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EFFECT OF CROP ESTABLISHMENT METHODS AND RESIDUE RETENTION ON SOIL PROPERTIES IN *KHARIF* MAIZE (*ZEA MAYS* L.) UNDER CONSERVATION AGRICULTURE IN INDO-GANGETIC PLAINS OF HARYANA

MOHIT[1], BALDEV RAJ KAMBOJ[1], PARDEEP PHOGAT[1,2,*], DHARAM BIR YADAV[1], ANKIT SINGH[3] AND RAJESH MOR[4]

[1]Department of Agronomy, CCS Haryana Agricultural University, Hisar-125 004 (Haryana), India
[2]Division of Soil and Crop Management, ICAR-CSSRI, Karnal-132 001 (Haryana), India
[3]Department of Soil Science, CCS Haryana Agricultural University, Hisar-125 004 (Haryana), India
[4]Faculty of Agricultural Science, SGT University, Gurugram-122 505 (Haryana), India
(e-mail: pardeepphogat0617@gmail.com)
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SUMMARY

A field experiment was conducted during *Kharif* 2018 at the Regional Research Station, Uchani, Karnal under CCS Haryana Agricultural University, Hisar to evaluate the effects of various maize (*Zea mays* L.) establishment methods and crop residue retention on soil physicochemical properties and nutrient dynamics. The study aimed to explore sustainable alternatives to the traditional rice-wheat system in the Indo-Gangetic Plains, with a focus on conservation agriculture practices. The trial was laid out in a randomized block design with eight treatments, including zero tillage and conventional tillage methods under different sowing techniques and residue management scenarios. Soil samples collected post-harvest were analysed for bulk density, pH, electrical conductivity, organic carbon and available nitrogen, phosphorus and potassium. Results revealed that while bulk density, pH and EC were not significantly influenced by establishment methods, zero tillage with residue retention notably improved soil organic carbon (0.41%) and enhanced the availability of nitrogen (129.5 kg/ha), phosphorus (17.9 kg/ha) and potassium (230.0 kg/ha). These benefits are attributed to minimal soil disturbance and improved nutrient cycling due to residue decomposition. The findings underscore the potential of conservation agriculture-particularly zero tillage with residue retention-as a sustainable strategy to enhance soil health and fertility in maize-based cropping systems in north-western India.

Key words: Conservation agriculture, zero tillage, residue retention, nutrient cycling and soil health

Maize (*Zea mays* L.), a C_4 plant, is a major cereal crop known for its high yield potential and adaptability across diverse agro-climatic conditions, often referred to as the "Miracle Crop" or "Queen of Cereals" (Anjum *et al*., 2014). Cultivated in over 150 countries, it exhibits wide variation in grain characteristics and serves multiple purposes-grain and stover for food and feed, as well as raw material for industries including starch, oil, sweeteners, pharmaceuticals and textiles (Kumar *et al*., 2015). Dent maize is the most widely cultivated type, and in developing nations, 50-55% is used as animal feed. In India, maize ranks third after rice and wheat, grown in *Kharif*, *Rabi* and spring seasons, with consumption dominated by poultry feed (52%), followed by food (24%), animal feed (11%), starch (11%) and other uses. Nutritionally, it contains 7.7-14.6% protein, 69.7-74.5% carbohydrates, 3.2-7.7% fats and 0.8-2.32% fiber. Globally, maize covers 197.2 million ha with a production of 1134 million tonnes and productivity of 57.54 q/ha; the USA, China, Brazil and India are leading producers, with India ranking fourth in area and sixth in production (FAOSTAT, 2017). *Kharif* accounts for 85% of India's maize, with Karnataka, Madhya Pradesh, Maharashtra and Bihar as major producers, and Andhra Pradesh and Punjab showing the highest productivity. To meet demand, India must scale production to 55 million tonnes by 2030. In Haryana, maize was grown on 5,000 ha with a productivity of 3,400 kg/ha in 2017 (INDIASTAT, 2017). Given its adaptability, market potential and low water requirement, maize is a viable alternative to rice, helping address water scarcity and resource degradation. The rice–wheat system dominant in the Indo-Gangetic Plains (IGP) has supported food security but caused soil fertility decline, groundwater depletion and environmental pollution (Jat *et al*., 2013). Maize integration with resource conservation technologies (RCTs) such as zero tillage and furrow irrigated raised bed systems (FIRBS) can improve soil health, water use efficiency and sustainability (Jat *et al*., 2007). Residue retention further enhances nutrient cycling and reduces stubble burning. Conservation agriculture (CA)—minimal tillage, residue retention and diversification—improves soil quality, resource use efficiency and climate change mitigation (Jat *et al.*, 2011). Studies confirm zero tillage, raised beds and residue management reduce water use and enhance maize productivity (Singh *et al*., 2011). Therefore, this investigation entitled "Evaluation of different methods of establishment in *Kharif* maize (*Zea mays* L.)" was undertaken to examine the impact of different planting techniques and residue management practices under conservation agriculture on soil properties. The study aims to identify sustainable alternatives to the rice-wheat system in order to ensure long-term agricultural viability in the Indo-Gangetic Plains.

