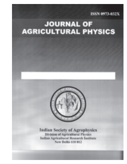
Vol. 19, No. 1, pp. 1-20 (2019)
Journal of Agricultural Physics
ISSN 0973-032X
http://www.agrophysics.in



Review Article

Conservation Agricultural Practices and Their Impact on Soil and Environment: An Indian Perspective

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ABSTRACT

Conventional agricultural practices including intensive cultivation and mechanisation are threat to agricultural sustainability. Drastic change in agricultural practices are required for achieving desirable productivity while nourishing the natural resources. Efforts to overcome the above situation resulted in evolution of conservation agriculture concept. The adoption of soil conservation practices is considered as the tools for improving soil properties for mitigation of adverse climate change, conservation of natural resources like soil, water and nutrients, while achieving environmental, social and economic benefits. This paper reviewed the present status of conservation agriculture along with the management practices involved in conservation agriculture and their impacts on soil, environment and socio-economic prospects along with few bottlenecks in larger scale adoption by the farming community.

Key words: Conservation agriculture, Water and nutrients, Tillage, Soil properties, Environment

Introduction

Currently, Indian agriculture is facing many challenges due to ever mounting population pressure leading to increased pressure on agricultural land besides depleting natural resources, adverse impacts of climatic variability, escalating input cost and unstable food prices. Majority of farmers are still practicing conventional agricultural practices, multiple and frequent tillage practices like ploughing, harrowing, disking and other inter-cultural operations which disturbs the soil and increase soil compaction, salinization, soil erosion, decreases soil organic matter and nutrient content, causes surface and underground water pollution, as well as increased water consumption (Wolff and Stein, 1998). Therefore, changing farming practices through removing unsustainable components of conventional agriculture (frequent ploughing/tilling the land, taking out all organic material, monoculture) is essential for maintaining future productivity along with sustaining the natural resources. Conservation agriculture (CA), an approach which was evolved for attaining the sustainability of agriculture at global level, has gradually increased worldwide to cover approximately 8% of the total world arable land (124.8 M ha) (FAO, 2012) but in India, it is still in infancy stage and is covering about 1.5 M ha area (Jat *et al.*, 2012). Conservation agriculture is a resource-saving agricultural production system that focuses to attain production intensification and high productivity while conserving the natural resource base by following three interrelated principles, along with other good production

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practices of crop nutrition and pest management (Abrol and Sangar, 2006). Adoption of conservation agriculture for improving resource use efficiency (RUE) and crop yield is very essential in present scenario for efficient management of natural resources and to achieve sustainability in agriculture.

Conservation agriculture and its principles

Conservation agriculture is a pathway towards management of agro-ecosystems for achieving enhanced and sustained productivity, increased profits and food security while conserving and improving the natural resource base along with environment. Conservation agriculture is practiced in many parts of the world as they are formed on ecological principles which make the land use sustainable (Behera *et al.*, 2010; Lal, 2013). It relies on the practical application of three linked principles, alongwith other relevant good agricultural practices (GAPs) of crop production (FAO, 2014) and must be taken care for suitable design, planning and implementation processes. These three principles are:

Minimum mechanical soil disturbance

Soil biological activities are generally supposed to produce very stable soil aggregates as well as variant sizes of pores which allows proper aeration and infiltration of water. With mechanical soil disturbance by tillage or other cultivation practices, the biological soil structuring processes fade away. Minimum soil disturbance is responsible for maintaining optimum composition of respiration gases in the root zone, moderate oxidation of soil organic matter, appropriate porosity for soil water movement, retention and release, and hinders the re-exposure and germination of weed seeds (Kassam and Friedrich, 2009). The term minimum mechanical soil disturbance indicates permanent low soil disturbance, no-tillage, and involves no-till direct seeding along with no-till weeding. Recently it is reported that the disturbed area for crop establishment must be less than 15 cm wide or less than 25% of the cropped area (whichever is lower) and no other periodic tillage operation that disturbs a greater area than the afore mentioned limits should be there (Kassam *et al.,* 2019). In some cases, low soil disturbance strip or band seeding can be done if the disturbed surface area is less than the set limits.

Permanent organic soil cover

A permanent soil cover is imperative in conservation agriculture to protect the soil from the harmful effects resulting from the exposure to rain and sun; to provide constant food supply to the soil micro and macro organisms; and to change the soil microclimate for optimum growth of soil organisms, together with plant roots. This, in turn, improves soil aggregation, carbon sequestration, soil biological activity and biodiversity (Ghosh *et al.,* 2010). Soil cover is attained with biomass obtained from crop residues, stubbles and cover crops. FAO (2014) prescribes that at least 30% of the total cultivated area should be covered by crop residues. There are three categories depending on the magnitude of land surface cover *i.e.* between 30% to 60%, between 61% to 90% and more than 91%.

Diversified crop rotations

Diversified crop rotation is required for providing food to the soil microorganisms along with utilization of nutrients by the crops in rotation which are present in different soil layers due to leaching. It can be achieved by rotating deep rooted crops with shallow rooted crops. Further, a diversity of crops in rotation leads to a diverse soil flora and fauna. The crop rotations which involves legumes are beneficial for biological nitrogen fixation, reducing pest infestation by disruption of the pests' life cycle and improving biodiversity (Kassam and Friedrich, 2009; Dumanski *et al.,* 2006).

Status of conservation agriculture and its extent of adoption in India

In India, approximately 1.5 M ha of area is reported to be under no-till practices by farmers in rice–wheat double cropping system (Farooq and Siddique, 2014) and in the rainfed upland areas for crops like maize, millets, sorghum, pigeon pea, cotton and chickpea. During the last ten years, the area under conservation agriculture in rice–wheat and rice–maize cropping systems has remarkably increased. The conservation agricultural practices have been extensively tested through the combined efforts of several State Agricultural Universities and Indian Council of Agricultural Research (ICAR) institutes. The CGIAR system also promoted adaption, promotion and development of these practices under Rice-Wheat Consortium and now these technologies are gaining rapid acceptance by the farmers in nearly 2 M ha area under rice-wheat system in IGP belt (Haryana, Punjab and Western Uttar Pradesh).

