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Review Paper

Conservation agriculture in India: History, progress and way forward

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ABSTRACT

Research work on conservation agriculture (CA)-based approaches involving zero tillage (ZT) is going on in India since 1990s. Despite highly encouraging results in the research trials, there has been no greater adoption of these technologies, except in wheat in some areas of Indo-Gangetic plains and central India, maize and sorghum in rice fallows of coastal Andhra Pradesh, rapeseed-mustard in rice fallows of NEH region, and also different crops in the Konkan region of Maharashtra. Analysis of the research papers published in three leading national journals revealed that CA-based topics are being increasingly investigated by the resource management scientists in the recent times. Unlike the conventional tillage (CT) systems, the CA-based technologies are knowledge-driven requiring skill for successful adoption. This article presents the historical aspects, progress made, and practical approaches based on 20 years of experience of the author in varied ecologies for adoption of CA technologies for improving crop productivity. CA has been the fastest adopted technology globally over the past decade, and all out efforts need to be made to outscale it by following a roadmap in India.

***Key words* :** Conservation agriculture, Conventional tillage, Crop residues, Crop rotations, Happy seeder, Weed control, Zero tillage

INTRODUCTION

Adoption of green revolution technologies during the 1960s led to increased productivity and elimination of acute foodgrain shortages in India. These technologies primarily involved growing of high-yielding dwarf varieties of rice and wheat, increased use of chemical fertilizers and other agrochemicals, and expansion of irrigation facilities. This was also accompanied by the other so called modern methods of cultivation, which included maximum tilling of land, virtually clean cultivation with complete removal of crop residues and other biomass from the field, fixed crop rotations mostly involving cereals, and elimination of fertility-restoring pulses and oilseed crops in the highly productive north-western plain zone of the country.

Over the last 4–5 decades, India has achieved not only self-sufficiency in foodgrain production but also the capability to export food commodities. This is cited as one of the greatest accomplishments of Indian agriculture in the post-independence era. However, the transformation from ‘traditional animal-based subsistence farming’ to ‘intensive chemical- and tractor-based modern agriculture’ has led to multiplicity of issues associated with sustainability of these production practices. Conventional crop production technologies are characterized by: (i) intensive tillage to prepare fine seed- and root-bed for sowing to ensure proper germination and initial vigour, faster absorption of moisture, control of weeds and other pests, mixing of fertilizers and organic manures; (ii) monocropping systems; (iii) clean cultivation involving removal or burning of all residues after harvesting leading to continuous mining of nutrients and moisture from the soil profile; and bare soil with no cover; (iv) indiscriminate use of pesticides, and excessive and imbalanced use of chemical fertilizers leading to decline in input-use efficiency and factor productivity, and increase in pollution of environment, ground water, streams, rivers and oceans; and (v) energy-intensive farming systems.

Conventional versus conservation agriculture systems

Conventional agriculture systems are characterized by intensive tillage operations, clean cultivation, fixed cropping, indiscriminate use of irrigation water and chemical fertilizers. Adoption of these systems has led to declining factor productivity, deteriorating soil health, surface and groundwater pollution, increasing cost of production and lower profitability. It is realized that soils are getting impoverished due to imbalanced use of fertilizers, discontinuation of traditional practices like mulching, intercropping

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and inclusion of legumes in cropping systems. Further, the use of organic manures, composts and green manure crops has also decreased considerably due to various reasons. Similarly, water resources are under great stress due to their indiscriminate exploitation and also getting polluted due to various human interferences. Burning of fossil fuels and crop residues, and puddling for rice cultivation are leading to emission of greenhouse gases, which are responsible for climate change and global warming. Further, there is now a growing realization that the productivity levels are stagnating and the incomes of the farmers are reducing due to the rising cost of the inputs and farm operations. It is feared that modern cultivation practices are not sustainable in the long-run, and there is a need to change the way we do crop production on arable lands.

Conservation agriculture (CA) is considered as a new paradigm in resource management for alleviating the problems associated with the so-called modern cultivation practices. Three principles of CA are: (i) continuous no or minimal mechanical soil disturbance, (ii) maintenance of permanent biomass soil mulch cover on the ground surface, and (iii) diversification of crop species. These principles are universally applicable to all agricultural landscapes and land uses with locally formulated and adapted practices. Strictly speaking, if the three principles are applied separately, they do not constitute a CA system. For example, the use of zero tillage (ZT) practice on its own does not qualify the production system to be CA-based, unless it is linked to the application of the other two practices of soil mulch cover and diversified cropping.

CA also requires suitable modifications in water, fertilizer, weed and pest management practices as well as farm machinery compared with conventional tillage (CT). It is a holistic approach towards increased productivity and improved soil health. The advantages of CA over CT were reviewed earlier (Sharma *et al.*, 2012). In the recent times, harvesting of most crops with combines and burning of residues *in situ* has become a major national issue, despite restrictions imposed and incentives offered by the Government. This is the most unhealthy practice as it leads to loss of precious plant nutrients and environmental pollution. In view of this, innovative approaches are needed to deal with emerging challenges under the changed circumstances.

Two major innovations in the latter half of 20th century have led to a change in our thinking on crop production. These are: (i) availability of new farm machinery, and (ii) effective herbicides, which suggest that ploughing of the fields is no longer required for sowing, fertilizer placement and weeding. New generation farm machinery can place the seed and fertilizer at an appropriate depth in the desired amount. Further, these machines can work in standing anchored as well as loose crop residues; thus providing a very effective mulch cover for moisture and nutrient conservation, temperature moderation and weed control. Availability of new herbicide molecules has also necessitated a change in our thinking about weed management. Further, other triggering factors for shift towards CA are labour scarcity, deteriorating soil health, declining factor productivity, rising cost and low income. Thus, CA systems help in overcoming the problems being experienced in conventional farming systems.

HISTORICAL ASPECTS OF CA

Agriculture is believed to have started since the dawn of human civilization. It was about 8000-10000 BC when settled farming started, which was virtually a sort of ZT cultivation of crops. When some iron made hand tools became available, the ancient dwellers started clearing the land using draft animals and opening the soils for sowing seeds. Subsequently, mouldboard ploughs were invented which turned the soil and incorporated weeds and residues into the soil. Tractors made an entry in the 1900s, which could pull multiple ploughs and also do other farm operations. Discovery of 2,4 D in 1945 led to a sort of revolution in chemical weed control of broad-leaved species in cereal crops. Development of ZT seeders in the 1960s, followed by new generation seed-cum-fertilizer drills and new herbicide molecules for weed control in the 1990s revolutionized agriculture in many countries of North and South America. Over the past 2 decades, advances in machinery and herbicides have made ZT practical on a commercial scale globally.

Agricultural milestones showing the major inventions and transformation leading to adoption of CA globally are given in Table 1.

Tull (1829), who is regarded as 'Father of Tillage' carried out numerous experiments dealing with cultural practices, and published a book '*Horse Hoeing Husbandry*'. This was regarded as the most authoritative book in the English circles for many decades. He believed that soil should be finely pulvarised to provide proper pebulum for the growing plants. He propounded a theory that '*Soil particulars are ingested through openings in plant roots due to the processes caused by the swelling of growing roots*'. This was not found true later, but adoption of this kind of agriculture for decades and centuries led to adverse effects on soil by causing erosion and loss of top fertile soil.

Tillage as a soil management concept was questioned for the first time in the 1930s. Dust Bowl era between 1931 and 1939 exposed the vulnerability of plough-based agriculture, as wind blew away precious top soil from the drought-ravaged southern plains of US, leaving behind failed crops and farms. It was realized that tillage is the root cause of agricultural land degradation – one of the most

Table 1. Agriculture milestones leading to transformation from conventional agriculture to CA

Period	Major invention and transformation
8000-10000 B.C.	Planting stick - the earliest version of zero-till, enabled the planting of seeds without cultivation. The earliest plough cleared a path through the ground cover and created a furrow into which seeds could be placed.
6000 BC	Draft animals replaced humans in powering the plough.
3500 BC	Plough share - a wedge-shaped implement tipped with an iron blade was used to loosen the top layer of soil.
1100 AD	Mouldboard plough - having a curved blade inverted the soil, buried weeds and residues.
Mid-1800s	Steel mouldboard plough - invented by John Deere in 1837 was able to break up prairie sod.
Early 1900s	Tractors - could pull multiple ploughs and did other farm operations.
1940s–1950s	Discovery of 2,4 D in 1945 revolutionized chemical weed control, and other herbicides like atrazine and paraquat enabled to manage weeds with less tillage.
1960s	Zero-till seeders - opened a slice / small groove for placing seeds, keeping soil disturbance to a minimum.
1970s-1980s	Discovery of glyphosate in early 1970s for non-selective weed control, new generation farm machinery for placing seed and fertilizers in standing / loose residues.
1990s	Introduction of herbicide-tolerant GM crops and development of low-dose high-potency post-emergence selective herbicides in most crops.
2000s	Zero-till revolution in Brazil and most other countries of North and South America.
2010s	Conservation agriculture became the fastest adopted technology globally.

Source: Adapted from Huggins and Reganold (2008)

serious environmental problems worldwide – which posed a threat to crop production and rural livelihoods, particularly in poor and densely-populated areas of developing countries.

Ideas for reducing tillage and keeping soil covered with crop biomass followed, and the term ‘conservation tillage’ was introduced for practices aimed at erosion control. Seeding machinery developments followed to seed directly without any soil tillage. At the same time, theoretical concepts resembling today’s CA principles were elaborated by Faulkner (1945) in his book ‘*Ploughman’s Folly*’. *Nature* magazine termed as “agricultural bombshell” when Faulkner blamed the-then universally used mouldboard plough for disastrous tillage of the soil. He questioned the use of plough for cultivation of crops, and showed that all standard wisdom used as a rationale for ploughing and working the soil was invalid. His ideas were considered ‘mad’ and ‘without merit’, until after his death when soil experts and other scientists began to admit *‘We didn’t pay attention to what he said when he was alive’*. He is regarded as the first true conservationist.