MATERIALS AND METHODS

A field experiment was conducted during *Kharif* 2018 at the Regional Research Station, Uchani, Karnal, under CCS Haryana Agricultural University, Hisar (Haryana, India), to assess the impact of various maize establishment methods under residue retention on soil properties and economic returns. The experimental soil was clay loam in texture, slightly alkaline in reaction (pH 8.1), with an electrical conductivity of 0.30 dS/m. The soil was low in organic carbon (0.40%) and available nitrogen (126 kg/ha), while medium in available phosphorus (16 kg/ha) and potassium (226 kg/ha). The trial was laid out in a randomized block design (RBD) with three replications and eight establishment treatments: zero tillage-drill sown with residue (ZTDS+R), zero tillage-drill sown without residue (ZTDS-R), zero tillage-dibbling with residue (ZTDB+R), zero tillage-dibbling without residue (ZTDB-R), conventional tillage-drill sown (CTDS), conventional tillage-dibbling (CTDB), conventional tillage-raised bed, multi-crop planter sown (CTRBDS) and conventional tillage-raised bed, dibbling (CTRBDB). Following the harvest of the preceding *Rabi* wheat crop in April, the hybrid maize cultivar HM-10 was sown on July 2, 2018, using a seed rate of 20 kg/ha. Raised beds were prepared using a single pass of a bed planter, followed by sowing via multi-crop planter or manual dibbling depending on the treatment. One row per bed (75 cm wide) was maintained. In conventional tillage treatments, sowing was carried out using a seed drill or manual dibbling at a spacing of 75 × 20 cm. Zero tillage treatments were sown with a zero-till seed drill or by manual dibbling, also maintaining a 75 × 20 cm row spacing. A pre-emergence herbicide, atrazine, was applied at 0.75 kg/ha on July 3, 2018, using a knapsack sprayer equipped with flat-fan nozzles, delivering 500 L/ha spray volume. To ensure uniform plant population, manual thinning and gap filling were performed at 20 days after sowing (DAS) as needed. Soil samples were analysed to assess key physicochemical properties using standard procedures. Soil bulk density was determined by the core method (Blake, 1965). Soil pH and electrical conductivity (EC) were measured in a 1:2 soil-to-water suspension (Jackson, 1973). Organic carbon content was estimated using the Walkley and Black (1934) wet oxidation method on oven-dried samples. For nutrient analysis, oven-dried and sieved soil samples were used to estimate available nitrogen using the alkaline permanganate method (Subbiah and Asija, 1956), available phosphorus using Olsen's method (Olsen *et al*., 1954) and available potassium using the flame photometer method (Jackson, 1973), with results expressed in kg/ha.