Research from IARI (2012) revealed that conservation agricultural practices including furrow irrigated raised-bed planting, laser assisted land levelling, unpuddled mechanical transplanting of rice and residue management practices are also being adopted by the farmers of the north-western region. In western Uttar Pradesh, inter-cropping systems like maize+ potato/onion/red beets or sugarcane+ chickpea/ Indian-mustard are also becoming popular with farmers (Gupta and Seth, 2007). Zero tilled (ZT) wheat has been widely adopted in the north western IGP in the rice-wheat cropping (RW) systems, and recently its adoption has also started to increase in the eastern IGP (Malik *et al.*, 2014). According to Smart Indian Agriculture (2015) in recent years, the conservation agricultural technologies have been successfully demonstrated at farmers' fields in district Jabalpur of Madhya Pradesh under the aegis of ICAR Directorate of Weed Research. Their results indicated that the black cotton soils of central India are among the best ones suited for conservation agriculture, and it has been the fastest growing cultivation technology in this region. The long-term study on different conservation agriculture based systems, initiated under AICRP weed management, has shown promising results in case of maize-sunflower in Tamil Nadu, pearl millet-mustard in Gujarat, rice-chickpea-green gram in Karnataka pointing towards the possibilities of extending the benefits of conservation agriculture to central and south India (DWR, 2014).

Benefits of conservation agriculture

There are several benefits of adopting conservation agriculture to the farmers, soil, environment and ultimately to the whole society by sustaining and conserving our natural resources. These benefits comprise of economic, environmental, resource conservation, sustained crop productivity, enhancement in water and nutrient use efficiency, erosion control, adaptation to climate change etc., and are discussed further:

Economic benefits

The conservation agriculture has been reported to reduce cost of production, while improving yield and conserving land and water resources. Cultivation of crops incur a significant cost. This cost is influenced by the selection of crops, their cultural practices and by many other factors. Farmers' experiences from various locations in the IGP (Indo-Gangetic Plains) depicted that ZT technology in wheat can reduce land preparation costs by about Rs. 2,500 ($41.7)/ha and diesel consumption by 50–60 L/ha (Sharma *et al.*, 2005). According to Erenstein and Laxmi (2008), ZT-wheat after rice in India generates significant benefits at the farm level by increasing farmers' income from wheat cultivation (US$97/ha) through the combined effects of yield improvement and cost-saving (Table 1). Similarly, Gupta and Seth (2007) reported net benefits of US$ 150/ha with ZT-wheat in India.

Krishna and Veettil (2014) reported 14% saving of cost by the farmers of Haryana through adoption of zero-tillage practice in wheat crop. Yadav *et al.* (2018) conducted a study in North-eastern hill region in direct-seeded upland rice-mustard cropping system under split plot design consisting of conventional tillage with 100% residue incorporation (CT-RI) and No-tillage with 100% residue retention (NT-RR) as main plot, and four different types of mulches as sub-plot. They reported that NT-RR treatment resulted in cost saving through machine operations, diesel and labour, but increased cost for plant protection chemicals as compared to CT-RI treatment (Fig. 1). Thus, NT-RR treatment caused net saving of cost by 29.4% than CT-RI treatment (Fig. 1).

Table 1. Summary of key impacts of zero tillage in India's Indo-Gangetic Plains

Indicator	Value
Households directly affected (estimate)	620,000
Extent of adoption (zero/reduced tillage, estimate)	1.76 m ha
Production cost saving	US$ 52/ha
Increase in crop yields	5-7% (140-200 kg/ha)
Increase in farm income from wheat production	US$97/ha
Increase in real household incomes	US$180-340/farm
Increase in food production	0.7% (343,000 tons)

Source: Erenstein and Laxmi (2008)

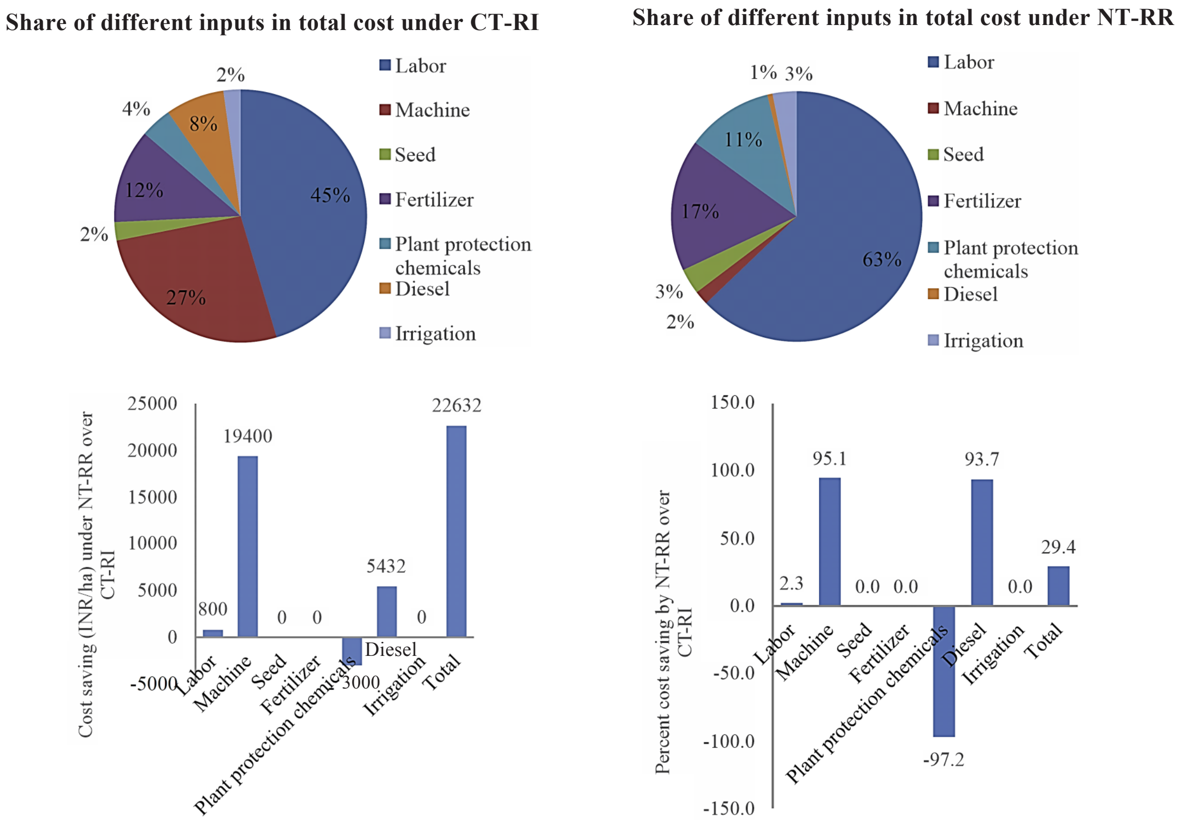

Fig. 1. Share of different component of cost of cultivation and cost saving over respective component under different tillage practices (CT-Conventional tillage; NT-No-till; RI-100% residue incorporation; RR-100% residue retention). Source: Yadav *et al.* (2018)

Sharma *et al.* (2011) reported that in maize-wheat cropping system in *Inceptisols*, the benefit-cost ratio was highest in minimum tillage (0.71) followed by permanent raised bed and no tillage treatments, whereas conventional tillage treatment had lowest ratio (0.44).