Fukuoka (1975) worked for more than 65 years at his farm in Japan and developed a system of natural farming. He did not plough his fields, used no agricultural chemicals nor prepared fertilizers, did not flood his rice fields as farmers have done in Asia for centuries, and yet his yields equaled or even surpassed the most productive farms in Japan. His book ‘*One Straw Revolution’* – one of the best selling book in agriculture - contained the spiritual memoir of a man whose innovative system of cultivating the earth reflects a deep faith in the wholeness and balance of the natural world.

In the recent times, Montgomery (2007) wrote the award winning book ‘*Dirt–The Erosion of Civilizations*’, which showed that with any form of tillage including the non-inversion tillage, the rate of soil degradation and soil erosion is greater than the rate of soil formation. According to his research, tillage has caused the destruction of agricultural base and of its productive capacity nearly everywhere, and continues to do so. The slow pace at which soil rebuilds makes its conservation essential.

Zero tillage entered into the farming practice in the USA in the 1960s. In the early 1970s and as a result of uncontrollable erosion problems in southern states of USA, ZT reached Brazil where farmers together with scientists transformed the technology into the system, which today is called by the term conservation agriculture (CA). Yet it took another 20 years before CA reached significant adoption levels. During this time, farm equipment and agronomic practices in ZT systems improved and developed to optimize the performance of crops, machinery and field operations. This process continues till today; the creativity of farmers and researchers is still producing improvements to the benefits of the production system, the soil and the farmer. While tillage-based agriculture has been researched for several centuries, CA is only a half a century old and the foundations of CA systems can only be understood as the agro-ecosystems evolve under the new production management.

Two decades of extensive research and experimentation with ZT methods allowed there systems to emerge in Brazil, involving no-soil turning, maintenance of a permanent vegetative cover, and rotations of both cash and cover crops (Bolliger *et al.*, 2006). From the early 1990s, the adoption of CA started growing exponentially, leading to a sort of revolution in the agriculture in North and South America (Kassam *et al.*, 2019). Realizing that the age-old practice of turning the soil before planting a new crop is a leading cause of farmland degradation, many farmers across the globe are looking to make ploughing a thing of the past and turning to a more sustainable approach, known as CA.

Global Spread of CA

Farmer-led transformation of agricultural production systems based on CA is progressing globally. About 69.9 M ha (38.7%) of the total global area under CA is in South America, corresponding to some 63.2% of the cropland of the region, and some 63.2 M ha (35.0%) is in North America mainly in USA and Canada, corresponding to 28.1% of the crop land of the region. Some 22.7 M ha (12.6%) is in Australia and New Zealand, corresponding to 45.5% of the cropland, and some 13.9 M ha (7.7%) is in Asia, corresponding to 4.1% of the cropland of the region. Some 10.8 M ha of the total global CA area is in the rest of the world, comprising 5.7 M ha in Russia and Ukraine, 3.6 M ha in Europe and 1.5 M ha in Africa, corresponding to 3.6, 5.0 and 1.1% of their total cropland area, respectively. In terms of CA adoption and uptake, Europe and Africa are the developing continents (Table 2).

Table 2. Global spread of cropland area under CA by region in 2015–16

Region	CA crop land area (M ha)	% of global CA cropland area	% of cropland area in the region
South America	69.9	38.7	63.2
North America	63.2	35.0	28.1
Australia and New Zealand	22.7	12.6	45.5
Asia	13.9	7.7	4.1
Russia and Ukraine	5.7	3.2	3.6
Europe	3.6	2.0	5.0
Africa	1.5	0.8	1.1
Global total	180.4	100.0	12.5

Source: Kassam *et al.* (2019)

It was estimated that global extent of CA cropland in 2008-09 covered about 106 M ha (7.5% of the global cropland) (Table 3). Since 2008-09, the adoption has increased exponentially with the impulse of the need for a new paradigm for sustainable intensification of crop production including the delivery of ecosystem services and as a base for 'climate resilient agriculture'. In 2015-16, CA cropland was about 180 M ha (12.5% of the global cropland) representing a difference of some 74 M ha (69%) over the 7 years period since 2008-09. Since 2008-09, the annual rate of change has been 10.5 M ha from 106 to 180 M ha, showing the increased interest of the farmers in CA farming system approach to sustainable production and agricultural land management. The number of countries where CA adoption and uptake has occurred increased from 36 to at least 78 in 2015-16. The growth of area under CA has been especially significant in South America where Argentina, Brazil, Paraguay and Uruguay are using the system on >70% of their total cropped area.

Table 3. Increase in cropland area (M ha) under CA in different countries of the world

Country	2008-09	2015-16	% increase
USA	26.5	43.2	63.0
Brazil	25.5	32.0	25.5
Argentina	19.7	31.0	57.4
Canada	13.4	19.9	48.5
Australia	12.0	22.3	85.8
Paraguay	2.4	3.0	25.0
Kazakistan	1.3	2.5	92.3
China	1.3	9.0	592.3
India	-	1.5	-
Others	4.4	16.1	265.9
Total	106.5	180.5	69.5

Source: Kassam *et al.* (2019)

Asian countries have adopted CA in many areas since 2008-09. CA has increased more than 4-fold from 2.6 M ha in 2008-09 to some 13.9 M ha in 2015-16. In 2008-09, CA area was reported in only 2 countries of the Asia region, but in 2015-16 in 18 countries. In rice-wheat cropping system of the Indo-Gangetic plains across India, Pakistan, Nepal and Bangladesh, large adoption of ZT wheat with some 5 M ha was reported but only modest adoption of permanent ZT and full CA (Farooq and Siddique, 2014). The exception appears to be India and Pakistan, where significant adoption (1.5 and 0.6 M ha, respectively) of ZT practices by farmers has occurred in recent years in the rice-wheat double cropping system. And also in the rainfed upland areas in India for crops such as maize, sorghum, millets, cotton, pigeonpea and chickpea, Bangladesh has begun to report some CA area with rice-based cropping system, particularly on permanent beds. This is expected to expand because the farmers have now access to ZT seeding machines from service providers when locally produced CA equipment is available.

In the past decade, CA has become the fastest growing production system for many reasons including: (i) greater farm productivity and farm output, (ii) reducing cost of production and improving profitability, (iii) greater resilience to biotic and abiotic stresses, (iv) minimizing soil erosion and degradation, (v) building soil health, and (vi) adapting and mitigating climate change. Whereas in 1973-74, CA was applied only on about 2.8 M ha worldwide (Figure 1), the area had grown to 6.2 M ha in 1983-84 and to 38 M ha in 1996-97. In 1999, worldwide adoption was 45 M ha, and by 2003, the area had grown to 72 M ha. During the period from 1999 to 2013, CA cropped land expanded at an average rate of 8.3 M ha per year from 72 to 157 M ha. Since 2008-09, the spread of CA worldwide appears to have been expanding at the rate of 10.5 M ha per annum. At this rate, the global spread of CA area might have crossed 225 M ha by now, which is >15% of total cropland area.

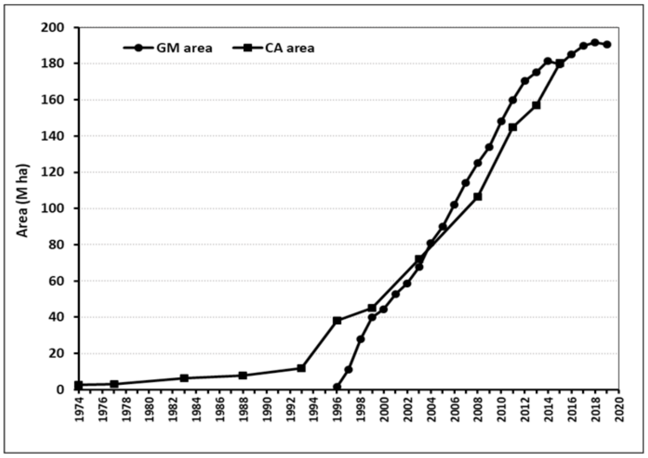

Fig. 1. Global area under genetically modified (GM) crops and conservation agriculture (CA)
Source: Kassam *et al.* (2019), ISAAA (2019)

Since mid-1990s, the adoption of CA has been triggered with the introduction of genetically modified crops, 47% area of which is under herbicide resistant and 41% with stacked traits (herbicide + insect resistant) (ISAAA, 2019). The biotech crops are also considered as the fastest adopted crop technology in the history of modern agriculture. These two technologies, i.e. CA and GM crops have revolutionized world agriculture and grown hand in hand showing double-digit growth over the past two decades, and covered 180 and 190 M ha in 2015-16 and 2019, respectively.

CA RESEARCH IN INDIA

In India, efforts have been made to advance CA research since mid-1990s through eco-regional programmes like Rice-Wheat Consortium (RWC), national initiatives like National Agricultural Technology Project (NATP), National Agricultural Innovation Project (NAIP), ICAR platform on CA, National Innovation on Climate Resilient Agriculture (NICRA), regional bilateral collaborative programs like Cereal Systems Initiative for South Asia (CSISA), Sustainable and Resilient Farming Systems Initiative for Eastern Gangetic Plains (SRFSI), CGIAR Research Programs (CRPs) on Climate Change, Agriculture and Food Security (CCAFS), Wheat-Maize Agri-Food System (WHEAT and MAIZE) and regional platforms like Borlaug Institute for South Asia (BISA) by involving large number of institutions and organizations. The uptake of CA in India has been slow but with science-based evidence on multiple benefits in addressing growing complexity of challenges and to deliver to several Sustainable Development Goals, CA has emerged as one of the major frontiers of future farming. However, scaling CA-based management practices in diversity of farm typologies and production ecologies for impact at scale need a collaborative approach of consortium of projects/programs/institutions involved in CA research for development (CAR4D) in India.