RESULTS AND DISCUSSION

The data pertaining to various soil physicochemical properties-namely bulk density, soil pH, electrical conductivity, soil organic carbon and available nutrients (nitrogen, phosphorus and potassium) - under different crop establishment methods following harvest are summarized in Tables 1 and 2.

Bulk density (Mg/m^3)

The bulk density of soil was not significantly affected by the different crop establishment methods, as shown in Table 1. Post-harvest, all treatments exhibited statistically similar bulk density values. The presence or absence of crop residue did not lead to any notable differences in bulk density and both zero tillage and conventional tillage methods recorded comparable values. Specifically, the bulk density of the surface soil layer (0-15 cm) remained unaffected by the various

TABLE 1
Effect of different methods of establishment on bulk density, soil pH and EC

Treatment	Bulk density (Mg/m^3)	pH	EC (dS/m)
ZT-Drill sown (with wheat residues)	1.36	7.93	0.27
ZT-Drill sown (without residues)	1.35	7.94	0.27
ZT-Dibbling (with wheat residues)	1.36	7.93	0.28
ZT-Dibbling (without residues)	1.35	7.94	0.28
CT (Flat bed)-Drill sown	1.36	8.02	0.28
CT (Flat bed)-Dibbling	1.35	8.03	0.28
CT (Raised bed)-MCP sown	1.34	8.02	0.29
CT (Raised bed) -Dibbling	1.34	8.03	0.29
SEm±	0.007	0.03	0.006
CD at 5%	NS	NS	NS

establishment approaches. However, findings by Jha *et al*. (2012) indicated higher bulk density under zero-till flat sowing (ZTFS), likely due to minimal soil disturbance, which reduces total porosity in comparison to conventional tillage flat sowing (CTFS) and raised bed systems (RBS). Similar observations of elevated bulk density under zero tillage were also reported by Singh *et al*. (2011) and Srivastava *et al*. (2005). Among the conventional tillage treatments, raised bed systems exhibited lower bulk density than flat beds, possibly due to reduced soil compaction and porosity. Ram *et al*. (2010) noted that treatments involving residue retention under zero tillage had lower bulk density than those without residue. Similarly, Devi (2015) found that combining zero tillage with mulching effectively reduced soil bulk density.

Soil pH and EC (dS/m)

The pH of the soil was not significantly affected by the different establishment methods, as shown in Table 1. Conventional tillage (CT) treatments recorded a slightly higher pH (8.03) compared to zero tillage (ZT) treatments (7.94) following crop harvest. The highest pH was observed under CT treatments, while the lowest was found under ZT treatments. Similarly, soil electrical conductivity after crop harvest was not significantly influenced by the various establishment methods. Crop residue retention did not result in any notable differences in EC compared to treatments without residue. The highest EC was recorded in the CT raised bed-MCP/dibbling treatment (0.29), whereas the lowest EC was observed in ZT-drill sown with or without residue (0.27). Both pH and EC were not significantly affected by the establishment methods, which may be attributed to the soil's buffering capacity, offering resistance to changes in pH and EC. Sharma *et al*. (2010) concluded from a decade-long study that soil pH remained stable across different soil management practices, including residue application. Jat (2015) also reported similar findings, indicating that these soil properties were not markedly influenced by the tillage or residue management practices employed. This suggests that the inherent characteristics of the soil played a major role in maintaining its pH and EC stability.