The adoption of zero tillage practice after rice crop in Indo-Gangetic plains also resulted in average cost saving of Rs. 2320 ha^{-1} (Erenstein and Laxmi, 2008). In wheat crop cultivated in *Typic Ustochrept* alluvial sandy loam soil in Indo-Gangetic plains, zero tillage enhanced the operational field capacity by 81%, specific energy by 17% and energy usage efficiency by 13% as compared to conventional tillage (Kumar *et al.*, 2013). Conservation agricultural practices save

Table 2. Average energy consumption of some tillage operations

Operations	Diesel consumption (L/ha)	Energy consumption (kcal/ ha)
Mouldboard plough	16.81	256,669
Cultivator	5.61	52,285
Disk harrow	6.55	61,046
"Chisel" plough	8,89	82,855
Harrow	3.37	30,476
Pass with no soil tillage	0.94	8,761

Source: Nalewaja (2001)

time, fuel, labor, cost, energy and water in comparison to the conventional practices. Average energy and diesel consumption in mould board tillage is much higher than other tillage operation (Table 2).

Environmental benefits

Conservation agricultural practice use resources more competently than traditional agriculture, thus, making resources available for other uses, as well as conserving them for future generations. Increased crop diversity, enhancement of soil biological processes, along with decreased erosion and leaching, can lead to more retention and efficient use of water as well as nutrients and reduction in the application of inorganic fertilizers and pesticides in the long duration. Ground water resources are recharged through improved infiltration of water and decreased surface runoff. This also improve water quality due to reduced contamination levels from agrochemicals and soil nutrients resulting from decreased leaching and soil erosion (Bassi, 2000). The substantial decrease in fossil fuel usage under ZT agriculture reduces the release of greenhouse gases into atmosphere and maintains cleaner air in the biome. A lesser use of agrochemicals in conservation agriculture, moreover, considerably lessens the pollution in air, soil and water. In view of global warming potential, emission of greenhouse gases is higher under conventional tillage as compared to zero tillage under both wheat and rice cropping systems (Table 3).

Table 3. Emission of greenhouse gases in wheat and rice with different technological option in the upper Indo-Gangetic Plains

Technology	Total GWP ($kg\ CO_2\ ha^{-1}$)	
	Wheat	Rice
Conventional tillage	1808	2934
Sprinkler irrigation	1519	735
Zero tillage	111	346
Integrated Nutrient Management	171	6089
Organic wheat/rice	1880	8569
Specific nutrient management	1696	2794
Nitrification inhibitor	1663	2461
Site- Straw fed to cattle	1824	3877
New cultivar	2056	2599
Yield maximization	3128	3634

Source: Pathak and Aggarwal (2012)

Benefits in resource conservation and improvement

Conservation agriculture (CA) is an approach for sustainable enhancement in the water use efficiency due to increase in soil water infiltration and retention, and reduction in evaporation loss, improvement in nutrient availability (Dahiya *et al.,* 2007; Verhulst *et al.,* 2010; Jat *et al.*, 2012; Saharawat *et al.*, 2012) and decrease in the incidence of weeds like *Phalaris minor* in wheat (Malik *et al.*, 2005). CA practices result in improving or sustaining crop growth and productivity (Aulakh *et al.,* 2012; Krishna and Veettil, 2014; Yadav *et al.*, 2019). Its long-term advantages in improving soil health (physical, chemical, biological), enhancing crop productivity, water and nutrient uptake, reduction in soil erosion and mitigation of climate change effects, are of enormous importance. Let us recollect systematically.

Soil physical health

Crop requires suitable soil conditions for its proper growth and development. So, the knowledge of impacts of conservation agriculture on soil physical quality is inevitable. Conventional tillage (CT) where the tillage operations are frequent and intensive, leads to physical breakdown of soil structure whereas reduced or no tillage maintains soil aggregation due to less soil disturbance and intact presence of roots fragments and mycorrhizal hyphae as binding agents. The permanent crop residue in conservation agriculture protects the soil from rain drop, wind and water erosion while that protection is absent in CT. Conservation agriculture reduce the effect of many constraints pertaining to soil physical health degradation like soil structure degradation, soil compactness, soil crusting and decrease in soil organic matter (Dalal *et al.,* 1996) and maintain larger aggregates (Bhushan *et al.,* 2007), higher mean weight diameter (Jat *et al.,* 2009). Zero tillage increase the stability of soil aggregates by increasing soil organic carbon content (Chauhan *et al.,* 2002). Choudhury *et al.* (2014) reported that the conservation tillage resulted in 15.65% and 7.53% increase in total water stable aggregates in surface (0-15 cm) and sub-surface (15-30 cm) soil, respectively as compared to conventional tillage. The soil aggregation and mean weight diameter of soil aggregates were also higher under permanent raised beds and no till flat treatments as compared to conventional tillage treatment in sandy loam soil possibly due to increase in soil organic carbon (Jat *et al.*, 2013). That is how the conservation agricultural practices improves soil structure and stability of soil aggregates.