Analysis of the research papers published on topics related to CA was undertaken in the 3 major Indian journals, viz. Indian Journal of Agronomy, Indian Journal of Weed Science, and Indian Journal of Agricultural Sciences. The articles on ZT alone (partial CA) or in combination with crop residue, weed control, fertilizer and water management in a single crop or cropping system were considered. During the period from 1995-2000, there was no article on CA published in the Indian Journal of Agronomy, while there were only 6 and 5 articles published in the Indian Journal of Agricultural Sciences and Indian Journal of Weed Science, respectively. From 2000-2003 also, there were only a few sporadic articles published in these journals. However, it was from 2004 onwards that the research work on CA picked up and progressed almost linearly in all the 3 journals. After 2010, there has been a steep rise in the number of articles, and the recent years have witnessed a quantum jump in CA-based articles (Figure 2). This indi-

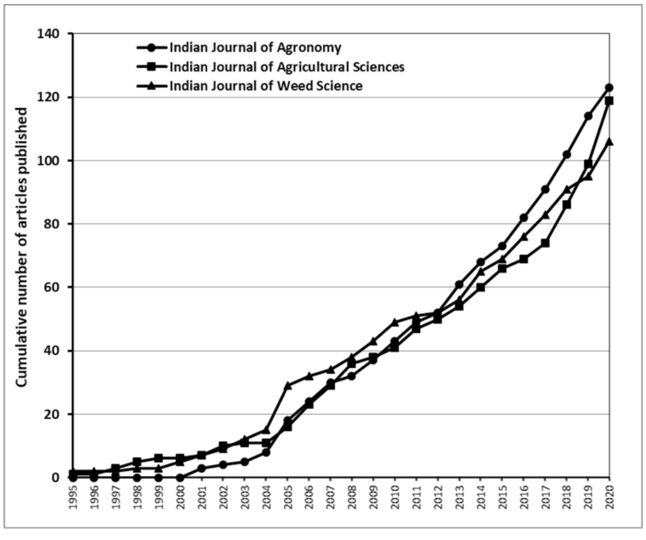

Fig. 2. Research articles related to CA published in the three leading Indian journals

cates that research work on CA has now become one of the major area of investigation by the resource management scientists in India.

An analysis was done on the comparison of grain yields obtained under CT and CA (ZT without or with crop residue) (Table 4). The yields varying under CA by a margin of ±5% were considered as higher or lower than CT. Most of the research on CA in India has been published on wheat (58.3%), which is a dominant crop of the winter season in north-western and central parts of the country. It was found that in 46% of the articles, the yields of wheat under CA were more than CT, while in 42% of the articles, the yields were same as under CT. The yields under CA were lower than CT in 12% articles. This suggests that yields of wheat under CA were either same or higher than CT in 88% of the articles. On the other hand, in case of rice, only 27% of the articles reported equal yields and 38% articles reported higher yields under CA, while 35% articles reported that yields were lower under CA than CT. In case of maize, the number of articles reporting lower yields was 38%, while 62% articles reported yields under CA which were either equal or higher than CT. The number of articles in other crops, viz. cotton, chickpea, soybean, mustard and greengram was relatively small, but a greater percentage of the articles reported yields either equal or more under CA than CT. This suggests that the most trials on crops grown in winter season (wheat, chickpea, mustard) showed either equal or better performance under CA than CT, while a greater percentage of articles on rainy season crops (rice, maize, soybean) showed relatively lower yields under CA than CT. This may be due to the fact that weeds, which are considered a major handicap under CA, showed greater infestation in the rainy season crops due to warm and humid conditions, while the weed problem is much less and easy to manage in the winter season crops. CA-based technologies are herbicide-driven, and efficient weed management is one of the major considerations for the success of CA (Sharma and Singh, 2014; Bhullar *et al.*, 2016).

Further scrutiny of the articles published state-wise revealed that CA has been the major area of research in the north-western and central parts of the country (Table 5). Maximum number of articles was published from Delhi, followed by Uttar Pradesh, Madhya Pradesh, Punjab, Uttarakhand and Haryana. These are also the states where there has been sizable coverage of CA-based technologies. This was followed by the eastern states of Bihar and West Bengal. The work done on CA in the southern and western regions of the country was relatively small. Evidently, the number of articles also depended on the size of the state and the number of researchers, but a greater focus of research on CA in the north-western India suggested greater adoption of these technologies, particularly for growing of wheat in the predominantly followed rice-wheat cropping system.

ADOPTION OF CA IN INDIA

Since mid-1990s, greater focus has been on development and promotion of CA-based technologies primarily for growing wheat under ZT in the predominantly followed rice-wheat cropping systems of the Indo-Gangetic plains. However, efforts have also been made over the past decade for promotion of ZT technologies in other crops like maize, sorghum, mustard, chickpea besides wheat and rice in the non-Indo-Gangetic plains including central India, coastal Andhra Pradesh, NEH region, and Konkan region of Maharashtra (Sharma *et al.*, 2017). Some of the successful examples of adoption of these technologies are given below:

North-western India

Rice-wheat is the major cropping system in the Indo-Gangetic plains (10.5 M ha) comprising Punjab, Haryana, Delhi, Uttar Pradesh, Bihar, and parts of Uttarakhand and Rajasthan. In this system, wheat is normally sown in fine seedbed prepared with 4-5 tillage operations which take 10-15 days time and Rs. 3000-3500 per ha financial liability for land preparation. The tillage operations increase the cost of production but they have hardly any benefit for in-

Table 4. Effect of CA (zero-tillage with or without residue) vs conventional tillage (CT) on crop productivity in India (no. of articles)

Crop	Yields equal under CA and CT	Yield higher under CA than CT	Yields lower under CA than CT	Total
Wheat	57	63	17	137
Rice	9	13	12	34
Maize	7	14	13	34
Soybean	1	5	4	10
Mustard	3	3	1	7
Chickpea	3	2	1	6
Cotton	2	1	1	4
Greengram	2	1	0	3
Total	84	102	49	235

Table 5. State-wise number of research papers published in national journals (1995-2020)

State	IJA	IJWS	IJAS	Total
Delhi	13	2	47	62
Uttar Pradesh	19	12	15	46
Madhya Pradesh	8	21	11	40
Punjab	10	15	4	29
Uttarakhand	9	15	2	26
Haryana	10	6	7	23
Bihar	8	1	5	14
West Bengal	6	5	2	13
Jammu-Kashmir	6	1	4	11
Himachal Pradesh	5	1	4	10
Karnataka	2	2	5	9
Chhattisgarh	2	6	0	8
Rajasthan	4	3	1	8
Andhra Pradesh	0	4	2	6
Odisha	3	3	1	7
Telangana	4	0	2	6
NEH	3	0	3	6
Assam	4	0	1	5
Tamil Nadu	2	3	0	5
Jharkhand	2	3	0	5
Maharashtra	1	1	1	3
Kerala	2	0	1	3
Gujarat	0	2	0	2
A&N Islands	0	0	1	1
Total	123	106	119	348

IJA - Indian Journal of Agronomy
IJWS - Indian Journal of Weed Science
IJAS - Indian Journal of Agricultural Sciences

creasing the grain yield. Further, there is a great concern about reduction in soil fertility, scarcity of farm labour, declining water table and high cost of production under conventional agriculture. In order to mitigate these problems, it was considered essential to adopt technically-feasible, economically-viable and ecologically-permissible technology to ameliorate late sowing, minimize weed infestation, lower cost of production, improve fertilizer/ water-use efficiency and improve soil fertility.

Initiatives have been taken since early 1990s to promote adoption of CA-based technologies in the alluvial soils of Indo-Gangetic plains. These programmes were initially implemented through the CIMMYT sponsored Rice-Wheat Consortium, which led to adoption of ZT cultivation of wheat on nearly 3 M ha by the beginning of current century. However, the area under ZT wheat declined subsequently as the harvesting of wheat progressed with combine harvesters leaving the residue on soil surface. The conventional ZT seed drill did not work in the loose residue conditions, and thus improved versions of seeding machines known as happy seeder and super seeder have become available in the recent times. Happy seeder cuts and lifts the residue, and sows the seeds directly into the soil, and deposits the cut straw as mulch over the sown area. The machine can work efficiently in anchored or loose residue conditions, and reported to achieve same or higher yields compared with the tilled systems (Keil *et al.*, 2021). Higher profits from the happy seeder system stem from slightly higher yields and lower inputs costs for land preparation. This technology has the potential to eradicate the practice of rice residue burning due to its ability to sow wheat directly into large amounts of anchored and loose residues. This technology has spread to several thousand ha in the last few years due to the easy availability of happy seeders at subsidized cost and restrictions imposed by the Government on burning of rice residues. It has been estimated that 20% area under direct-seeded rice and about 30% area under ZT wheat was covered in the state of Punjab during 2020-21, which is likely to increase further in the coming years as the farmers gain confidence and perfect the technology suited to their requirements.

Central India

Crop production in the central plateau region of India is dominated by rice, soybean, maize and sugarcane in the rainy season, followed by wheat, chickpea, lentil, pea and mustard in winter season. Soils are deep black in most of the areas belonging to vertisols. Farmers follow conventional practices like intensive ploughing of the land, clean cultivation (removal or burning of all crop residues and stubbles), fixed crop rotations, and little use of organic manures and moderate use of chemical fertilizers, and other pesticides including herbicides. Combine harvesting of major crops is followed predominantly and the crop residues are invariably burnt in most of the areas. There is only small area under greengram/blackgram during summer due to social problems like open cattle grazing. Due to the rising costs of cultivation, the profitability margins are generally low. Keeping this in view, it is necessary to promote the adoption of resource conservation technologies for reducing the cost of cultivation and improving soil health, besides other benefits.

