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Conservation Agriculture (CA)-Based Tillage Practices in Maize for Enhancing Crop Yield, Resource use Efficiency and Soil Health: A Review

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ABSTRACT

The triple challenge of acute water crisis, stagnant crop yield and soil health deterioration in NW Indo Gangetic Plains (IGP) ramble a search for potential alternative crop establishment technique (CET). Hence, maize-based crop rotations under best-bet conservation agriculture (CA) practices can plays a critical role in sustainable crop production. The CA-based tillage and CET *viz*. zero tillage (ZT) and permanent raised beds (PB) hold potential to intensify crop yield per hectare, improving resource use efficiency besides bringing desirable changes in soil physico-chemical and biological properties. Therefore, it needs to be popularized in larger scale chiefly under maize-based rotation to makes farming more attractive, profitable and sustainable.

Key words: Conservation agriculture, Maize, Resource use efficiency, Soil health, Tillage, Yield.

Globally, agriculture is entering a new era confronted with problems related to climatic change and issues of food security. Maize (*Zea mays* L.), being a versatile and highly adaptive crop to diverse agro-ecologies with highest genetic yield potentials fundamental to ensure food and nutritional security to the millions (Shiferaw *et al*., 2011; Jat *et al*., 2013). In India, maize occupies an area of ~ 9.8 M ha with annual production of ~ 19.8 million tones (GOI, 2020). Among various maize-based rotation maize-fallow, maize-mustard, maize-chickpea, maize-maize, maize-potato, are the promising systems across the country. However, conventional maize production have several restraints, mainly due to poor crop establishment and inputs management (Yadav *et al*., 2017; Parihar *et al.,* 2017) leading to lower crop productivity and resource use-efficiency. Similarly, soils of the major maize growing are as low in soil organic matter (SOM) and nitrogen (N) (Jat *et al*., 2014). In this context, CA-based maize rotation is being advocated as an alternative to conventional practices. The conservation agriculture concept is evolved in a response to the concerns of agricultural sustainability (Bhan and Behra, 2014). Which is based on three fundamental inter-linked principles; (i) minimal mechanical soil disturbance, (ii) permanent soil cover and (iii) crop diversification. The years of intensive tillage had a remarkable negative outcome on the soil health (Parihar *et al*., 2016) and resource use efficiency (Govaerts *et al.,* 2005) thereby affecting crop yields. Similarly, tillage practices also determine the content and distribution of SOM, which is a key indicator of a soil quality (Thomas *et al.,* 2007). Hence, proper optimization of tillage along with crop residue retention is necessary as it provides multiple benefits *viz*. enhance soil microbial diversity, creates positive soil carbon / nitrogen stocks (Melero *et al.,* 2011; Parihar *et al*., 2018), improving water use efficiency (Chauhan *et al*., 2000) and agronomic efficiency of applied fertilizer (Kamanga *et al.,* 2014). Therefore, this article reviews a performance of maize in relation to crop yield, resource use efficiency and different soil properties under CA-based tillage practices.

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Principles of conservation agriculture (CA)

According to FAO conservation agriculture is based on three universally applicable and acceptable principles:

Minimum mechanical soil disturbance

This principle primarily focuses on the soil conservation. Practicing no-till system moderates SOM oxidation (Ladha *et al.,* 2009; Thomas *et al*., 2007), soil water movement (Bhan and Behra. 2014), bulk density and soil resistance to penetration (Saha *et al*., 2010) besides lowering cultivation expenditure (Sharma *et al.,* 2011).

Permanent soil cover through organic crop residues

In India, annual generation of crop residues is estimated around 500 MT (GOI. 2016). Thus, the surplus residues can be recycled after being used for feeding cattle, cooking fuel and organic manure production (Devi *et al.,* 2017). Residue retention creates a favorable crop micro-climate, act as safeguard against beating action of rains (Pimentel *et al*., 1995), reducing surface evaporation (Tolk *et al.,* 1999) and leads to improvement in soil physico–chemical and biological properties (Jat *et al*., 2014). Recently, crop residue management using cover crops under CA is gaining much popularity across the globe (Teasdale and Sharley*.,* 1998; Kuo *et al*., 1997).

