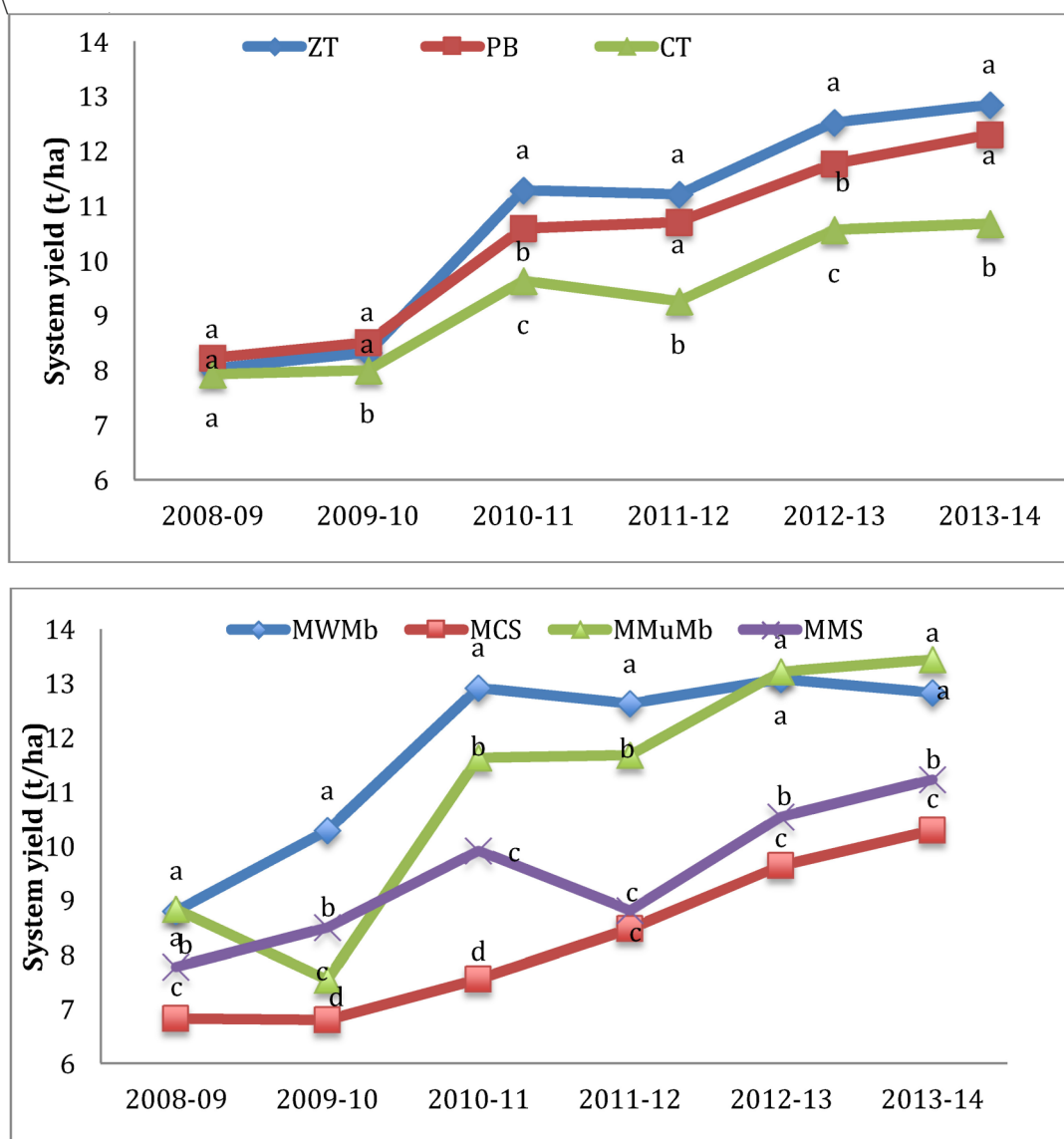


Fig. 6 Six-year trend in the system yield of maize under CA vs CT practices.