ICAR-Directorate of Weed Research, Jabalpur took a major initiative and launched a flagship research programme in 2012 to develop and promote technologies related to weed management in CA. After laser leveling of the fields, trials were initiated on ZT sowing of wheat, chickpea, mustard and maize (winter), followed by greengram (summer) while retaining the residues of previous crop *in situ*. Sowing of seed and placement of basal fertilizer was done with happy seeder immediately after the harvest of previous crop with combine. Following the success of these crops, the technology was extended to rainy-season crops like rice, soybean, maize, and pigeonpea. All crops showed either the same yield or 5-10% higher yield under CA than CT when sowing was done at the same time (Table 6).

Table 6. Yield performance of different crops under conventional and conservation agriculture systems at the DWR during 2012–2016 (Figures in parentheses indicate number of trials)

Season/crop	Grain yield (t/ha)		% increase under CA over CT
	*Conventional agriculture (CT)	**CA-based practices	
Rainy season			
Rice (10)	4.02	4.06	0.0
Maize (12)	4.03	4.39	8.9
Soybean (4)	0.94	1.06	11.3
Pigeonpea (5)	2.15	2.23	3.7
Winter season			
Wheat (10)	4.19	4.56	8.8
Chickpea (8)	1.89	2.01	6.3
Mustard (4)	1.83	1.94	6.0
Gobhi sarson (4)	3.97	3.72	6.3
Field pea (4)	1.56	1.67	7.2
Summer season			
Greengram (9)	1.05	1.04	0.0

*Conventional agriculture involved 3-4 ploughings with a disc harrow, cultivator and rotavator before sowing. All crop residues were removed from the field.

**CA-based practices involved zero-till sowing in full residue of the previous crop.

Note: Crop under CA and CT was sown at the same time.

Simultaneously with the on-station trials, the on-farm trials in participatory mode were also undertaken in the farmers' fields of Jabalpur district from 2012-13. Initially, the farmers expressed serious doubt about growing a crop without ploughing. However, the farmers were persuaded to provide their lands for demonstrating the potential of CA technology with an assurance that they will be compensated if the technology fails to perform. Wheat was sown using happy seeder for the first time in the farmers fields, without tilling in the existing rice stubbles. Contrary to the general belief of the farmers, the crop showed good emergence and stand establishment. Weed population in these CA-based trials was lower compared to the crop in which the land was prepared by conventional cultivator and disc harrow. Herbicide application controlled the weed flora effectively and increased yield of wheat by almost 2 times as compared to that cultivated by conventional practice.

Following the success of wheat, greengram was grown during summer (mid-April to mid-June) under ZT using happy seeder while retaining the residues of wheat on soil surface. A spray of glyphosate was used before sowing where there were previously growing weeds in the field. Subsequently, imazethapyr was applied at 15-20 days of growth. Residue mulch helped in checking soil moisture loss through evaporation, moderated soil temperature, prevented emergence of weeds and improved soil health. The crop under CA yielded 1.0-1.4 t/ha compared with 0.7-0.8 t/ha under the conventional farmers' practice.

After getting very encouraging results in 2012-13, a large number of OFR trials were undertaken in a participatory mode from 2013-14 in different locations around Jabalpur (Gosalpur, Shahpura, Kundam, Bankhedi and Majholi). Sowing of rice in rainy season, wheat in winter and greengram in summer was done on 1 acre area (0.40 ha) in each farmer's field. From 2014 onwards, the OFR trials on CA-based technology were extended under *Mera Gaon Mera Gaurav* programme in the adjoining districts, viz. Mandla, Seoni, Narsinghpur and Katni. In each district, 5 villages and 8-10 farmers from each locality were identified. Resource conservation technologies such as direct-seeding of rice, brown manuring with *Sesbania*, ZT sowing of crops, residue retention on soil surface, growing of summer legumes like greengram or *Sesbania* in the crop rotation, and integrated weed management were demonstrated in diversified cropping systems. About 100 OFR trials were laid out in 25 villages of the 5 districts of Madhya Pradesh during 2015–16. Performance of all crops sown at the optimum time under CA was far better than the delayed-sown crops under conventional farmers practice (Table 7). The increase in grain yield ranged from 9–36% in rice, 27–50% in wheat, and 33–80% in greengram. Besides, there was considerable saving of resources and thereby increase in net profit.

CA–based technology like zero-till sowing of crops in the presence of residue of the previous crop with improved weed management practices has proved to be the most promising technology in the vertisols of Madhya Pradesh (Sharma and Singh, 2018). Adoption of CA technologies at the DWR, Jabalpur ensured timely sowing of crops (by June-end for rainy-season crops, October-end for mustard and chickpea, mid-November for wheat, and March-end for greengram); increase in cropping intensity from <150% in 2012 to 300% in 2016; large savings in diesel cost, machinery repair and irrigation water; increased productivity (>10 t/ha/year) and profitability; and apparent improvement in soil health. This has proved to be a climate-resilient technology as it avoided burning of crop residues, puddling for rice transplanting, and ensured C-sequestration through residue recycling and zero-till cultivation. Contrary to the general belief, the weed infestations reduced considerably under CA compared with the conventional practices. This has found rapid acceptance among the farmers of Jabalpur, Katni, Seoni, Narsinghpur and Mandla districts of Madhya Pradesh. This has spread to several thousand ha and the demand for happy seeder machines increased in the region.

Farmers were highly convinced with this technology as it saved time, provided good weed control, maintained soil moisture status, and improved soil fertility, besides being environment friendly.

Coastal Andhra Pradesh

Rice is predominantly grown in eastern and coastal areas of India, following which lands remain mostly fallow. Relay / sequence cropping with short duration pulses / oilseeds was practiced previously but the yields were low and highly variable due to poor crop stand and weed growth. Blackgram was popular in coastal Andhra Pradesh but it was affected by yellow vein mosaic virus and parasitic weed *Cuscuta*.

Cultivation of maize under ZT conditions immediately after the harvest of wetland rice has gained popularity in areas of Andhra Pradesh and Telangana (Sreelatha *et al.*, 2015). Large number of farmers are practicing ZT planting and getting higher profits in these states under rice-maize system. Similarly, ZT sorghum in less irrigated areas has gained popularity among the farmers and virtually revolutionized its cultivation in rice fallows (Chapke and Babu, 2016; Chapke *et al.*, 2017). Sowing is done manually in wet soil in holes after harvest of preceding rice crop during mid-December, and fertilizers are applied after about one month, and 2-3 irrigations applied thereafter. Weeds are controlled by tank-mix application of atrazine + paraquat (0.75 kg + 0.50 kg/ha) just after sowing but before crop emergence. It has been reported that grain yields of maize (8-10 t/ha) and sorghum (6-8 t/ha) are obtained under ZT cultivation compared with <0.5 t/ha from blackgram (Fig-

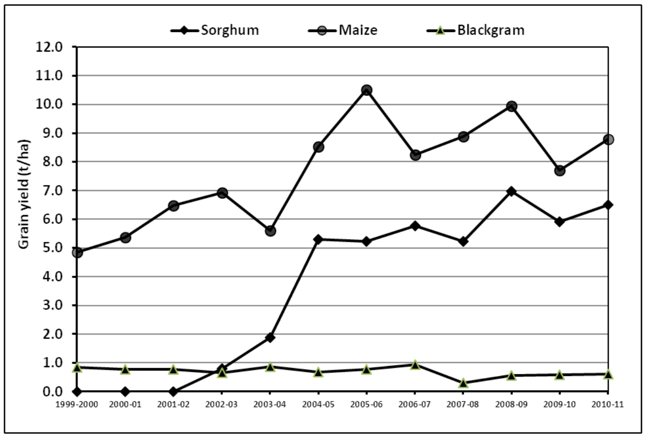

Fig. 3. Success story of zero-till sorghum / maize revolution in rice fallows of coastal Andhra Pradesh

Table 7. Comparative performance of ZT-sown crops and FP in OFR trials in different districts of Madhya Pradesh during 2015–16 (Figures in parentheses indicate number of trials)

District / villages / crops	Grain yields (t/ha)		% increase under CA over FP
	*CA–based practice	**Farmer's practice (FP)	
Jabalpur (villages – Bharda, Nipaniya, Nibhora, Neelkheda, Repura, Katangi, Chanti)			
Rice (8)	3.7–4.0	3.2–3.4	16–18
Wheat (16)	3.8–4.2	3.0–3.2	27–34
Greengram (9)	0.9–1.3	0.6–0.8	50–62
Mandla (villages – Bhawal, Bijegaon, Gojarsani, Lalipur, Harratikur)			
Rice (10)	3.9–4.3	3.0–3.2	30–34
Wheat (17)	4.2–4.4	3.2–3.4	29–31
Greengram (12)	1.0–1.2	0.7–0.9	33–42
Narsinghpur (villages – Baglai, Khamariya, Simariya, Kushiwara)			
Rice (7)	3.5–4.2	2.6–3.5	20–34
Wheat (8)	4.0–4.4	3.7–4.0	8–10
Katni (villages – Banda, Bichhiya, Chhitwara, Ghughra, Lakhapateri)			
Rice (8)	4.5–4.7	4.1–4.3	9–10
Wheat (10)	4.8–5.1	3.4–3.7	38–42
Greengram (8)	1.1–1.3	0.8–0.9	38–44
Seoni (villages – Ghughri Nagar, Khoot Khamariya, Nagan Deori, Dongargaon, Salaiya)			
Rice (7)	4.1–4.4	3.4–3.6	20–22
Wheat (12)	4.2–5.0	2.8–3.7	35–50
Greengram (5)	1.2–1.7	0.8–0.9	50–80

*CA-based practice involved ZT sowing in standing residue of the previous crop, 10–15 days ahead of the farmer's practice

**Farmers practice involved burning or removal of the previous crop residues, followed by 3–4 ploughings before sowing.

ure 3). An area of about 1.5 lakh ha is estimated under ZT maize in coastal Andhra Pradesh. This is often cited as one of the success story of adoption of ZT in coastal Andhra Pradesh and has immense potential for extension to other states including Odisha and West Bengal.