Crop diversification

Diversifying crops fulfills human dietary requirement (Bhan and Behra. 2014), stabilized income / crop productivity (Das *et al.,* 2014), provides protection against pest / disease / weed infestation (Howard *et al.,* 2003) and also improves soil productivity (Stagnari *et al.,* 2009). In this regard, the Government of India (GOI) had also initiated several schemes for promoting sustainable crop diversification to address the burning issue of agriculture and allied sectors.

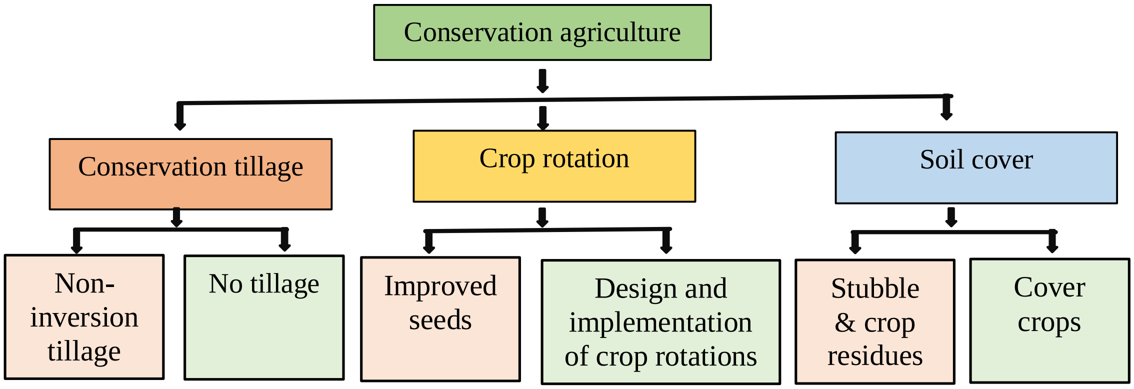
Impact of CA-based tillage practices

Yields levels

Globally, ever–growing population and shrinking land resources has threatened sustainable crop production. Hence, sound agronomic intervention plays an important role to ensure food and nutritional security. The CA-based tillage practices has come up to achieve maximum production potential through sustained agronomic productivity. The study (six year) conducted by (Parihar *et al*. 2016), in NW-IGP of India, had documented 9.4-12.2% greater pooled grain yield and highest system productivity (11.3–12.9 Mg ha^{-1}) with CA-based tillage practices. Several other studies also conform the higher maize yield ranged from 17-19% with CA-based practices (Bachmann and Friedrich. 2002; Blanco-Canqui *et al.,* 2006; Kaschuk *et al*., 2010; Das *et al*., 2014; Singh *et al*., 2014). While, Jat *et al*. (2006) reported marginally lower maize yield under zero-tillage system due to more infestation of perennials weeds. The maize planted on permanent–bed resulted in enhanced maize yields compared CT practices (Potter *et al*., 1996). Likewise, Aquino *et al*. (1998) had also reported yield advantage of wheat, maize and soybean under raised bed planting. Which was in consistent with the investigation of Jat *et al*. (2013) in which maize on raised bed provides substantial yield advantage up to 24–40% compared to CT based practices. Similarly, Ram *et al*. (2010); Jat *et al*., (2006); Kumar *et al*., (2004); Govaerts *et al*. (2005); Thierfelder *et al*. (2018) concluded that higher maize yield under CA based system might be attributed to better water regimes, compound effects of additional supply of nutrients and improvement in soil physical properties, improved soil carbon status resulted from residue imbedded tillage with practices.