Soil organic carbon (%)

The data on soil organic carbon recorded after crop harvest under different establishment methods revealed that SOC content was significantly affected by the establishment practices (Table 2). Among the various methods, zero tillage (ZT) resulted in higher organic carbon values (0.40-0.41%) compared to conventional tillage (CT), which recorded lower values (0.38-0.39%), , although the differences were not always statistically significant. Notably, ZT-drill/

TABLE 2
Effect of different methods of establishment on SOC, available N, P and K

Treatment	SOC (%)	Available N (kg/ha)	Available P (kg/ha)	Available K (kg/ha)
ZT-Drill sown (with wheat residues)	0.41	129.5	17.9	230.0
ZT-Drill sown (without residues)	0.40	123.8	15.8	218.5
ZT-Dibbling (with wheat residues)	0.41	127.5	17.8	229.4
ZT-Dibbling (without residues)	0.40	122.7	15.7	217.8
CT (Flat bed)-Drill sown	0.38	121.0	14.3	215.8
CT (Flat bed)-Dibbling	0.38	119.5	14.1	217.6
CT (Raised bed)-MCP sown	0.39	123.3	15.5	225.6
CT (Raised bed) -Dibbling	0.39	122.2	15.3	225.3
SEm±	0.006	1.3	0.3	2.3
CD at 5%	0.02	3.9	1.0	6.9

dibbling with wheat residue led to the highest SOC (0.41%), which was significantly greater than that of drill/dibbling in CT-flat beds (0.38%), but was at par with CT-raised bed treatments (0.39%). In conventional tillage, all crop establishment methods-flat bed-drill sown, flat bed-dibbling, raised bed-MCP sown and raised bed-dibbling-showed similar SOC content. Previous studies by Singh *et al*. (2011) reported an 8.4% increase in SOC under zero tillage, while Singh *et al.* (2015) observed a 13.2% increase in SOC under no-till flat beds compared to conventional tillage. Conservation agriculture practices, such as reduced or zero tillage, crop rotation and residue retention, have been shown to promote SOC sequestration, improving soil quality and contributing to food security (Lal, 2004). Zero-tillage, especially when combined with permanent soil cover, facilitates the build-up of SOC in the surface layers (Lal, 2005). Furthermore, no-tillage practices help reduce soil organic matter losses, making it a promising strategy to maintain or even enhance soil carbon and nitrogen stocks (Jat, 2015). These findings align with those of Devi (2015), though the improvement in SOC content under ZT with residue in the present experiment was modest. Conclusive impacts of residue retention on SOC would likely require long-term studies to assess more significant changes.

Available nitrogen (kg/ha)

The available nitrogen in the soil after harvest was significantly influenced by the different crop establishment methods (Table 2). Among the various methods, zero tillage (ZT) resulted in higher available nitrogen (122.7-129.5 kg/ha) compared to conventional tillage (CT) (119.5-123.3 kg/ha), although the differences were not always statistically significant. Notably, ZT-drill/dibbling with wheat residue yielded significantly higher available nitrogen (127.5-129.5 kg/ha) than ZT-drill/dibbling without residue (122.7-123.8 kg/ha) or any of the CT methods. Among zero tillage treatments, the highest available nitrogen was recorded under ZT-drill sown with wheat residue (129.5 kg/ha), while the lowest was found under ZT-dibbling without residue (122.7 kg/ha). In conventional tillage, all methods-flat bed-drill sowing (121.0 kg/ha), flat bed-dibbling (119.5 kg/ha), raised bed-MCP sowing (123.3 kg/ha) and raised bed-dibbling (122.2 kg/ha) showed similar nitrogen levels. The highest available nitrogen across all establishment methods was under ZT-drill sown with wheat residue (129.5 kg/ha), while the lowest was recorded under CT-flat bed-dibbling (119.5 kg/ha). The available nitrogen in the soil after harvest was noticeably higher in methods that included wheat residue, likely due to the nitrogen released from residue decomposition, which contributed additional nitrogen to the soil. This is consistent with findings by Doran (1980), who observed a 20% increase in nitrogen content in surface soil under no-till conditions compared to conventional tillage. Additionally, Singh *et al*. (2015) found that no-till systems, including those with residue, had higher nitrogen availability than conventional tillage systems. The addition of crop residues, such as wheat residue in zero tillage, not only contributes organic matter but also enhances nutrient cycling, leading to improved nitrogen availability. The improved nitrogen status in zero tillage with residue highlights the role of conservation practices in maintaining or enhancing soil fertility over time.