The maize, wheat and mustard yields were statistically similar in first year of study irrespective of residue retention or removal, whereas during subsequent years, yields of maize, wheat and mustard were significantly ($P < 0.05$) higher by 10.1-16.7%, 9.3-23.6% and 13.6-21.9% under residue retained plots (full CA) than residue removed plots (partial CA), respectively (Jat et al., 2019a).

Experiments on nutrient management in maize-based cropping system under different tillage practices have also shown encouraging results. In maize-wheat-mungbean cropping system, ZT resulted in significantly higher crops yield and SSNM gave higher yield over farmer's fertilization practices (FFP) and RDF at Banswara. In rice-maize cropping system, at Dholi the tillage practice of permanent beds (PB) resulted in significantly higher cob yield and SSNM gave higher yield over FFP and RDF in grain yield and RDF found statistically at par. Planting of maize-mustard/chickpea system under rainfed condition planting of maize with ZT resulted in 7.0-11.6% higher yields in various zones (IIMR, 2017). The various duration experiment shows that CA in the long run benefits more due to build-up in soil fertility (Table 8).

c) Economic profitability

Land preparation is the most energy intensive and costly farm operation. Adoption of CA based farming has lesser land preparation cost as it reduces number of tractor passes from 4-5 to one. It saves 30-45 liters of fuel per ha as compared to conventional method. Prohibition of tillage, replacement of manual weeding with herbicide applications, lesser irrigation and drainage demand in CA subsequently decrease the labour requirement by 26-44%. Overall, CA reduces cultivation expenses by 4,000-5,000 INR/ha while simultaneously boosting profitability up to 20-40% compared to CT systems. In maize-based cropping systems, ZT, gave up to 31% higher net returns with production costs reduced by 72\$/ha compared to CT (Parihar et al., 2016). Crop residue retention in zero tilled PB increased cost of cultivation by 125 and 147 USD/ha in MMuMb and MWMB systems, respectively (Jat et al., 2019c). The higher yield and profitability of CA based maize systems are widely reported in India (Table 10).



Table 8. Effect of CA on the productivity of various cropping system in India.

Soil type/location	Cropping system	Comparisons	Duration (years)	Changes in yield (%)	Reference
Sandy loam	Maize-wheat-mungbean	ZT Vs CT	6	18.93% higher system yield under ZT	Parihar et al., 2016
Sandy loam	Maize-wheat-Mungbean	PB/ZT Vs CT	4	18.9-20.1 % higher system yield in PB and ZT	Parihar et al., 2017
Sandy loam	Maize-wheat/chickpea	PB+R/ ZT+R Vs CT-R	2	21.1-21.9 % higher system yield in PB+R and 18.7-27.5% higher in ZT+R	Parihar et al., 2019
Sandy loam	Maize-wheat/mustard	Residue retention Vs residue removal	5	10.1-16.7% (maize) 9.3-23.6% (wheat) and 13.6-21.9% (mustard) higher yield were obtained with residue retention	Jat et al., 2019a
-	Maize-wheat	CA Vs CT	5	16% higher system yield in CA	Jat et al., 2020
Anantapuram	Rice-zero till maize	ZT vs farmer practice	4	11.4 % higher maize in ZT	Kumari and Sudheer, 2016
Eastern Gangetic Plains	Rice- maize	ZT Vs CT	2	5.8 % higher system yield in ZT	Islama et al., 2019
Shrinagar	Maize-oat	ZT Vs CT	4	8.35 and 7.15 % higher maize yield in PB and ZT, respectively	IIMR AICRP Kharif Report 2015-2019
Banswara	Rainfed Maize based cropping system	ZT Vs CT	3	14 % (5.8-22.7%) higher maize yield in ZT	IIMR AICRP Kharif Report 2017-19
Dholi	Rice-maize	PB/ZT vs CT	3	5.6 and 8.7 % higher maize yield in PB and ZT, respectively	IIMR AICRP Kharif Report 2017-19
Ludhiana	Maize-wheat	CT based rice-wheat (RW) Vs maize-wheat (MW)	2	33% higher system yield in CA based MW	IIMR 2019
Sandy loam	Maize-wheat	Residue retention Vs residue removal	2	12.6 % higher maize yield with residue retention	IIMR, 2019



Table 10. Effect of CA on the profitability of various cropping system in India.