Resource use efficiencies

The inefficient resource use in conventional practices leading to declining factor productivity and low input use efficiency. Several studies conducted in past demonstrated the effects of CA based tillage practices exclusively on input use efficiencies such as higher water use efficiency (Chauhan *et al*., 2000), higher energy output, increased energy productivity and net energy (Parihar *et al*., 2017; 2018). Similarly, Jain *et al.* (2007) also reported higher energy–use efficiency and energy productivity under conservation tillage relative to traditional practices. Out of total operational energy, $^{1}/_{3}$rd of energy and 36 liters ha^{-1} of diesel (equivalent to minimizing CO_2 emission of 93 kg ha year^{-1}) could be saved under ZT system compared to CT based practices (Srivastava, 2003; Erenstein and Laxmi, 2008). Similarly, Jat *et al.* (2014) had reported significantly ($P<0.05$) higher carbon sustainability index (CSI) and carbon efficiency (CE) with permanent bed planting followed by zero in maize–maize–sesbania system and they concluded as did by Dubey and Lal, (2009). However, Kamanga *et al*., 2014; Six *et al*., (2004) had registered contrast results regarding nutrient use efficiency under CA-based tillage practices.



(Sources: Stagnari *et al*., 2009)

Fig 1: The three interlinked principles of conservation agriculture (CA) and the major practices and means needed to achieve respective principle.

Soil chemical properties (pH, SOC, N, P and K)

Soil chemical environment can be modified through different agronomic practices and maintenance is equally important to achieve higher crop growth and productivity. The CA-based tillage *viz*. ZT and PNB had a remarkable positive impact on the chemical properties as it preserves organic matter content and improves status of different nutrient in the soil (Wright and Hons. 2004; Owens *et al*., 2002). Similarly, Govaerts *et al.* (2007) observed linear relationship of soil organic matter with an amount of straw retention under permanent raised bed system. Similar findings were also obtained by Lal. (1997); Hulugalle and Entwistle (1997); Utomo *et al*., (2013). Likewise, Parihar *et al.* (2016) had reported 23.6-35.3% higher soil carbon content at 0–15 cm soil depth under CA based tillage pertained to CT practices. However, several other studies confirmed higher SOC ranged from 19.4 to 67% with CA based practices at 0-30 cm soil section compared to maize planted on CT plots (Thomas *et al*., 2007; Kaiser *et al*., 2014; Six *et al*., 2004; Das *et al*., 2014) (Table. 1). The adoption of CA-based tillage in conjugation with crop residues residue retention hold potential to influences soil total and mineralizable–N content (Gosai *et al.*, 2009), available soil nitrogen status (Mohanty and Mishra. 2014), extractable–P content and K content in the surface soil layer (Ismail *et al*., 1994). Which was ascribed to less leaching, fixation and release of several chelating agents resulted from improvement in soil properties due to optimization of tillage and crop residue management under CA based cropping system (Betrol *et al.,* 2007; Du Preez *et al.,* 2001; Robbins and Voss 1991; Standley *et al.,* 1990).

Soil physical properties

Tillage practices have a direct impact on soil physical health. It modifies water regimes, root proliferation / penetration into the soil and controlled the absorption of soil nutrient by the plants. The ZT technology proved to be a wise choice to improve the overall soil physical health. Several findings suggested that maize when planted under no–tilled plots had shown a significant ($P<0.05$) improvement in soil bulk density, infiltration rate, hydraulic conductivity and penetration resistance and other related physical properties relative to CT based system (Wilkins *et al*., 2002; Afzalinia and Zabihi. 2014; Lampurlanes and Cantero–Martinez. 2006; Lal. 2000; Jat *et al*., 2005; Parihar *et al*., 2016). However, some researchers had reported a non-significant results with respect to soil bulk density with no-tillage system (Gwenzi *et al*., 2009; Horn, 2004; Ram *et al*., 2002; Kumar *et al*., 2002). Similarly, Yang and Wander. (1999) and Salem *et al*., (2015), concluded that changes in soil physical properties is mainly attributed to lesser trafficking of machinery along with proper crop residue management under zero tillage in comparison with CT practices.