Many studies have reported that conservation agriculture increases bulk density in surface soil (Gomez *et al.,* 1999; Fuentesa *et al.,* 2009; Singh *et al.,* 2014) whereas some observed decrease in it (Ghuman and Sur, 2001). Some studies observed no difference in bulk density between conservation and conventional tillage (Sharma *et al.,* 2005). However, Singh *et al.* (2014) reported higher bulk density in sub-soil under conventional tillage due to increased traffic flow as compared to conservation tillage and better soil aggregation was found under zero tillage due to increased soil organic carbon. Jat *et al.* (2013) found that under maize-wheat cropping system in sandy-loam soil, the bulk density and penetration resistance was lower in permanent raised bed treatment and no-till flat as compared to conventional tillage at 10-25 cm soil depth due to formation of plough layer in conventional tilled treatment. According to Somasundaram *et al.* (2018), the sequence of bulk density under different tillage systems was: Conventional tillage > no-tillage > reduced tillage. Similar trend was found for soil porosity. This is due to enhanced organic matter content and macro-faunal activity. In zero tillage, the accumulation of crop residues reduced the level of compaction in wheat crop at the depths of 0-15 and 15-30 cm (Sharma *et al.*, 2011). Mishra *et al.* (2015) revealed that during third year of conventional agriculture in puddled transplanted rice in rice-wheat cropping system, the penetration resistance exceeded 2 MPa, whereas in direct seeded rice with brown manuring with zero tilled wheat rotation, the penetration resistance remained below 1.5 MPa upto 0-60 cm soil depth indicating ideal conditions for root growth. So, the CA practices provide conducive soil physical environment for root growth and penetration.

Sharma *et al.* (2011) reported that the infiltration rate under minimum tillage, no tillage and permanent raised beds system was 1.16, 1.21 and 1.11 times more than conventional tillage. Jat *et al.* (2013) found higher infiltration rate under conservation tillage as compared to conventional tillage due to minimum disturbance of soil pore continuity. The hydraulic conductivity in zero tillage plot was more than conventional tillage in rice-wheat cropping system because conventional tillage caused destruction of soil aggregates and reduced non-capillary pores whereas zero tillage had more macropores continuity. Plant available water content was also higher under zero tillage than conventional tillage (Bhattacharyya *et al.,* 2006). Zero tillage resulted in improved saturated hydraulic conductivity than conventional tillage system due to formation of macropores having higher water transmission resulting from decreased soil disturbance and increased organic matter (Singh *et al.,* 2014).

The soil evaporation rate decreases with increasing the amount of crop residues on the surface (Gill and Jalota, 1996; Prihar *et al.,* 1996). Rani *et al.* (2019) reported that crop residue mulch reduced the evaporative flux, but increased the deep percolation flux under wheat crop in sandy loam soil. Aulakh *et al.* (2012) reported that conservation agriculture retained more moisture content in soil profile as compared to conventional agriculture as crop residue retained on the surface in conservation agriculture reduce evaporation loss and reduce surface soil temperature during summer season. Somasundaram *et al.* (2018) reported that in a 4-years experiment on conservation agricultural practices in rainfed Vertisols, no-tillage had higher water retention than conventional tillage system in 0-15 cm soil depth at lower suctions due to the formation of intricate network of macropores and inter-aggregate pores resulting from higher soil organic matter content. Thus, conservation agricultural practices increase moisture content in soil profile and enhances its availability to plants by reducing evaporation and increasing infiltration and hydraulic conductivity.

Also, conservation agricultural practices positively influence the hydro-thermal properties of soil. Somasundaram *et al.* (2018) found that conservation agricultural practices moderate the variation in soil temperature due to presence of crop residue at the soil surface such that minimum temperature is relatively higher and maximum temperature is lower than conventional tillage practices. Somasundaram *et al.* (2019) reported that soil moisture content, mean weight diameter, and percent aggregates in the surface soil of Vertisols were significantly higher under reduced tillage than conventional tillage after 3 years of experimentation. Overall, conservation agriculture has positive impacts on various soil physical properties.

Soil chemical health

Soil requires adequate chemical environment like soil organic carbon, nutrients, etc. for cultivation of crops. The practices of conservation agriculture are found to reduce the nutrient requirements of crops on account of nutrient recycling and minimizing their loss by runoff and leaching. This is achieved generally in the long run when sufficient residue cover is available on the soil surface and an equilibrium of nutrient release from the organic residues is established. In a long-term (15 years) study conducted in zero tillage in wheat under rice-wheat cropping system in semi-arid regions of Indo-Gangetic plains, it was found that zero tillage increased the soil organic carbon significantly and the depth of its build-up increased with increase in the fineness of the soil texture (Singh *et al.* 2014). This is due to deeper penetration of wheat roots and less oxidation of in-situ organic matter in zero tillage system. More clay content retains more organic carbon, therefore, fine texture retained organic carbon at deeper depth. This indicates that adoption of conservation agriculture in fine-texture soils have more potential of soil carbon sequestration. Das *et al.* (2018) added that conservation agriculture based system, with residue retention, has higher organic carbon, total soil organic carbon pools and carbon sequestration potential than conventional system under maize-wheat cropping system in the North-western Indo-Gangetic plains. Parihar *et al.* (2018) inferred that conservation agricultural practices significantly increased the SOC stock and mineral nitrogen fractions in 0-30 cm of soil depth in sandy-loam soils of Inceptisols. Kushwa *et al.* (2016) conducted long term experiment on conservation agriculture for 12 years in Vertisols of Central India under Soybean-Wheat cropping system to study the soil profile distribution of available Phosphorus content. They found that available Phosphorus concentration was higher in No tillage (NT) (11.9 mg kg^{-1}) and reduced tillage (RT) (10.8 mg kg^{-1}) followed by mouldboard tillage (MB) (9.6 mg kg^{-1}) and conventional tillage (CT) (7.9 mg kg^{-1}). The profile distribution is shown in the figure 2. The higher concentration of available P in CA practices is due to higher organic matter and conversion of organic P present in it into available P. Jat *et al.* (2018) revealed that CA system enhances the content of available N, P, K, Zn, Fe and Mn in surface soil along with saving of 30% and 50% of Nitrogenous and Potassic fertilizers. Thus, it was reported to have beneficial effect of conservation agriculture on nutrient supplying capacity of soils.