Soil type	Cropping system	Comparisons	Duration (years)	Changes	Reference
Sandy loam	Maize-wheat-mungbean	ZT Vs CT	6	31% higher system net returns in ZT	Parihar et al., 2016
Sandy loam	Maize-wheat-mungbean	ZT Vs CT	6	72\$ ha ⁻¹ lower cost of cultivation in ZT	Parihar et al., 2016
Sandy loam	Maize-mustard-mungbean (MMuMb) and maize-wheat-mungbean (MWMb)	Residue retention Vs residue removal in ZT based PB	5	Residue retention increased cost of cultivation by 9,537 INR/ha in MMuMb and 11,216 INR/ha in MWMb	Jat et al., 2019c
Sandy loam	Maize-Wheat	CA Vs CT	5	36% higher system profitability in CA	Jat et al., 2020
Ludhiana	Maize-wheat	CT based rice-wheat Vs CA based maize-wheat (MW)	2	Up to 50% higher system profitability in CA based MW	IIMR 2019
Sandy loam	Maize-wheat	ZT Vs CT	2	5,495 INR/ha lesser cost of production in ZT	IIMR 2019
Sandy loam	Maize-wheat	ZT Vs CT	2	31% higher net profit in ZT	IIMR 2019



d) CA and water productivity via a-vis input use efficiency

CA plays a pivotal role in enhancing water productivity in agriculture through better water infiltration and retention and reduce soil evaporation. Permanent bed planting had significantly higher water productivity and water use in both maize and wheat crops, but the benefits were more in maize than wheat (Jat et al., 2008). ZT and PB practices reduced the irrigation water requirement by 40-65 ha-mm and 60-98 ha-mm, respectively compared to CT system and resulted in enhanced system water productivity by 19.4% equally under both ZT and PB in maize systems (Parihar et al., 2016). Compared to the rice-wheat system water saving (82 %) was observed in CA-based maize-wheat system (IIMR 2019). Substitution of rice with maize (MW system) recorded 19.7% higher productivity, saved 84.5% of irrigation water and increased net returns by 48.9% compared to farmer's practice (Jat et al., 2019). ZT gave maximum system productivity (11.3-12.9 t/ha) with reduced irrigation water requirement by 40-65 ha-mm.

e) CA and ecosystems services

In the last few years, South Asia has witnessed adverse effects of climatic variations in terms of terminal heat stress on wheat productivity. For adapting the climate change effects, the immediate solutions could be altered management practices involving CA approach for buffering soil and canopy temperatures. Farmers' participatory field trials were conducted across IGP under the aegis of the CSISA for developing and defining innovative solutions for addressing terminal heat stress in wheat productions. The innovative adaptations strategies developed and validated include (i) advancing planting time, (ii) cultivar choices, (iii) no-till & mulching, (iv) irrigation management, (v) relay cropping of Sesbania/mungbean, and (vi) balanced plant nutrition. Results of farmers participatory field trials across IGP reveal that ZT facilitates timely planting and the terminal heat effects are less in zero till. Even in cases of late planting (after 21st November till 20th December), ZT experiences lower heat effects (65 kg/ha/day), as compared to CT, which encounters higher yield penalty (77 kg/ha/day) due to heat stress. Zero-till drilling in residues keeps canopy temperature lower by 1 to 1.5°C during grain filling stage (cooling due to transpiration) owing to sustained soil moisture availability to the plants. Significant tillage x genotype x cropping system interactions were also observed suggesting redefining recommendations for cultivar choices. Further, layering, rescheduling of irrigation and plant nutrient applications had further positive effects in adapting wheat to terminal heat effects. Therefore, layering these innovative management practices can be an immediate solution for adapting to climate change effects (IIMR Annual Report 2015-16).