North-eastern hill region

Oilseed cultivation in the NEH region faces several constrains, such as water scarcity during post-monsoon season, lack of irrigation facilities, short time lag after rice harvest for seed sowing and high incidence of pests and diseases in late-sown crops. As a result, only monocropping of rice is practiced and the farmers leave their land fallow during winter season.

Central Agricultural University, Imphal in collaboration with ICAR-Directorate of Rapeseed-Mustard Research, Bharatpur implemented an extension project for augmenting rapeseed-mustard production of tribal farmers of NEH region for sustainable livelihood security (ICAR, 2012; http://www.cau.ac.in/directorates.html). The growth and yield parameters of rapeseed-mustard were better in ZT than CT due to residual soil moisture after rice harvest. Among the varieties, yellow sarson, Ragini and NRCHB-101 gave average yield of 1.0 t/ha under ZT cultivation. The number of farmers, area covered and the yields increased progressively over a period of 7 years (Figure 4). Motivated by the success, a large number of farmers in Manipur, Mizoram and Arunachal Pradesh adopted this technology and the area coverage under ZT cultivation of rapeseed-mustard increased to >1000 ha over a period of two years.

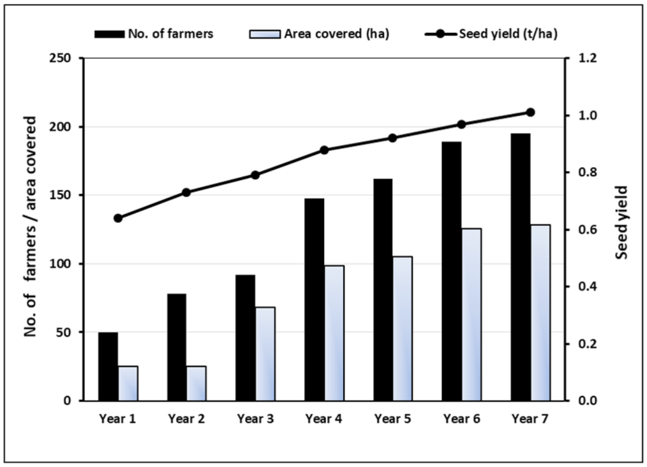

Fig. 4. Progress of zero-till rapeseed-mustard in rice fallows in the NEH region
Source: http://www.cau.ac.in/directorates.html

The success story indicated that rapeseed-mustard is a climate resilient crop which can be grown without water in the residual soil moisture. By adopting ZT, the farmers could increase the productivity, reduce cost of cultivation, increase the cropping intensity and earn an additional income with less effort. ZT also helped in timely sowing (October-November), conserved soil moisture and required less water, saved tillage cost and time, and the soil was protected from erosion due to the retention of surface residues. The improved version of ZT cultivation with bee pollination and no chemical method of plant protection has been recommended to the resource-poor farmers of the NEH region.

Konkan region of Maharashtra

In the Konkan region of Maharashtra including areas around Mumbai, zero-till broad-bed technology has been developed and promoted over the past decade by a local organization. Known as Shaguna Rice Technology (SRT), it is primarily meant for rice but can also be extended to other crops like groundnut, lablab bean, greengram and vegetables grown in succession (https://srt-zerotill.com/srt/). This technology involves preparing broad-beds (about 1 m wide) either manually with spade or with tractor-drawn bed maker, markings on the beds with a specially-designed implement, placing the seeds and fertilizer manually, and using herbicides for weed control. The technology has found wide acceptance among the farmers as it saved time and cost, improved soil fertility, crop yields and profitability compared with conventional transplanting of rice following puddling. Several farmers have adopted it and more are following as they are learning and becoming aware of it.

Considering the erratic rainfall pattern of the region, it is advocated to advance the sowing of rice to last week of May or early June so that seeds germinate with the early monsoon showers by mid-June and attain enough growth before heavy rains start from June-end. Farmers having irrigation facility can go for irrigation before or immediately after sowing. Fertilizer should be basally placed to provide an initial boost to the growth of plants. It is essential to use herbicides before sowing, after sowing and also during crop growth period for weed control. A light manual weeding can also be done to avoid seed set from the left over weed plants and minimize the problem in the next season. Crabs are a serious problem in early stages, which must be controlled using the appropriate insecticides. Similarly, wild boars, birds, rats, termites and other insects should be controlled with available technologies.

SRT appeared to be more suitable for small farmers and those having family labour as a team of 10-12 persons is required for sowing an area of one ha in a day. Large farmers owing >4-5 ha of land can use a tractor-drawn ZT seed-cum-fertilizer drill which will further reduce the cost / time and also ensure optimum crop stand. The benefits will multiply if a part of the crop residues is retained on the soil surface. Large increases in the soil organic matter content over a short period of time and increase in earthworm population due to ZT cultivation and recycling of root biomass are reported.

This technology has been adopted by over 5000 farmers who are reporting very high rice yields of >10 t/ha. Based on the experiences of the farmers and also witnessing the excellent crops of rice in the fields under SRT under aberrant weather conditions, this technology has the potential to replace conventional puddling / transplanting, and revolutionize rice cultivation in the high rainfall areas of Konkan region of Maharashtra.

PRACTICAL TIPS FOR SUCCESS OF CA

Unlike CT, the CA requires greater skill and expertise for its successful adoption. The best management practices based on practical experiences on CA are described below:

Land suitability

CA has been adopted across the globe on soils that vary from 90% sand to 80% clay. The soils with very high clay content and sticky in nature have not been a hindrance to ZT adoption. Soils that are readily prone to crusting and surface sealing under tillage farming disturbance do not exhibit this problem under established CA systems. This is because minimum soil disturbance, mulch cover and increased soil organic matter contribute to enhancement of soil quality that avoids the formation of crust. In some situations, CA has even allowed expansion to marginal soils in terms of rainfall or fertility. In highly-degraded soils, it may not show encouraging results initially but continuous adoption essentially with residue recycling and inclusion of legumes in the system, such soils also respond to CA. In India, CA has been successfully demonstrated in the light-textured soils of north-western India and Indo-Gangetic plains, black cotton soils or the vertisols in central India and coastal alluviums of south India. Since the land is not ploughed, therefore it is essential to ensure perfect leveling of the land preferably through laser leveler. This will ensure placement of the seed and fertilizer at proper depth in the soil. In fact, perfect land leveling is a pre-requisite for adoption of CA.

Suitability of crops

Most research on CA in India has been done on wheat. Studies have also been made on rainy season crops like rice, maize, soybean, pigeonpea and cotton, and winter crops like chickpea, mustard, lentil and pea, and summer crops like greengram. In majority of these trials as mentioned in the earlier sections, equal or higher yields under CA compared with CT have been obtained. This suggests that principles of CA are applicable for small-seeded crops like mustard as well as large-seeded crops like maize and soybean. The experience shows that winter crops are more suitable to be grown under CA probably because of lower weed infestation in the season. After developing adequate expertise and confidence, especially with respect to weed management, the crops in summer and rainy season can also be grown quite successfully under CA. It is essential that a systems approach is followed and there must be inclusion of a legume or cover crop in the system.

Residue recycling

One of the essential requirements of CA is residue recycling without which it may work for a few years initially but the long-term success is not assured. There are questions raised on the availability of crop residues for recycling in crop production in India because these are an important fodder for the animals. But this is also a reality that crop residues in many areas are also available for recycling, where these are wasted or burnt, especially in the combine-harvested crops. Since the land is not disturbed under CA, it is possible that it may become compact and hard if the residues are not retained on the soil surface. Residue retention promotes biological tillage through the activity of earthworms and soil microorganisms and the soil in fact becomes more porous and friable over a period of time than in the CT system. Residue retention as mulch modifies the micro-climate, and helps in soil moisture conservation, weed control, temperature moderation in the soil as well as within the crop canopy, and enhances the fertility of the soil. It has been proved based on long-term experimentation that soil porosity and infiltration rates are much higher under CA than in the tilled soils. Crop residue load of 6-8 t/ha can be effectively managed while working with happy seeder, provided it is spread uniformly over the entire field and it is not too wet.

Sowing and crop establishment

Ensuring optimum plant population is the key to realize potential productivity. Any loss in initial poor crop stand due to improper sowing is rarely compensated. Therefore, sowing under CA should be perfect by using appropriate seed drill which can place the seed as well as basally-applied fertilizer close to each other. Most drills are so designed as to place the fertilizer typically 2-3 cm below the seed. Zero-till seed–cum-fertilizer drills of normal type (knife-type types) for sowing in residue-free or in anchored residue conditions, and happy seeder in anchored or loose residue conditions are available. Hand sowing with manually-drawn seed drills often does not produce the desired results. The machine needs to be well calibrated and proper spacing should be maintained for the given type of crop. In some small-seeded crops like mustard, the seed and fertilizer (granulated SSP or DAP) can be mixed together in definite proportion without any harmful effect on germination. If the sowing is done under optimum soil moisture and the possible damage by termites, birds, rodents etc. is effective checked, a normal seed rate is adequate. However, it may be advisable to use 20-25% higher seed rate than normal to offset the poor germination due to inadequate seed-soil contact likely under some field conditions.