Soil biological health

Long term adoption of conservation agriculture is supposed to enhance not only the

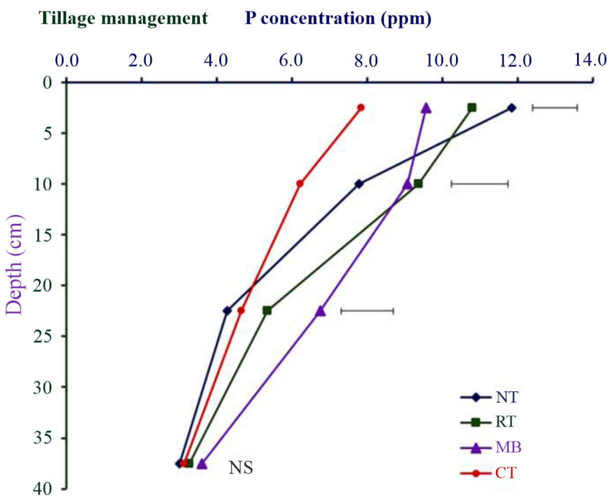

Fig. 2. Effect of long-term tillage management (12 years) on profile distribution of available Phosphorus in a vertisol under soybean-wheat cropping system. Horizontal lines represent LSD ($P < 0.05$) between the treatments for a particular depth, NS not significant *Source:* Kushwa *et al.* (2016)

biological activity but also their biomass and diversity compared to CT (Lupwayi *et al.*, 2001). The soil microbial biomass carbon (SMBC) and soil dehydrogenase enzyme activities (DHA) are found to be higher in reduced or no tillage as compared to conventional tillage due to enrichment of soil organic matter from the crop residues (Yadav *et al.*, 2019). The SMBC is an important indicator of soil quality. With decreasing the tillage frequency in rice-wheat cropping system in eastern Indo-Gangetic plains, the microbial biomass carbon and nitrogen as well as the activities of extracellular enzymes responsible for mineralization of carbon like β-D-glucosidase, cellobiohydrolase, alkaline phosphatase, and urease increased, especially under no-tillage system possibly due to enhanced soil organic matter content (Pandey *et al.,* 2014). Similar findings were reported by Das *et al.* (2014a) in North-eastern region of India. Sharma *et al.* (2016) conducted a study on Alfisols and reported that minimum tillage with surface application of *Gliricidia* loppings and Nitrogen application @ 90 kg ha^{-1} resulted in increasing the activity of several soil enzymes like aryl sulphatase, urease and dehydrogenase along with increasing the concentration of microbial biomass carbon and labile carbon. Chaudhary *et al.* (2017a) added that the activity of dehydrogenase enzyme as well as Walkley and Black Carbon under long-term CA system having maize-based cropping systems was significantly higher than conventional tillage system. Bhattacharyya *et al.* (2012) found higher "labile" and "less labile" soil organic carbon pool in NT-NT and NT-CT plots than CT-CT plots under rainfed lentil-finger millet cropping system cultivated in sandy clay loam soil of the Indian Himalayas. These research evidences support that conservation agriculture improves the soil biological properties by enhancing carbon pools, enzyme activities and growth of microflora and fauna for surface residues available as substrate to them.

Crop productivity

Farmers are generally reluctant towards adoption of CA due to decrease in crop productivity in initial few years of its adoption. But many studies have reported that CA have either no or positive impact on crop productivity. Krishna and Veettil (2014) studied the impact of on-farm adoption of zero tillage in wheat in Haryana and reported 5% increase in the productivity of wheat crop. Adoption of conservation tillage with improved plant nutrient management and 30% residue retention for three years in rice-rice cropping system which is being practiced in eastern and north-eastern regions of India, enhanced the grain yield by 51.1-52.2% over existing farmer's practices (Yadav *et al.*, 2019). Das *et al.* (2014a) reported higher rice grain yield in conventional tillage than minimum tillage. However, the yield stabilized in minimum tillage after four years along with improved soil quality and nutrient recycling. Jat *et al.* (2013) reported that maize crop produced higher grain yield under permanent raised beds system as compared to no-till flat and conventional flat system whereas wheat crop had significantly higher yield under no-till flat system during first year and non- significant difference in succeeding two years. Hence, the CA practices can show yield benefits.

Laik *et al.* (2014) conducted a study for evaluation of four scenarios of rice-wheat cropping system in eastern Indo-Gangetic plains and reported that lowest yield was obtained in first scenario representing current farmers' practice which involve intensive tillage with complete removal of crop residues. In second scenario, productivity of wheat and rice crop was increased by 21-31% and 5-10%, respectively by avoiding tillage in wheat and including mungbean in crop rotation. The yields of both wheat and rice were further increased by inclusion of more CA components in third scenario. The maximum increase in yield was obtained in fourth scenario by including higher cropping intensity and diversification with CA components. A study on conservation agriculture in rice-wheat crop rotation in eastern Indo-Gangetic plains having clay-loam soil for seven years was conducted and Jat *et al.* (2014) found that conventional tilled based rice system had higher rice grain yield in the initial three years than CA based system whereas during fourth and fifth years, rice grain yield was comparable, but the rice grain yield under CA started increasing over CT from sixth year onwards. However, the wheat grain yield was higher in CA based system than CT based system from the second year onwards. Thus, the literature support that CA improves crop productivity in long term if practiced with appropriate crop rotations and management practices.

Water and nutrient use efficiency

Tillage, residue management and crop rotation strongly affect the soil physical environment and water, nutrient dynamics of any soil through their effect on mineralization, recycling of soil nutrients, moisture retention and controlled evaporation. Zero tillage is generally practiced in wheat crop after rice in Indo-Gangetic plains of India. Approximately 20-35% of irrigation water can be saved in wheat crop through zero tillage as compared to the conventional tillage (Mehla *et al.*, 2000; Gupta *et al.*, 2002). This practice contributed towards saving of pre-sowing irrigation in wheat crop as the residual moisture after harvesting of paddy crop. The practice also made it possible to sow and harvest wheat crop earlier which further eliminated the use of one or more late season irrigations. By including the CA components in rice-wheat rotation in eastern Indo-Gangetic plains, the irrigation water productivity in winter season was increased by 39-138% than conventional system (Laik *et al.,* 2014). Jat *et al.* (2013) conducted an experiment on maize-wheat cropping system in sandy-loam soil where permanent raised bed treatment showed 16% higher water use efficiency than conventional tillage. The irrigation water requirement in permanent raised beds and no-till flat treatment was 24.7% and 10.8% less than the conventional tillage treatment. In pigeonpea-wheat cropping system, CA system had higher water use efficiency as compared to CT system (Das *et al.*, 2016). CA based plots reduced the evaporation by 23-37% than CT plots in North-western Indo-Gangetic plains (Parihar *et al.*, 2019). Here the permanent raised bed plots recorded higher water productivity than Zero tilled and conventional tilled plots by 14-35% and 30-36%, respectively.