CA based practices provide an integrated approach aimed at adaptive and mitigation strategies to face the risk of climate change on agriculture. Adaptive strategies includes improved use efficiency of water and nutrients; improved ability to cope with extreme events - drought, excess rain period, soil temperature variation, changed pest/disease scenario; opportunity to develop a biologically mediated



approach aimed at sustainable productivity enhancement; ensuring timely sowing due to saving of time spent on tillage and opportunities offered for crop intensification in the face of resource constraint. The CA based mitigative strategies for the impact of climate change on agriculture are enhanced sequestration of carbon through soil and biomass; reduced dependence on chemicals contributing to reduction in GHGs emissions and reduced GHGs emissions on account of practices like minimal tillage, crop residue retention, carbon sequestration etc.

Conservation tillage fields act as a sink for CO₂ and conservation farming applied on a global scale could provide a major contribution to control air pollution in general and global warming in particular. The conservation of resources (land, water, energy) saves the cost of water and energy and protects the environment while leading to improved productivity on a sustainable basis. Targeting the resource conserving technologies offers newer opportunities of better livelihood for the small and marginal farmers. Hence, adoption of resource conserving technologies viz., new cultivars, reduced or minimum pre-planting tillage, soil water management practices is essentially needed to revert the damage done to the natural resources. RCTs improve input use efficiency at low cost and preserve ecological integrity of crop production system. Global warming potential (GWP) under CT system was higher by 18.1 and 17.4%, compared to CA-based ZT and PB, respectively (Parihar et al., 2018a).

In the conventional system involving intensive tillage, there is a gradual decline in soil organic matter through accelerated oxidation and burning of crop residues causing pollution, GHGs emission and loss of valuable plant nutrients. When the crop residues are retained on soil surface in combination with no tillage, it initiates processes that lead to improved soil quality and overall resource enhancement. The tillage aims to create a soil environment favorable to plant growth. Appropriate tillage practices are those that avoid the degradation of soil properties but maintain crop yields as well as ecosystem stability. Beside all these, the key benefits of CA to the farmers are:

- ✓ Reduced cost of cultivation through savings in labour, time and farm power.
- ✓ Improved and sustainable yield with lower use of inputs (fertilizers, pesticides).
- ✓ In mechanized farming, longer life and minimum repair of tractors and other farm machineries and less water, power and much lower fuel consumption.



Success story of CA based maize system in India CA/zero tillage: Profitable technology in A.P.



CA based maize

The trends in area, production and productivity of maize in Andhra Pradesh have shown a remarkable increase during the past six decades. During 1950-51, the maize acreage in the state was very less (1.4 lakh ha) that has grown up by 5.7 times to the present (2007-08) level of 7.9 lakh hectares. However, production has increased dramatically from merely 40 thousand tonnes during 1950-51 to 41.4 lakh tonnes during 2007-08 which is nearly 109 times higher. Similarly, the productivity of maize in the state was merely 275 kg ha⁻¹ during 1950-51 that has increased to 5240 kg ha⁻¹ during 2007-08 which is highest state average in the country and in some of the district it is > 10 tonnes. The Andhra Pradesh though is a non-traditional maize growing state but has emerged as one of the potential maize growing states that contributes nearly 21 % of the total maize production in the country. For over a decade during 1980-81 to 1990-91, there was a decreasing trend in area, production and productivity of maize in the state. Trends show that till 1990's the growth in area, production and productivity of maize was very slow but thereafter it took momentum. However, the major increase was achieved during the past 1990's there has been a perceptible increase in area, production and productivity of maize mainly due to adoption of single cross hybrids and zero till in rice maize system since past 2 years in the state. These two technologies can address the issues of water scarcity in intensive irrigated regions of Krishna and Godavari zones and the SCHs experiences better productivity even in the scarce rainfall areas like Ananthpur. It is adopted in ~1.0 lakh ha area of Erstwhile Andhra Pradesh and Tamil Nadu. According to Sreelatha et al., (2018), CA based farming in A.P. led to following benefits:



- ✦ Area increasing in rabi
- ✦ Crop intensification
- ✦ Timely operation
- ✦ Saving fuel, natural resources, eco-friendly
- ✦ Reducing cost of cultivation
- ✦ Increase/day productivity
- ✦ Improving soil health
- ✦ Farmers are harvesting up to 10 t/ha maize grain

Do's and don'ts in CA

Farm operation	Do's	Don'ts
Land levelling and field layout	✓ Lesser area under furrow/bund/channel. ✓ Land to be levelled and if not do levelling first before going to CA. ✓ More tilled soil should be sub-soiled to break hard pan.	✓ Undulating land surface
Tillage/tilling soil/mechanical manipulation	✓ Only for seeding and fertilizer placement by opening narrow slit.	✓ Opening
Crop establishment/sowing	✓ By opening narrow slit for placing seed. ✓ Covering of seed ✓ Closing of the opened furrow	✓ The opening should not be
Residue application	✓ Anchored/standing residue for smooth seeding operations. ✓ Spreading or uniform distribution of residue ✓ Atleast hard residue or any other part not used for animal and other competitive uses to be retain over surface.	✓ Residue removal ✓ Accumulation of residue at one place.
Weed management	✓ Herbicide based weed management ✓ Uprooting of hardy weeds throughout season in initial year ✓ Prevention of seed setting. ✓ Non-season weed control.	✓ No hand weeding with khurfi or by mechanical soil disturbance as this disturbance will bring more weed seed from below soil.



For Success of CA in maize system

- ✦ FIRST: Chiseling of rice system soil before start of maize cultivation to break hard pan
- ✦ Leveling of field
- ✦ Weed management in off season and off farm
- ✦ Avoid saline/waterlogged areas

Future thrust

There is needed to make small-scale machineries for seeding under CA in maize systems for small and marginal farmers for its enhanced adoption. The good post emergence herbicides (Tembotrione, Topramezone) available should be demonstrated in maize systems. The making of small videos in the vernacular languages about practices and potential benefits of CA needs to be made on maize systems and made available in social media for its enhanced adoption. The activities of the soil fauna and microbes are not well documented in CA based maize systems that need to be explored. The enhanced yield responsible microbial consortia in CA can be an important input in agriculture that needs due attention for extending its benefits. The insect and disease dynamics and specially the potential threat if any also need to be studied in detail for making it more sustainable. The weed bank seed dynamics is important in CA for making future plausible decisions on out-scaling CA.

The strengthening of the component crop management practices will help in enhancing its adoption owing to more benefits and making it as CA+. Thus, the research evidence suggested that conservation agriculture-based management practices in maize systems have the potential for enhancing crop yield, resource use efficiency, profitability and soil health and these need to be out-scaled appropriately for sustainable maize systems in India and similar ecologies with the best bet input management practices.

Way forward

- ✦ Customized CA for various agro-ecologies and farm typology
- ✦ Farmer participatory research
- ✦ Videos on the do's, don'ts and benefits
- ✦ Identification of domains by SWOT analysis
- ✦ Strengthening of input management tailored to CA
- ✦ Harnessing interaction of G x E x M
- ✦ Incentive/recognition to farmers adopting it as carbon credit, resource saver
- ✦ Availability of scale appropriate machinery