Soil and residue conditions

It is essential to ensure proper soil moisture at sowing for efficient working of the machine and obtaining good germination. Happy seeder works efficiently only when the soil has optimum moisture and also the residue is dry not too wet or green. In the absence of these conditions, the machine often creates problems. Moreover, if the soil is wet (moisture content more than field capacity), the wet soil gets collected with the tines and the pores also get clogged. Further if the soil is too dry and hard, the seed and fertilizer will not be placed at proper depth and also there will be too much energy required for the tractor, causing wear and tear of the machine. Dry residue of most crops is shredded well but the wet and fibrous residue of crops like rice, groundnut, greengram, dhancha etc. may not be chopped by the rotating blades, and may cause problems during sowing. Such problems can be overcome with experience in a particular crop and situation. It is advisable to have standing and anchored residue instead of cut and loose residue for efficient working of the machine.

Machine for sowing

As emphasized earlier, the manual sowing with the hand-drawn seed drills on small plots for experimental purpose often does not work in untilled soils. Tractor-drawn seed drills having knife type tines and separate boxes and pores for dropping seed and fertilizer are needed. Happy seeder is the most suitable machine for sowing in combine-harvested fields having standing/anchored as well as loose residue conditions. Happy seeder is a combination of two machines – one is the rotating device with blades which cuts the residue, and the attached seed-cum-fertilizer drill. Therefore, a relatively greater amount of energy is needed for sowing with happy seeder for cutting the residue and simultaneously putting seed and fertilizer in the unploughed soil. A heavy duty tractor of 50 HP or more is often required for carrying the load and for sowing with happy seeder. New machines such as super seeder which mixes the residue in the top soil layer before placing seed and fertilizer, and roto-double disc drill which can work with less energy requirement and in heavy residue load like sugarcane trash are also being developed and perfected for sowing.

Uniform spreading of the crop residue is essentially needed for proper functioning of the happy seeder for sowing. Previously available combine harvesters used to leave the residue in rows and heaps after retaining the grains. This residue was required to be spread manually, but now a days, the combine harvesters attached with Straw Management System (SMS) are available which release the residue uniformly spread simultaneously during the harvesting operation. Sometimes, a mulcher or grass cutter is run for cutting and uniform distribution of the residue before sowing, which involves an extra cost.

Fertilizer management

Efficient fertilizer management is an essential requirement for the success of CA. Since the land is not ploughed, there is no question of mixing the fertilizer with soil nor it is advisable to broadcast the fertilizer on the surface of soil. As far as possible, the fertilizer must be placed close to the seed / plant, not only at the time of sowing (basal fertilizer) but also as top dressing. Happy seeder or the even the normal seed-cum-fertilizer drill has separate boxes and pores for seed and fertilizer, which can effectively place the fertilizer at proper depth. Granulated fertilizers like urea, SSP and DAP are available now which do not pose much problem by clogging the pipes or tynes but ordinary prilled urea or MOP sometimes block the pipe especially during the rainy season due to greater humidity. Mixing of these fertilizers with the granulated ones often solves this problem. A proper calibration is required for the optimum fertilizer rate. Even for top dressing of urea fertilizer, some locally-designed and crop-specific machines are available which can place the fertilizer below the soil surface close to the plant roots in the standing crop.

The crop under CA does not look very attractive and vigorous during the first one month after sowing. This is partly because of the residue lying on the soil surface giving a shabby look, and may be some initial setback to the crop plants due to nutrient immobilization and inhibited growth. However, the plants pick up growth after irrigation and application of first dose of top-dressed N, and soon overcome the initial setback. It is often advisable to use 20-25% higher fertilizer dose, especially N, to promote the initial slow growth of plants and check any possible lock up of the nutrients due to immobilization. However, experience has shown that fertilizer dose may have to be reduced after 3-4 years due to build-up of soil fertility by the addition of crop residues which decompose over a period. Since the P is not lost from the system, and the fixed P becomes gradually available to the plants, the requirement of P may decrease in the successive cropping cycles. Further since a lot of K is being recycled with the addition of crop residues, the requirement of K fertilizer may not be needed after some cropping cycles.

Weed management

Weeds are often considered as the major constraint for CA. In fact increased weed infestations are cited as the foremost reason for the poor performance or failure of the crop under CA by many researchers. All of us have been taught from the early stages that one of the major purposes of tillage is weed control besides other benefits. Therefore, it is understandable that ZT will lead to increased weed proliferation, particularly of the perennial species like *Cyperus rotundus, Cynodon dactylon, Sorghum halepense*, and others if adequate control measures are not taken. The experience has shown that with ploughed systems over the decades, the weeds problems have actually aggravated. In fact with tillage operations, weed seeds in the soil get a sort of stimulation due to exposure to light and air, and the seeds lying in the lower layers are brought to the surface and *vice-versa*. The result is that weed seed distribution becomes quite uniform in different soil layers, which keep germinating at different stages or flushes, and thus provide competition to the crop plants throughout the growth period.

Another dimension of increased weed infestation in CT systems is the general emphasis on control of weeds during the period of critical crop-weed competition. It is advocated that weeds should be controlled up to a certain stage only in the early part of the crop growth period so as to avoid economic loss, as the weeds emerging in the later stages do not cause much harm to the crop. However, these weeds in the later part of the season produce enough seeds by the time crop is harvested. Also these weeds keep growing even after the crop harvest during the fallow period and enrich the weed seed bank in the soil. The result is that the weed problem in the next season will either be the same or even more than in the previous season, and the cycle goes on.

Evidently, the weed problems in CA systems are likely to be much higher if proper weed control measures and related precautions are not followed. A strategy aimed at season-long weed control with integrated approach involving chemical and non-chemical methods is needed. Residue retention on the soil surface does help in suppressing the emergence and growth of weeds to some extent but it cannot provide effective and full season control. Growing cover crops with an objective to develop full canopy within the shortest possible time is another way of checking weed growth. This is also one of the essential requirements of CA systems. Certain weeds are associated with the specific crops, and therefore, crop rotations are advocated to get rid of peculiar weed species. For example, if pulses and oilseeds are grown in a field infested with broadleaved weeds like *Chenopodium album, Rumex dentatus, Anagallis arvensis, Medicago sativa, Cichorium intybus, Vicia sativa* and others, there are likely to be problems because we do not have effective and selective herbicides for such situations. Therefore, it is advisable to go in for cereal-based rotations where such broad-leaved weeds can be effectively controlled by the available herbicides like 2,4 D, metsulfuron, carfentrazone, bensulfuron and others.

In the CA system, only the lines where the seed and fertilizer are placed, are opened and the inter-row spaces remain virtually undisturbed, rather these remain covered with the mulch of crop residues. Weed seeds lying in the upper soil layer (0-5 cm) emerge in the first flush after sowing, while are killed with a pre-emergence herbicide. There is relatively lower emergence of weeds in the subsequent flushers after a month or so, by which time the crop has developed adequate canopy to suppress their growth. A suitable post-emergence herbicide is also applied as per availability and requirement of the situation. Further, sporadic manual weeding by uprooting or cutting from the base with hand hoe is suggested to ensure weed-free conditions throughout the season.

It is essential that weeds growing in the field at the time of sowing are killed, otherwise these weeds will take an upper hand even before the crop emerges. Since the ploughing of the land is not be followed for killing the existing weeds, the only alternative is to use a complete weed killer and non-selective herbicide like paraquat or glyphosate to kill the existing weeds. Paraquat is recommended for rapid desiccation and for killing of the annual not-so-hardy type of weeds, while glyphosate is used for the control of perennial and relatively hardy weed species. It is not possible to think of CA without the use of herbicides. In fact, CA is a herbicide-driven technology requiring rational use of herbicides before sowing as well as after sowing, and during the crop growth period.

In the conventional agriculture systems, we aim at controlling the weed plants, while under CA, the focus is on minimization of the weed seed bank. For this a constant watch has to be kept on weed plants throughout the crop season to prevent them from flowering and setting seeds. As the famous quote in weed science '*One year seeding is seven years weeding*'; therefore, the preventive measures are given equal or even more importance than the curative measures of weed control under CA. Weeds are to be controlled even after the crop harvest. In some countries, weeds seeds after crop harvest are either collected or burnt through flaming using special machines.

It has been conclusively proved based on long-term experiments under CA elsewhere that weed problems gradually decrease if all the principles of CA along with the best management practices w.r.t. to crop, nutrient, weed, water and other pest management are followed in a holistic manner. Initially there may be some increase in herbicide use but it is possible to reduce dependence on herbicides after some years with deceased weed infestations. It is a fact that herbicides are an integral part of the integrated weed management strategy under CA, without which it cannot be practiced. However, it must be emphasized that herbicides should be used judiciously by following the principle of 5 Rs i.e. right source, right kind, right dose, right time and right method of application. Weed management under CA requires greater skill and expertise, and it is not only science but an art as well.

Water management

There is a saving of water required for irrigation under CA systems. In most cases the next crop can be sown under residual soil moisture. Even if the soil moisture at the time of crop harvest and sowing of next crop is not sufficient for germination, it is advisable to sow the crop in time, and go in for light irrigation through sprinkler after sowing. There is no greater problem of crust formation after irrigation to inhibit germination as the residue on the soil surface provides a congenial environment for the crop to emerge. Retention of crop residues on the soil surface prevents evaporation loss of soil moisture, and keeps the soil in relatively wetter condition for a longer period of time. The experiences have shown that the irrigation interval can be prolonged by 1-2 weeks under CA compared with CT system. Resultantly, there is requirement of 1-2 irrigations less under CA than CT. Accordingly, there is 20-30% saving of water under CA, more so under the sprinkler system practiced widely in central India. Crop residue retained as mulch on the surface gradually decomposes through the action of water applied through irrigation, N fertilizer as top dressing, and build-up of microbial populations in the soil.