Aulakh *et al.* (2012) reported that Nitrogen uptake was reduced by 3-5% under conservation agriculture in winter grown wheat crop as compared to that of conventional agriculture. N, P, K, S and Zn use efficiency was significantly increased by 11, 16, 14, 13 and 21%, respectively by adoption of CA in maize-horse gram cropping system in Alfisols (Kundu *et al.,* 2013).

Soil erosion control

Soil erosion, when not controlled, leads to the loss of fertile top soil resulting in decreased sustainability on one hand and cause the sedimentation and eutrophication of water bodies downstream on the other. CA practices, are found to reduce run off which is otherwise responsible for transporting residual agrochemicals and soil sediments, thereby affecting surface and ground water pollution (Kukal *et al.,* 1991). Kurothe *et al.* (2014) reported that average soil loss under no tillage was 37.2% lower than the conventional tillage. The runoff under ridge farming tillage, no tillage and stubble mulch farming tillage were less by 69.4, 16.2 and 59.6%, respectively as compared to conventional tillage. Ghosh *et al.* (2015) reported that adoption of CA in area having 2% slope in maize-wheat cropping system, resulted in reducing soil loss along with increasing crop yield and moisture conservation. Thus, CA can play significant role in reducing soil erosion.

Climate change mitigation/adaptation

CA has potential to contribute towards mitigation and adaptation for extreme weather events that occur as a consequence of climate change. CA can reduce the release of atmospheric greenhouse gases (GHGs) by minimizing fuel consumption in reduced tillage operation as well as can enhance soil organic carbon sequestration which can help in climate change mitigation. In rice-rice cropping system, 1.30 Mg C ha^{-1} was accumulated with 427.9 kg ha^{-1} yr^{-1} rate of Soil Organic Carbon (SOC) sequestration by practicing reduced tillage with improved plant nutrient management (IPNM) and 30% rice residue retention in wet season rice. It was reported that adoption of CA with IPNM/INM and residue retention or incorporation had potential of ~1.6 Mg CO_2 ha^{-1} yr^{-1} in paddy soil which can contribute towards mitigation of climate change (Yadav *et al.*, 2019). Jat *et al.* (2019b) reported that conservation agriculture on permanent bed system with crop residue retention in Maize-Mustard-Mung bean cropping system and Nitrogen application through neem coated urea can reduce carbon footprint, and thus is an environmentally safe and efficient practice.

Cultivation of direct-seeded upland rice-mustard cropping system in North-eastern region under no tillage with 100% residue retention had 13% less carbon dioxide equivalent emission than conventional tillage with 100% residue incorporation treatment (Yadav *et al.,* 2018). Aryal *et al.* (2016) added that conservation agriculture-based wheat production system produces better yield than conventional tillage-based wheat production system in Haryana especially under untimely excess rainfall conditions which indicates that the conservation agriculture has potential to cope with rainfall variability and can help in climate risk adaptation. Chaudhury *et al.* (2017b) revealed that cultivation of rice in Indo-Gangetic plains through turbo happy seeder, bed planting, reduced tillage and zero tillage had lower Global Warming Potential than transplanted rice. Flux of greenhouse gases *i.e.* carbon dioxide, methane and nitrous oxide from rice-wheat cropping system soils in Indo-Gangetic plains was 10-15% less and global warming potential per unit of wheat yield was 10 times lower in CA based system than CT based system (Sapkota *et al.*, 2015). This may be because tillage induced disturbances in CT based system resulted in higher decomposition causing higher carbon dioxide emissions.

The higher redox potential in zero tillage-based rice crop arrest the methanogenesis process resulting in lower methane emissions. Parihar *et al.* (2018) reported that in Inceptisols, the CA based practices in maize-based cropping systems have lower nitrous oxide emissions than CT due to increased oxygen diffusion rate which decreased the denitrification and, thus, production of nitrous oxide. Such research information are testimonials and validate that CA can be an effective tool to mitigate the climate change by reducing greenhouse gases and adapt climate change conditions while maintaining crop productivity.

Management Practices Concentric to Conservation Agriculture

Conservation agriculture facilitates good agricultural practices and improves overall land husbandry for crop production in rain-fed and irrigated areas. These good agricultural practices involve usage of quality seeds, and integrated nutrient, pest, weed and water management. In this way, CA form a base for sustainable agricultural production intensification (Fredrich, 2013; Farooq, 2014; Jat *et al.*, 2014). Several researches are going for defining appropriate and optimum management strategies for different cropping systems under CA. Some of the management practices related to CA in context of India are discussed in this paper:

Conservation tillage practices

Conservation tillage practices involves zero or no tillage, reduced or minimum tillage, mulch tillage, ridge tillage, and contour tillage. In no tillage (NT), there is no disturbance of soil surface through tillage. A small area of soil surface is only disturbed during sowing. In minimum or reduced tillage, only primary tillage operations are performed. In mulch tillage, the soil is tilled in manner that allows the remaining crop residues to cover maximum extent of the soil surface. In ridge tillage, crops are planted either on both sides or on top of the ridges which are prepared during sowing.

In contour tillage, soil is tilled across the slope which serves as soil and water conservation measure by virtue of tillage furrows hindering free flow of runoff and giving more opportunity time for runoff water to infiltrate down the profile. Das *et al.* (2014b) found that permanent broad beds with residue retention performed better than permanent narrow bed with and without residue retention, zero tilled flat with and without residue retention, and conventional tilled treatments in terms of productivity, profitability and resource conservation under irrigated cotton-wheat cropping system of the western Indo-Gangetic plains. Kumar *et al.* (2019) added that the cultivation of zero tilled direct seeded rice and zero tilled wheat both with residue retention in rice-wheat cropping system in Indo-Gangetic plains provided maximum yield and net profits as compared to transplanted rice after rotavator puddling and either zero or conventionally tilled wheat. In rainfed Vertisols, the performance of crop was in the order of No-tillage > Reduced tillage > Conventional tillage (Somasundaram *et al.*, 2018). Thus, the relevance of type of conservation tillage practice to be adopted is dependent on soil type and cropping system.