REFERENCES

- Andersen, A. (1999) Plant protection in spring cereal production with reduced tillage. II. Pests and beneficial insects. *Crop protection*, **18**, 651-657.
- Borie, F., Rubio, R., Rouanet, J.L., Morales, A., Borie, G., and Rojas, C. (2006) Effects of tillage systems on soil characteristics, glomalin and mycorrhizal propagules in a Chilean Ultisol. *Soil Tillage Research*, **88**, 253-261.
- Hendrix, P.F., Parmelee, R.W., Crossley, D.A., Coleman, D.C., Odum, E.P., and Groffman, P.M. (1986) Detritus Food Webs in Conventional and No-Tillage Agroecosystems. *Bioscience*, **36**, 374-380.
- IIMR 2017. IIMR Annual report 2016-17. ICAR-Indian Institute of Maize Research, Ludhiana.
- IIMR 2019. IIMR Annual report 2018-19. ICAR-Indian Institute of Maize Research, Ludhiana.
- Islama S, Gathalaa MK, Tiwaria TP, et al. (2019). Conservation agriculture based sustainable intensification: Increasing yields and water productivity for smallholders of the Eastern Gangetic Plains. *Field Crops Research*, **238**: 1-17.
- Jat, H.S., Sharma, P.C., Datta, A. et al. 2019. Re-designing irrigated intensive cereal systems through bundling precision agronomic innovations for transitioning towards agricultural sustainability in North-West India. *Scientific Report* **9**: 17929. <https://doi.org/10.1038/s41598-019-54086-1>.
- Jat, M.L., Dagar, J.C., Sapkota, T.B., Singh, Y., Govaerts, B., Ridaura, S.L., Saharawat, Y.S., Sharma, R.K., Tetarwal, J.P., Jat, R.K., Hobbs, H. and Stirling, C. 2016. Climate Change and Agriculture: Adaptation Strategies and Mitigation Opportunities for Food Security in South Asia and Latin America. *Advance in Agronomy* **137**:127-236.
- Jat, S.L. Parihar, C.M., Singh, A.K., Nayak, H.S., Meena, B.R., Kumar, B., Parihar, M.D. and Jat, M.L. 2019a. Differential response from N sources with and without residue management under conservation agriculture on crop yields, water-use and economics in maize-based rotations. *Field Crops Research*, **236** (2019) 96-110.
- Jat, S.L., Parihar, C.M., Dey, A., Nayak, H.S., Ghosh, A., Parihar, M.D. and Parihar, N. 2019b. Dynamics and temperature sensitivity of soil organic carbon mineralization under medium-term conservation agriculture as affected by residue and nitrogen management options. *Soil and Tillage Research*. **191**: <https://doi.org/10.1016/j.still.2019.02.005>
- Jat, S.L., Parihar, C.M., Singh, A.K. Kumar, B., Choudhary, M., Nayak, H.S., Parihar, M.D., Parihar, N. and Meena, B.R. 2019c. Energy auditing and carbon footprint under long-term conservation agriculture-based intensive maize systems with diverse inorganic nitrogen management options. *Science of the Total Environment* **664** (2019): 659-668. <https://doi.org/10.1016/j.scitotenv.2019.01.425>.
- Jat H S, Choudhary K M, Nandal DP, Yadav A, Poonia T, Singh Y S, Sharma P, and Jat M L. 2020. Conservation agriculture-based sustainable intensification of cereal systems leads to energy conservation, higher productivity and farm profitability, environmental management. DOI: 10.1007/s00267-020-01273-w.
- Kumari, C R and Sudheer, J M. (2016). On farm demonstration of zero tillage maize in farmers fields of Anantapuram district of Andhra Pradesh. *International Journal of agricultural Sciences*, **12** (1) : 134-138.
- Parihar, C.M., Jat, S.L., Singh, A.K., Datta, A., Parihar, M.D., Varghese, E., Bandyopadhyay, K.K., Nayak, H.S., Kuri, B.R. and Jat, M.L. 2018. Changes in carbon pools and biological activities of a sandy loam soil under long-term