It is myth that irrigation or rain water does not percolate down the soil profile under CA, rather the evidence shows that water accumulates on the soil surface for a longer period under the conventionally-ploughed systems, causing temporary waterlogging and also crop lodging under some situations.

Pest and disease management

CA involves a total paradigm shift from conventional agriculture systems. Therefore, it is likely that pest and disease infestations will vary drastically when the land is not ploughed and residues are retained on the soil surface.

Sowing in untilled soils results in some seeds lying at or near the soil surface which are prone to attack by various pests like birds, termites, ants, and rodents. In fact bird damage is considered as a major limitation for adoption of CA in some situations. Termites and other ants also take away the seeds lying at or near the soil surface. Similarly, the rodents hide beneath the residue mulch in the field or in the burrows on the bunds which cause damage to the seeds. These problems are aggravated when the seeds are not placed at the proper depth in the soil or remain uncovered, and also there is no effective seed-soil contact. In view of this, it is essential to treat the seeds with suitable insecticide, sowing at proper depth and in proper soil moisture condition. Also suitable measures are needed for the control of birds and rodents during the first few days after sowing.

Some of the pests and diseases are soil-borne. Hence, it is often recommended under CT systems to plough the fields during hot summer to expose the hidden egg masses and disease causing pathogens to light and sun so that these are killed during the hot weather cultivation. Further, clean cultivation without any stubble is recommended as a preventive measure to avoid infestation of pests and diseases. However, under the CA system, all these practices are avoided, with the result that the pest and disease infestation may undergo a complete change. It has been observed that infestation of root aphid in wheat, wilt and root rot in chickpea and soybean, and nematodes in rice are increased under the CA systems. However, such problems may also be noticed even under the CT systems, and CA alone cannot be blamed for that.

Experiences over the years from long-term CA studies have shown that pest and disease infestations are not insurmountable which are uncontrollable. Suitable measures need to be undertaken as per the situation to keep a check on the incidence and proliferation of specific pests and diseases under CA systems. Application of need-based insecticides and fungicides may be needed. The exudates from the decomposed residues also contain allelo-chemicals which keep a check on such pests and maintain a balance in the ecosystem.

DOS AND DON'TS OF CA

CA works with some essential requirements which must be ensured for its success. In fact it is a controversial subject for researchers and other stakeholders who argue both in favour and against its relevance and adoption in Indian conditions. Following 'dos' and 'don'nts' will clear some of the misgivings and lead to success of CA:

Dos

- Kill all the existing weeds before sowing with blanket spray of non-selective herbicide
- Ensure perfect leveling of the field
- Ensure good initial crop stand

- Maintain optimum soil moisture at sowing
- Uniform and adequate amount of crop residues as mulch
- A well calibrated seed drill and an experienced driver for sowing
- Placement of seed and fertilizer at the desired soil depth
- Seed treatment with appropriate insecticide and fungicide
- Increase seed rate and fertilizer dose by 20-25% in the initial years
- Spray recommended herbicide before sowing, after sowing and during crop growth period as per need
- Focus on minimization of weed seed bank
- Follow sporadic manual weeding for the control of left-over weeds
- Top dressing of N fertilizer following post-emergence herbicide in cereal and other crops
- Apply irrigation preferably with sprinkler if the residual soil moisture at sowing is not adequate for germination
- Delay irrigation by 1-2 weeks when crop residue is retained as mulch
- Follow intercropping (cereal + legume) wherever possible
- Start CA with winter season crops, followed by summer and rainy season crops
- Follow a cropping system approach
- Must include a cover crop preferably a legume in the system
- Follow CA in all crops in the sequence for maximum benefits

Don’ts

- Do not follow ZT without crop residue mulch
- Do not broadcast basally applied fertilizer
- Do not use conventional seed drill for sowing which opens wide furrows
- Do not practice CA on undulating gravelly / stony lands
- Do not keep land fallow or uncovered at any time of the year
- Avoid sowing in too wet soil or undried loose crop residue
- Do not allow the perennial weeds to proliferate.
- No need to bak the CA cycle afternoon years as none argue.

REASONS FOR LOW YIELDS UNDER CA

Different researchers have reported varied results on the performance of crops under CA. Observations from all over the country have shown that similar or higher yields can be obtained under CA as with CT systems. However, there are also good number of studies which reported low yields under CA. This may be because of several deficiencies in the implementation of CA and not following the full protocol. Derpsch *et al.* (2014) enumerated several reasons for the low yields, and advocated standardizing ZT research for a uniform and valid comparison of yields and other advantages of CA across locations, crops, soils and weather conditions. A number of factors may be responsible for low yields under CA, such as the following:

Lack of period of conversion

CT systems are being followed for decades or centuries; therefore, the time to recover and realize full benefits of CA may be longer. There is requirement of a time period between conversion of native vegetation under conventional system and adoption of CA. The desired response to CA is normally not obtained in the initial years of conversion, and it is only after 3-4 years that the results of CA on yield performance of crops start becoming noticeable.

Lack of knowledge and expertise

As mentioned earlier, CA is a knowledge-driven technology and requires expertise on how to manage the crops under the new system. Most researchers do not follow all the required protocols and adopt a half-hearted approach when cropping under CA. With knowledge and experience, the confidence in CA improves and the results are far better in the later than in the early years.

Lack of a systems approach

It is suggested to follow a systems approach under CA, and the findings on the basis of single crop trials often lead to erroneous conclusions. The direct, residual and cumulative effects of the crops grown in sequence and their management practices must be considered. For example in rice-based cropping system, there may be some penalty on the yield of rice under CA but the loss is more than compensated in the following crops in winter and summer season; and thus overall system productivity is higher. It is not sufficient to only stop tilling land the with all other management practices remaining the same as in the conventional systems. There is a need to bring about suitable changes and follow the best management practices with respect to sowing, residue mulching, fertilization, weed control, and pest and disease management.

Insufficient soil cover with crop residues

Surface residue cover is a key factor for the success of CA systems in the long-run. Some researchers follow ZT with bare soil conditions or with insufficient cover with residues. Studies have shown that removing residues can lead to reduced yields and lower economic returns with ZT alone. Therefore, it is advisable not to follow CA if the residues are not available for recycling as mulch cover on the soil surface.

Lack of experience of tractor driver

CA requires a different approach and the experience of the tractor driver who is operating the machine for seeding is very important. Sowing cannot be done blindly or with less care as in the case of ploughed soils, with inadequate regulation of the seeding equipment, seed furrows staying open after seeding, too deep or too shallow seed placement, soil smearing because of excessive moisture etc. The machine operator requires thorough knowledge and patience while undertaking sowing, and should ensure proper drilling and placement of seeds at the required soil depth.

Inappropriate seeding machinery

Poor crop stand and establishment is often due to inappropriate farm machinery used for sowing. Inadequate furrow closing and seed placement can lead to poor crop stand e.g. the seeds are placed too shallow or too deep or seed-soil contact is insufficient. Quite frequently the researchers use CT seeding machinery in ZT experiments as well, which leads to poor results. New generation seeding machines are available with separate boxes for seed and fertilizer metering mechanism, pores and pipes for dropping seeds, and their placement at proper depth. The seed furrows are to be closed so that a proper seed-soil contact is ensured and the seeds are not exposed to the predators.

Poor weed control

This is the most cited reason for poor yields under CA. Most researchers are not able to control weeds with the available technologies. There is either inadequate selection of the herbicides or weed suppressing technologies, insufficient or excessive dose of herbicide causing weed escapes, crop injury, non-uniform coverage of the herbicide etc. Frequently, the researchers insist on using the same herbicide programme for all treatments (conventional, minimum and zero-tillage), because the tillage is the only variable they want to change. This may favour one system but be detrimental to the other.

Poor disease and insect control

CA system may favour or disfavour some diseases and pests differently in comparison with other tilled systems. There is likely to be a total paradigm shift in the infestation of diseases and insects under CA systems. Researchers often use calendar application of pesticides for all treatments instead of using system-specific pest management methods, which are needed under CA.

Non-adjustment of fertilizer rate

CA involves minimum disturbance and retention of crop residues, and nutrient availability in the soil may be a bit restricted in the early stages of plant growth. Therefore, a relatively higher fertilizer rate especially of N is needed in the early stages of transformation from CA to CT. It is likely that N fertilization may not have been adjusted during the first few years of ZT technology or a legume crop may not have been seeded previously to provide the additional N needed initially to take care of immobilization of N in surface residues and soil organic matter.

Extremely degraded soils

The beneficial effects of CA have been reported across different soil types. However, low yields of crops may be obtained on extremely degraded and/or eroded soils with very low organic matter content, in which poor macro- and micro-biological activity and fertility may limit initial success. In such degraded soils, an advantage may be confined to CT initially through continued mineralization of N with tillage disturbance until the organic matter is depleted. It is also possible that the yields are lower in the newly-reclaimed soils or the recently-leveled fields due to considerable shifting of the soil from one part of the field to the other. It may be essential to grow green manure or other legume crops for 1-2 seasons to build uniform level of fertility over the entire area before regular cropping is taken up on these soils.

Inadequate crop rotation and diversity

Dynamic crop rotation is the third major principle of CA, and it is essential to follow a judicious combination of cereals, pulses, oilseeds and other cover crops in the system. Optimized crop rotation for CT may not be the same as for ZT. Additionally CA system may provide different opportunities for cover crop planting, whereas the conventional system may be limited due to time and moisture lost with tillage. The land should not remain fallow and must always be covered throughout the year under CA.