Residue management practices that avoid burning

All the residue management practices that avoid its burning are useful in one or the other way for the natural resources and environment. Under Indian conditions, the management of crop residues may comprise of mulching, conservation agriculture, composting, mulch tillage, biochar making and animal feeding. Crop residues either kept on soil surface as mulch or incorporated as compost, biochar and farm yard manure (FYM) from animals, generally protect soil surface from extremes of rainfall and temperature, enhances the activity of various soil macro and micro-organisms, which further contribute in formation of stable soil aggregates. Crop residues decrease surface compactness, surface sealing and crusting, and diminish the dispersion and breakdown of soil aggregates. Ruan *et al.* (2001) reported that the extent of beneficial impacts of crop residue cover in a region is determined by various bio-physical factors like soil type, topography, temperature, intensity and amount of rainfall, wind speed, amount and magnitude of soil surface cover by crop residues and prevalent cropping pattern. Blanco-Canqui *et al.* (2006) mentioned that more the land surface cover, greater is the protection of soil physical properties against natural and man-made disturbances. Jat *et al.* (2019b) conducted a study on permanent bed system for four years and reported that application of crop residue increased the system productivity by 11.7% as compared to one without crop residue.

The beneficial effect of CA in terms of higher nutrient availability, to a certain extent, may be due to crop residues retention on soil surface in comparison with incorporation of crop residues with CT and partly due to arresting their leaching losses by reducing decomposition by being surface placed (Ismail *et al.*, 1994; Balota *et al.*, 2004; Kushwaha *et al.*, 2000). Many authors reported that the crop with residue retained on surface performed better than crop cultivated without residue retention in CA system (Das *et al.*, 2014b; Rani *et al.*, 2017; Kumar *et al.*, 2019; Somasundaram *et al.*, 2018). Therefore, it is recommended to retain crop residue on surface for gaining maximum benefits from CA so that we may save the billions of monetary loss which is otherwise happening due to crop residue burning.

Crop diversification practices

Crop rotation is the important component of conservation agriculture besides conservation tillage and residue management. The nature and type of crops in crop rotation determine the level and extent to which soil physical health might be modified. Suitable crop rotation facilitates the formation of various micro and macro-pores that are responsible for movement of water, air and nutrients into the soil, which is beneficial for crop root growth. Jat *et al.* (2019b) reported that cultivation of Maize-Mustard-Mungbean rotation in permanent bed system of conservation agriculture resulted in approximately 11% higher benefit-cost ratio, higher net energy and 9% less carbon footprint as compared to Maize-Wheat-Mungbean rotation.

Maize-wheat cropping system is being suggested as an alternative cropping system of Rice-wheat in Indo-Gangetic plains due to high water requirement of rice which led to the depletion of ground water table (Humphreys *et al.*, 2010). Parihar *et al.* (2016) suggested adoption of CA based practices in Maize-Mustard-Mungbean and Maize-Wheat-Mungbean crop rotations as an alternative to Rice-Wheat crop rotation in sandy-loam soil of north-western India for combating the problem of declining ground water table and resource degradation as these cropping systems have higher equivalent yield of maize under CA practices.

By adoption of CA in Alfisols of southern India having semi-arid climatic conditions, it is possible to conserve soil moisture and nutrient which made it possible to cultivate horse gram in rabi season which generally remains fallow. Thus, double cropping system like maize-horse gram can be adopted under CA in semi-arid regions (Kundu *et al.*, 2016). Therefore, inclusion of shallow and deep-rooted crops alternatively as well as leguminous crops in the cropping systems under CA can improve the overall soil quality and system productivity due to nutrient recycling by deep rooted crops, formation of deep bio-pores upon decomposition of roots which facilitate infiltration, addition of residues and nitrogen which acts as food for more microbial activity and thus improvement of soil health.

Nutrient and water management practices

There is a need to refine the nutrient and water management practices with respect to CA to achieve maximum benefits and sustainability as CA affects various physical, chemical and biological properties of soil which in turn determines the nutrients and water availability. Jat *et al.* (2019b) reported that application of nitrogen through neem coated urea in permanent bed system with crop residue resulted in 10.9% higher system productivity than non-coated prilled urea. Aulakh *et al.* (2012) conducted a study for four years in soybean-wheat cropping rotation in north-western part of Indo-Gangetic plains having soil with loamy sand texture, low organic carbon and available Phosphorus, and reported that soybean productivity could be improved under conservation agriculture as compared to conventional agriculture either by applying 25 kg N and 33 kg P ha^{-1} or 20 kg N and 26 kg P ha^{-1} along with 10 t FYM ha^{-1}. Jat *et al.* (2019a) reported from his 5-years study on CA that in Maize-Wheat-Mungbean cropping system, application of nitrogenous fertilizer through Neem coated urea and in Maize-Mustard-Mungbean cropping system through sulphur coated urea is beneficial in western Indo-Gangetic plains in terms of crops yield and profitability. Parihar *et al.* (2017) suggested the adoption of Nutrient Expert® based site-specific nutrient management (SSNM) in CA for gaining maximum benefits. Humphreys *et al.* (2011) reported that retaining rice straw mulch in wheat in Punjab retained more moisture and saved 75 mm of irrigation amount when coupled with soil matric potential based irrigation scheduling. Rai *et al.* (2018) reported that conservation agriculture practices improved the infiltration capacity of the soil. Jat *et al.* (2019b) reported that residue retention in permanent raised bed system with residue retention in Maize-Wheat-Mungbean and Maize-Mustard-Mungbean cropping system resulted in saving of 50-55 ha-mm of irrigation water. Further research is going on in this aspect to provide the farmers practicing CA with exact and appropriate nutrient and water management practices depending upon the local conditions.

Weed management practices

The major and most cited hurdle in adoption of CA by farmers is shifting in weed species and increase in weed density which result in reduction of crop yield. Several researchers reported that cover crops may play a key role in weed management in CA systems, however, presently their level of adoption is very less. Alteration in patterns of tillage, planting systems, and other management practices can change the soil environment which can lead to a major shift in weed flora. Usage of herbicides have been an extremely essential component of weed management in CA systems but efforts are required to integrate it with non-chemical weed control options.