Soil biological properties

The soil has the most diversified population of flora and fauna and it has been estimated that the 1 gram of soil contains millions of living organism like, bacteria, fungi, mycorrhiza, protozoa, nematodes, earthworms, mites, enchytraeids ants, termites, beetles and spiders etc. (Hawksworth. 1991). Higher soil microbial population and soil enzymatic activities are supposed to be key factors for nutrient cycling in an agro-ecosystem (Dick. 1994; Hungria *et al*., 2009; Salinas-Garcia *et al*., 2002). Long-term adoption of resource conservation practices along with residue retention often increase microbial populations, biomass and enzymatic activities by providing substrates for their growth (Stott *et al*., 2009; Singh *et al*., 2009). Which in turn nourishes

Table 1: Impact of CA-based tillage on soil organic carbon (SOC) under maize-based rotation.

Tillage practices	Cropping system	Study durations (years)	Depth (cm)	% Increase in SOC over CT	References
PB + R	WMCS	3	0–30	19.4	Das *et al.* (2018)
ZT–DSR/M	RMCS	5	0–30	25.8	Singh *et al.* (2016)
SSM	WMCS	8	0–20	5.65	Shao *et al.* (2016)
PB	MBCS	5	0–30	19.6–37.5	Parihar *et al.* (2018)
ZT+ R	MWMS	6	0–15	67	Jat *et al.* (2019)

Note: PB + R= Permanent bed with residue; ZT–DSR/M= Zero till direct seeded rice/maize SSM= Sub soiling mulching; ZT+ R= Zero tillage with residue; WMCS= wheat–maize cropping system; RMCS= Rice–maize cropping system; MBCS= Maize based cropping system; MWMCS= Maize–wheat–mungbean system and MWCS= Maize–wheat cropping system; CT= conventional tillage.

Table 2: Impact of CA-based tillage on soil microbial properties under maize-based rotation.

Tillage practices	Cropping system	Study durations (years)	Depth (cm)	% Increase in MBC over CT	% Increase in DHA over CT	References
PB	MBCS	6	0–5	46.6	57.3	Parihar *et al.* (2018)
ZT+R	MWCS	3	0–10	56	154.8	Choudhary *et al.* (2018)
NT	MCCS	4	0–10	80	–	Wright *et al.* (2005)

Note: PB= Permanent bed; ZT+R= Zero tillage with residue; NT= No till; MBCS= Maize based cropping system; MWCS= Maize–wheat cropping system; MCCS= Maize–cotton cropping system; MBC= Microbial biomass carbon and DHA= Dehydrogenase activity.

soil through nutrient recycling back to the soil system (Marinori *et al*., 2000; Singh *et al*., 2009). It has been documented that CA-based maize rotation can increase soil microbial biomass carbon (SMBC) and dehydrogenase activity up to 25-80% and greater than 100% compared to CT practices (Table. 2). The undisturbed soil, more vertical distribution of organic residues, improved aeration and water content are responsible for higher enzymatic activity under zero tillage system. (Melero *et al.,* 2011; Green *et al.,* 2007; Roldan *et al*., 2007; Ladd. 1985). The long-term study conducted by Parihar *et al.,* (2016) had also reported higher (on average 45–48.9%) improvement in soil microbial biomass carbon (MBC) and soil enzymatic activities i.e., fluorescine diacetate, dehydrogenase, b glucosidase and alkaline phosphatase at 0-30cm soil depth under CA based systems. Similarly, Kladivko. (2001) suggested that, microbial diversity is negatively correlated with the intensity of tillage. Which was in similar line with the results of Ferrerus *et al*. (2000) and Hassen *et al*. (2007).

CONCLUSION

Currently, Indian agriculture is reeling under the myriad of problems such as adversary of climate change, yield stagnation, high cost of cultivation, soil health degradation etc. This situation demands a paradigm shift in farming practices, conservation agriculture concept, if followed in true spirit, could be a panacea for the said problems. Further, it has been proved that the CA-based maize rotation are the better alternative for the prevalent resource inefficient traditional cropping system. It can be concluded that conservation based tillage practices (ZT and permanent bed) in long run found to be suitable cultivation practice to obtain better maize productivity, improving use efficiencies and overall soil health.

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