CONSTRAINTS IN ADOPTION OF CA

CA is a highly specialized set of technologies, requiring optimum conditions and expertise for its successful adoption. It requires application of all the principles of CA in a holistic manner coupled with other best management practices. The major handicap in the adoption of CA is the conventional mindset of the various stakeholders who resist change. Despite proven benefits, the adoption of CA systems requires a total paradigm shift from conventional agriculture with regard to crop management. The CA technologies are essentially herbicide-driven, machine-driven and knowledge-driven, and therefore require vastly-improved expertise and resources for adoption in large areas. For wider adoption of CA, there is an urgent need for policy makers, researchers and farmers to change their mindset and explore these opportunities in a site- and situation-specific manner for local adaptation. This is a highly technology-driven agriculture and its very basic principles of sowing seeds in an untilled land and without removing crop residues are in sharp contrast to the traditional belief. Tremendous amount of efforts are needed to persuade the farmers for adoption of this technology.

Several factors have limited the adoption of CA in India, such as the following:

- Typical mindset of continuing with business-as-usual, and lack of will power to innovate and adopt new technology
- Incomplete application of the CA principles and associated best management practices causing poor performance of crops
- Lack of suitable machines for sowing and fertilizer placement
- Fragmented and small land holdings coupled with low purchasing power of the farmers
- Farmer education and technical knowledge is not sufficient to adopt CA technology
- Non-availability of crop residues and their competitive role for feed/fodder in some regions
- Lack of expertise in weed management and use of suitable herbicides
- Pest infestations like nematodes, termites, birds, rodents etc. and lack of control measures.

ROADMAP FOR CA

CA-based technologies have been developed, and the benefits in terms of enhanced productivity, profitability, soil health and climate resilience have been shown in most parts of the country. However, these technologies have been adopted on a limited scale due to the apparent apprehensions, lack of will power and some operational constraints. There exists immense scope for bringing barren and fallow areas under profitable cropping systems with the adoption of CA-based technologies. There is required to be a coordinated effort involving multi-stakeholders to make the farmers aware and demonstrate these technologies on a large scale. Further, necessary back-up in the form of suitable farm machinery is required to be provided to enable farmers to adopt these technologies.

There is a need for analysis of factors limiting adoption and acceptance of ZT cultivation among farmers. Lack of information on the effects and interactions of minimal soil disturbance, permanent residue cover, planned crop rotations and integrated weed management, which are key CA components, can hinder CA adoption. Information has mostly been generated on the basis of research trials, but more on-farm research and development is needed. Farmers' involvement in participatory research and demonstration trials is essential for accelerated adoption of CA.

Jat *et al.* (2018) proposed a 10-point roadmap for promotion of CA in India: (i) CA contributes to at least 8 of the UN's Sustainable Development Goals (SDGs) and should be valued by policy makers accordingly. (ii) There is a need to better aggregate and map knowledge of CA across sites in order to define recommendation domains. (iii) On-farm research-cum-demonstration with farmers' participation involving Krishi Vigyan Kendras (KVKs) for validating CA performance on a broader scale. (iv) Commercial availability of scale appropriate machinery and establishment of CA mechanization hubs. (v) Investigations on soil biology and pest dynamics (insects and pathogens) under CA. (vi) Creation of National Initiative on Conservation Agriculture (NICA) for evidence-based promotion of CA. (vii) Development of scalable and sustainable business models for promoting adoption of CA and capacity building of all stakeholders. (viii) CA should be the part of course curriculum including practical crop production programme of the Agricultural Universities. (ix) Establishment of a learning platform/ CA-Community of Practitioners (CA-CoP) for regular interactions, knowledge sharing and capacity development. (x) Establishment of 'India CA Center' - a Technical Working Group on Conservation Agriculture (TWGCA) involving key researchers from national and international organizations to promote CA in India.

CA is a challenging and exciting subject for researchers, requiring multi-disciplinary approach to address all the related issues in a comprehensive manner. Resource management scientists, especially those belonging to the Agronomy discipline, should take lead to work on CA and perfect the technologies in their respective domains. Gone are the days of conventional routine marry-go-round type on-station research, for which there are no takers in the present times. Focus must be on reducing the cost of production while enhancing productivity, produce quality and soil health. Scientists should be the first adopters of the technologies generated by them - first on the research farms to the fullest extent possible and then demonstrate on large areas at the farmer's fields. CA-based on-farm research should be integral part of on-station research, without which the research findings cannot be transformed into technologies. CA has shown wonders globally and the agronomists should discharge their share of responsibility to make it happen in India.

REFERENCES

Bhullar, M.S., Pandey, M., Sunny Kumar and Gill, G. 2016. Weed management in conservation agriculture in India. *Indian*

Journal of Weed Science **48**(1): 1–12.

Bolliger, A., Magid, J., Amado, J.C.T., Neto, F.S., Ribeiro, M.F.S., Calegari, A., Ralisch, R. and Neergaard, A. 2006. Taking stock of the Brazilian "ZeroTill Revolution": A review of landmark research and farmers' practice. *Advances in Agronomy* **91**: 47–110.

Chapke, R.R. and Babu, S. 2016. Promising practices for highest sorghum productivity in rice fallow under zero tillage. *Indian Farming* **65**(12): 46–49.

Chapke, R.R., Babu, S., Subbarayudu, B. and Tonapi, V.A. 2017. *Growing Popularity of Sorghum in Rice-Fallows: An IIMR Case Study*. Bulletin, p. 48. ICAR-Indian Institute of Millets Research, Hyderabad.

Derpsch, R., Franzluebbers, A.J., Duiker, S.W., Reicosky, D.C., Koeller, K., Friedrich, T., Sturny, W.C., Sa, J.C.M. and Weiss, K. 2014. Why do we need to standardize no-tillage research? *Soil and Tillage Research* **137**: 16–22.

Farooq, M. and Siddique, K.H.M. (Eds.). 2014. *Conservation Agriculture*. Springer International, Switzerland.

Faulkner, E.H. 1945. *Plowman's Folly*. Michael Joseph, London.

Fukuoka, M. 1975. *One Straw Revolution*. Rodale Press. English Translation of Shizen Noho Wara Ippeon No Kakumei. Hakujusha Co., Tokyo.

http://www.cau.ac.in/directorates.html. Zero tillage cultivation - a viable option for large scale production of rapeseed-mustard in rice fallow.

Huggins, D.R. and Reganold, J.P. 2008. No-till: The quiet revolution. *Scientific American Inc*. (July 2008): 71–77.

ICAR. 2012. Zero tillage cultivation of rapeseed mustard in Imphal East district by tribal farmers. *ICAR Reporter*, April-June, 2012, pp. 13.

ISAAA. 2019. *Global Status of Commercialized Biotech / GM Crops*. International Service for the Acquisition of Agribiotech Applications (ISAAA) Brief No. 55. Ithaca, New York.

Jat, M.L., Biswas, A.K., Pathak, H., McDonald, A.J., Patra, A.K., Acharya, C.L., Sharma, P.C., Chaudhari, S.K., Rajbir Singh, Bhaskar, S., Sharma, R.K., Jat, H.S., Agarwal, T., Gathala, M.K., Suresh Pal, HS., Yadvinder-Singh, Keil, A., Saharawat, Y.S., Jat, R.K., Balwinder-Singh, Malik, R.K., Sharma, A.R., Parihar, C.M., Das, T.K., Singh, V.K., Jat, S.L., Jha, B.K., Pratibha, M., Singh, Prem, Singh, R.C., Sharma, S., Satyanarayana, T., Sidhu, B.S., Gehlawat, Suresh, Sen, S.K. and Sikka, A.K. 2018. *Conservation Agriculture Roadmap for India*. Policy Brief, 4 p. ICAR-CIMMYT, New Delhi. http://www.sit-zerotill.com/sst

Kassam, A., Friedrich, T. and Derpsch, R. 2019. Global spread of conservation agriculture. *International Journal of Environmental Studies* **76**(1): 29–51.

Keil, A., Krishnapriya, P.P., Mitra, A., Jat, M.L., Sidhu, H.S., Krishna, V.V. and Shyamsundar, P. 2021. Changing agricultural stubble burning practices in the Indo-Gangetic plains: Is the happy seeder a profitable alternative? *International Journal of Agricultural Sustainability* **19**(2): 128–151.

Montgomery, D. 2007. *Dirt: The Erosion of Civilizations*. California University Press, Berkeley.

Sharma, A.R. and Singh, V.P. 2014. Integrated weed management in conservation agriculture systems. *Indian Journal of Weed Science* **46**(1): 23–30.

Sharma, A.R. and Singh, P.K. 2018. Adoption of conservation agriculture-based technologies in the vertisols in Madhya Pradesh. *Indian Farming* **68**(5): 12–15.

Sharma, A.R., Jat, M.L., Sahrawat, Y.S., Singh, Y.P. and Singh, R. 2012. Conservation agriculture for improving productivity and resource use efficiency: Prospects and research needs in Indian context. *Indian Journal of Agronomy* **57**(3rd IAC Special Issue): 131–140.

Sharma, A.R., Mishra, J.S. and Singh, P.K. 2017. Conservation agriculture for improving crop productivity and profitability in the non-Indo-Gangetic regions of India. *Current Advances in Agricultural Science* **9**(2): 178–185.

Sreelatha, D., Reddy, M.L., Reddy, V.N., Swarnalatha, V. and Sekhar, J.C. 2015. *Production Technology for Zero-Till Maize*. Bulletin, 10 p. Maize Research Centre, PJTSAU, Rajendranagar, Hyderabad.

Tull, J. 1829. *Horse-Hoeing Husbandry*, 465 p. William Cobbett, Fleet Street, London.