Farmer-participatory model of research has been proved to be highly efficient in developing acceptance for CA in rice-wheat system in the IGP. However, still more efforts are needed to enhance the rate of adoption of direct seeded rice and zero-till wheat throughout the IGP (Bhullar *et al.*, 2016). Many researchers reviewed that cultivation of wheat crop in zero tillage after harvesting of rice in Indo-Gangetic plains has been reported to lower the infestation of *P. minor* weed by reducing the soil movement (Mehla *et al.*, 2000; Mehta and Singh, 2005). Integrated weed management with inclusion of bio-herbicides, allelopathy and optimum crop nutrition along with chemical herbicides can be effective tools for weed management without harming the environment (Bajwa, 2014). For efficient management of weeds in CA, one hand weeding at appropriate crop stage could also be practiced. Further research in developing suitable and integrated weed management tools is required.

Bottlenecks for Adoption of Conservation Agriculture

Although the concept of CA is viable, feasible and applicable, yet the techniques and practices for every condition are to be developed and validated. Besides number of benefits associated with conservation agriculture, there are number of restraint problems associated with the adoption of conservation agriculture like machinery and equipments, weed control, mind-set of farmers, and policy constraints. The major hurdles in adoption of CA by Indian farmers are briefly discussed below:

- ***Lack of appropriate machineries****:* While significant efforts have been made to develop and promote machinery for sowing wheat in no-till systems, successful adoption will require accelerated efforts to develop, standardize and encourage quality machinery for a range of crops and cropping sequences. These would involve the development of appropriate machinery to manage crop residues and simultaneously perform the operations like uniform shredding of residues that are generally piled in the field after combine harvest, collection of part of residues for animal feed and also apply the fertilizers at proper place in proper quantity along with seeding.

  In this context, Punjab Agricultural University, Ludhiana has developed a new machine called 'Happy Seeder' in collaboration with Australian Centre for International Agricultural Research. This Happy Seeder machine requires 45 HP tractor for its operation. It cuts, lifts and manages the standing stubble and loose straw by retaining it as surface mulch and sows the wheat crop in a single operational pass of the field. But still machine weight, load on the tractor and choking of machine under heavy stubble load are the major constraints in its operation. Now a super straw system attachment into the combine has been devised that ensures cutting and uniform spreading of piled or anchored residues, in the field. So, this could be an effective solution to overcome the residue management problem.

  In case of Turbo happy seeder, the power requirement of the tractor has to be more than 50 HP. This is another hinderance in residue management as most of the farmers have the tractors of 40 or less horse power. In such case, the draft requirement of Turbo happy seeder can be reduced by reducing the number of tines and then farmer need not purchase new tractor of high power. Also, the farmers are reluctant to purchase these machines because this machine remain idle during most of the time of a year.

- ***Infrastructural Constraints**:* For promotion of CA, the inputs like herbicides, seeds for rotational and cover crops and farm machinery for direct sowing, planting and residue management are often entirely different to the traditionally used ones and these machineries have to be made easily available in the markets. This can be achieved by better input supply infrastructure, and proactive attitude of the supply sector including dealers and manufacturers.
- ***Obnoxious/Stubborn/Resistant Weeds:*** In CA, weed infestation, distribution, diversity, growing pattern, resistance level has been changed. In long span, weed infestation is controlled up to some extent by herbicide application. The emergence of weeds along with time is the serious problem as most of the weeds are generally controlled by herbicidal application. However, most of the weeds become resistant to the herbicide application by time. Obnoxious weeds are not controlled even by herbicides. In order to control such weed species in CA farm, frequent application of herbicides may pose the threat to the soil biodiversity and quality of crop produce. So, we may need to redefine the CA and allow one hand weeding at appropriate stage of crop. It will be the effective method to control weeds without much disturbance to the soil and at the same time save the fields from being overloaded with herbicidal residues.
- ***Traditional mind-set of farmers and lack of confidence***: Residue burning has become a deeply percolated and inherited idea in the minds of farmers over the generations, for getting rid of additional crop residues, especially in the rice-wheat system of north India. As most of the farmers are of the view that residue burning cleans the field for next sowing, changing this mindset of farmer is of utmost need for successful implementation and mainstreaming of CA. Therefore, multifaceted extension activities and field demonstrations are required to build confidence among farmers for adoption of CA instead of burning crop residues and ruining soil health as well as environment.

  Another major retardant factor in the way of technology adoption is the lack of confidence of its success among the farmers until it proves itself in farmer's fields. To win their confidence, the technology demonstration in farmer's fields is a process of utmost importance to mainstream the promising technologies like CA.
- ***Policy Constraints**:* For promotion and rapid adoption of CA, the practices involved in it like sowing, water and nutrient management, diseases and pest control, harvesting, etc. need to be evolved, evaluated and matched in the purview of modern system. Managing conservation agriculture system needs improved scientific competence to tackle its problems from a systems perspective and capability to work in close association with farmers and other related stakeholders. For this purpose, strong knowledge and information sharing mechanisms are required. Appropriate policies can enhance the adoption of CA by Indian farmers significanlty by eliminating the constraints discussed before. This can be done through information and training campaigns and extension activities, suitable legislations and regulatory frameworks, research and development, and incentive and credit programs. But the problem is that most of the policy makers are also not aware about CA and, therefore, many existing policies don't promote the adoption of CA.

Conclusion

Conservation Agriculture has wide scope for, conservation of natural resources like soil, nutrients, water, sustaining agricultural production, ensuring food security and mitigating or adapting crops under climate change conditions. Conservation Agriculture has numerous benefits such as improvement of soil physical, chemical and biological health, sustaining crop production by conserving natural resources and maintaining soil quality, saving of cost, energy and labour, improvement in water and nutrient use efficiency, reduction in emission of GHGs by carbon sequestration, reduction in soil erosion and environmental pollution by eliminating the need of burning crop residues, and climate change mitigation as well as adaptation. The management practices of CA are different from the conventional system, and these management practices varies with soil, crop and availability of resources. Albeit, there are few bottlenecks in its adoption at a large scale. Suitable farm machinery, especially for residue management, may be easily available to the farming clientele through appropriate policy. The farm machineries for CA have to be developed keeping in view the needs of small and medium farmers. Besides, there is a need to redefine the term 'conservation agriculture' by introducing the concept of one hand weeding at appropriate crop stage for controlling obnoxious weeds. Further research is required to refine these management practices depending upon the local conditions.

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Received: February 12, 2019; Accepted: April 14, 2019