- conservation agriculture and diversified cropping systems. *European Journal of Soil Science* September 2018, 69: 902–912. doi: 10.1111/ejss.12680.
- Parihar, C.M., Jat, S.L., Singh, A.K., Ghosh, A., Rathore, N.S., Kumar, B., Pradhan, S., Majumdar, K., Satyanarayana, T., Jat, M.L., Saharawat, Y.S., Kuri, B.R. and Saveipune, D. 2017. Effects of precision conservation agriculture in a maize-wheat-mungbean rotation on crop yield, water-use and radiation conversion under a semiarid agro-ecosystem. *Agricultural Water Management*, **192**: 306-319. 10.1016/j.agwat.2017.07.021.
- Parihar, C.M., Jat, S.L., Singh, A.K., Kumar, B., Yadvinder-Singh, Pradhan, S., Pooniya, V., Dhauja, A., Chaudhary, V., Jat, M.L., Jat, R.K. and Yadav, O.P. 2016. Conservation agriculture in irrigated intensive maize-based systems of north-western India: Effects on crop yields, water productivity and economic profitability. *Field Crops Research* **193**:104-116. Doi: doi:10.1016/j.fcr.2016.03.013
- Parihar, C.M., Jat, S.L., Singh, A.K., Majumdar, K., Jat, M.L., Saharawat, Y.S., Pradhan, S. and Kuri, B.R. 2017a. Bio-energy, water-use efficiency and economics of maize-wheat-mungbean system under precision-conservation agriculture in semi-arid agro-ecosystem. *Energy* **119**: 245-256. DOI: 10.1016/j.energy.2016.12.068.
- Parihar, C.M., Parihar, M.D., Sapkota, T.B., Nanwal, R.K., Singh, A.K., Jat, S.L., Nayak, H.S., Mahala, D.M., Singh, L.K., Kakraliya, S.K., Stirling, C.M. and Jat, M.L. 2018a. Long-term impact of conservation agriculture and diversified maize rotations on carbon pools and stocks, mineral nitrogen fractions and nitrous oxide fluxes in Inceptisol of India. *Science of the Total Environment* 640–641:1382-1392.
- Parihar, C.M., Yadav, M.R., Jat, S.L., Singh, A.K., Kumar, B., Pradhan, S., Chakraborty, D., Jat, M.L., Jat, R.K., Saharawat, Y.S. and Yadav, O.P. 2016a. Long term effect of conservation agriculture in maize rotations on total organic carbon, physical and biological properties of a sandy loam soil in north-western Indo-Gangetic Plains. *Soil and Tillage Research* **161**: 0167-1987. doi:10.1016/j.still.2016.04.001.
- Parihar, M D, Parihar C M , Nanwal R K , Singh A K, Jat S L, Nayak H S , Ghasal P C, Jewliah R, Choudhary M And Jat M L. (2019). Effect of different tillage and residue management practices on crop and water productivity and economics in maize (*Zea mays*) based rotations. *Indian Journal of Agricultural Sciences*, 89 (2): 360–6.
- PariharCM, JatSL, SinghAK, GhoshA, RathoreNS, Kumar B, PradhanS, Majumdar . , Satyanarayana T , Jat ML, Saharawat YS, Kuri BR, SaveipunD.(2017).Effects of precision conservation agriculture in a maize-wheat-mungbean rotation on crop yield, water-use and radiation conversion under a semiarid agro-ecosystem,*Agricultural Water Management* 192: 306–319.
- Reeleder, R.D., Miller, J.J., Coelho, B.R.B., and Roy, R.C. (2006) Impacts of tillage, cover crop, and nitrogen on populations of earthworms, microarthropods, and soil fungi in a cultivated fragile soil. *Applied Soil Ecology*, **33**, 243-257.
- Simmons, B.L. and Coleman, D.C. (2008) Microbial community response to transition from conventional to conservation tillage in cotton fields. *Applied Soil Ecology*, **40**, 518-528.





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