Available phosphorus (kg/ha)

The available phosphorus content in the soil after crop harvest varied significantly among different crop establishment methods (Table 2). Zero tillage (ZT) treatments showed notably higher available phosphorus levels (15.7-17.9 kg/ha) compared to conventional tillage (CT) methods (14.1-15.3 kg/ha), although not all differences were statistically significant. Within ZT, drill sowing or dibbling with wheat residue resulted in the highest phosphorus availability (17.8-17.9 kg/ha), significantly surpassing ZT without residue (15.7-15.8 kg/ha) and all CT methods. The lowest phosphorus availability within ZT was observed under dibbling without residue (15.7 kg/ha). In CT treatments, raised bed sowing (MCP/dibbling) recorded moderately higher phosphorus (15.3-15.5 kg/ha) than flat-bed methods (14.1-14.3 kg/ha). Among all treatments, ZT-drill sowing with wheat residue had the highest available phosphorus (17.9 kg/ha), while the lowest was under CT-flat bed dibbling (14.1 kg/ha). Compared to the initial soil nutrient levels, the phosphorus content after harvest declined across most treatments, except ZT with wheat residue, which showed an improvement. This enrichment is likely attributed to the mineralization of added crop residues that contributed organic phosphorus during decomposition, enhancing the available P pool. Regular application of phosphatic fertilizers, combined with residue retention, may have also supported the higher P availability in ZT treatments.

Singh *et al.* (2015) reported similar findings where available phosphorus levels were higher in no-till systems than in CT. The results align with the concept that conservation agriculture practices, such as residue retention and reduced soil disturbance, enhance nutrient cycling and sustain soil fertility by minimizing phosphorus fixation and losses.

Available potassium (kg/ha)

The post-harvest data on available potassium revealed significant variation across different crop establishment methods (Table 2). Zero tillage (ZT) treatments recorded consistently higher potassium levels (217.8-230.0 kg/ha) compared to conventional tillage (CT) methods (215.8-225.6 kg/ha), although not all differences were statistically significant. Within ZT, drill sowing or dibbling with wheat residue produced the highest potassium availability (229.4-230.0 kg/ha), significantly outperforming all CT-flat bed treatments (215.8-217.6 kg/ha), but statistically comparable to CT-raised bed methods (225.3-225.6 kg/ha). Among ZT practices, the lowest potassium was noted under dibbling without residue (217.8 kg/ha), indicating a positive effect of residue retention on nutrient availability. In CT systems, raised bed methods recorded higher potassium levels than flat-bed methods, suggesting that bed planting could help conserve soil nutrients. The relatively higher potassium levels under ZT with residue can be attributed to mineralization of organic matter, improved soil structure and reduced nutrient leaching due to minimal soil disturbance. Additionally, residue decomposition may release potassium into the soil, enhancing its availability. These observations are supported by Singh *et al.* (2015), who found elevated levels of available potassium under no-till systems. The findings suggest that conservation agriculture practices, especially ZT with residue retention, are effective in maintaining or enhancing soil potassium content, likely due to better nutrient recycling, reduced erosion and improved moisture retention. Kumar *et al.* (2016) also reported that potassium availability increases under such systems, possibly due to enhanced root biomass and nutrient mobilization.

CONCLUSION

The study demonstrated that maize establishment methods under conservation agriculture significantly affected soil fertility. Zero tillage with wheat residue retention proved most effective, improving soil organic carbon and available N, P and K, with little impact on bulk density, pH and EC. These gains support long-term soil health and sustainable productivity in the Indo-Gangetic Plains. With lower water demand and positive effects on soil, maize under conservation agriculture offers a sustainable alternative to the rice–wheat system. Wider adoption of zero tillage and residue retention can drive more resilient, resource-efficient cropping systems.

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