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RESEARCH ARTICLE

Impact of medium-term conservation agriculture on maize (*Zea mays* L.) yield and soil nutrient dynamics in the Terai region of West Bengal

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Abstract

Conservation agriculture (CA) is widely recognized as a sustainable approach to maintaining soil health, improving crop productivity and mitigating environmental challenges associated with conventional farming practices. The study was conducted to evaluate the effects of CA practices on maize yield and soil fertility in the seventh year of medium-term experiment. Seven experimental treatment combinations of varying amounts of crop residue (0, 3 and 5 t ha^{-1}) and fertilizer doses (RDF, 160 kg N ha^{-1} with recommended PK and 200 kg N ha^{-1} with recommended PK) have been applied under zero tillage condition in the present study. Field experiment compared the effects of different treatments to on plant height, cob length, seed index, kernel count, cob weight, grain yield, stover yield and soil nutrient distribution at three soil depths (0-10, 10-20 and 20-40 cm). The treatment with highest residue load and nitrogen, showed the most significant improvements in crop parameters, recording the tallest plants (305.43 cm), longest cobs (18.63 cm), highest seed index (31.10), maximum kernels per row (27), heaviest cobs (25.74 g) and superior grain yield (9.77 t/ha) and stover yield (10.58 t/ha) along with higher soil available nitrogen and potassium content. Although, soil organic carbon (SOC) increased significantly in the surface soil (0-10 cm), particularly in highest residue load but recommended N level (1.03 %), while changes in deeper layers were not statistically significant. CA methods have little effect on soil pH. This reflects the importance of appropriate management of residue and soil nutrients for sustainable crop production.

Keywords: available nitrogen; conservation agriculture; crop residue; soil organic carbon; sustainable crop production

Introduction

Conservation agriculture (CA) has emerged as an environmentally friendly farming approach that advances soil health for sustainable agricultural productivity (1). Conservation agriculture practices, including zero tillage, reduced tillage, residue mulching and crop rotation, have gained a wide recognition for maintaining soil structure, increasing organic carbon content and improving overall soil quality (1, 2). Crop rotations, mulching, cover crops and intercropping systems practiced under CA agriculture additionally improve nutrient availability through enhancing nutrient absorption and minimizing leaching and erosion losses. (3-6). Implementing CA practices can be challenging, but they are crucial in the areas experiencing economic and environmental stress (4). In modern agriculture, techniques such as conventional tillage and inappropriate fertilizer management have resulted in soil quality degradation and reduced crop yield. Long-term conservation tillage and nutrient management approaches have demonstrated the potential to increase soil physical, chemical and biological characteristics and sustain production, making CA a better option than conventional tillage systems (5). In the Terai region of West Bengal, CA practices have the potential to increase production of *Zea mays* L. (maize) by improving soil health, nutrient use efficiency and proper utilization of natural resources through minimum soil disturbance, residue retention and crop diversification (7-10). The soils in this region are typically light-textured and acidic in nature and they are influenced by subtropical climatic conditions. It faces numerous problems like- nutrient leaching and soil erosion (8). Recognizing these challenges, specific nutrient management and the adoption of conservation tillage approaches, such as permanent bed planting and zero tillage with residue retention, are crucial for improving soil quality and crop yields (5). The CA can promote *Zea mays* L. (maize) yield, profitability and soil fertility (11). In addition, *Zea mays* L. (maize)-legume cropping systems under CA practices can improve the physico-chemical and biological properties of soil, as well as *Zea mays* L. (maize) yield (12). Such type of diversification in the farming system help to improve nutrient cycling as well as improve the overall flexibility of the system. Considering the potential of CA to overcome the challenges of farming in the Terai region of West Bengal, this study aims to assess the medium-term effects of CA practices on yield-attributing characteristics of *Zea mays* L. (maize) crop and soil nutrient availability. By investigating these factors, the research seeks to provide insights into the use of CA approaches for enhancing agricultural productivity and environmental sustainability in this region. Understanding the effects of medium-term CA practices is important for promoting sustainable agriculture, ensuring food security and maintaining soil health in the Terai region of West Bengal (10).

Materials and Methods

Experiment details and location

The experiment was conducted during the *rabi* season of 2023-24 at Uttar Banga Krishi Vishwavidyalaya (UBKV), Cooch Behar, West Bengal which was the 7th year of the long-term research trial that started in the year 2017. The area comes under the Terai agro-climatic region. The initial status of the soil has been presented in Table 1. The experiment was laid out under zero tillage (ZT) condition in randomized block design with seven treatments and replicated three times giving total 21 no. of experimental plots, each of 11 cm × 10 cm area. The treatment combinations include varying levels of crop residue load and nutrient dose viz. T_1- R1 + RDF, T_2- R1 + FD-1, T_3- R1 + FD-2, T_4- R2 + RDF, T_5- R2 + FD-1, T_6- R2 + FD-2 and T_7- R0+RDF (where, R0- No Residue incorporation; R1- Residue incorporation- 3t/ha paddy residue; R2- Residue incorporation- 5t/ha paddy residue; RDF-180:75:75 (N: P_2O_5 :K_2O kg/ ha), Fertilizer Dose (FD)-1= 160 kg/ha Nitrogen; FD-2= 200 kg/ha nitrogen and source of chemical fertilizer 10- 26- 26). The incorporation of crop residue has been done before sowing of the crop. The experimental site is located at 26°19'86" N latitude and 89°23'53" E longitude, at an altitude of 43 meters above mean sea level, in Cooch Behar, West Bengal, India. The meteorological data during the crop growing period under this trial is presented in Fig. 1. The mean minimum and mean maximum temperature ranged between 9.9 °C to 23.4 °C and 21.9 °C to 34.1 °C respectively. The maximum and minimum mean relative humidity varied between 68.5 % to 92.6 % and 48.3 % to 63.5 %, respectively.

Analysis of the soil samples

Soil analysis was done for parameters such as pH, soil organic carbon, available nitrogen, available phosphorus and available potassium. Soil samples were collected from the experimental field at depths of 0-10, 10-20 and 20-40 cm using a soil auger. The samples were then air-dried, grinded, passed through a 2 mm sieve and stored for further analysis.

Soil pH was measured using a pH meter with a glass electrode. A soil solution was prepared by mixing soil and deionized water in a 1:2.5 (w/v) ratio (13). The mixture was stirred for 30 minutes and then allowed to settle for 30 minutes. Soil organic carbon was determined using the wet oxidation method taking 0.5 g of ground soil samples (14). The available soil nitrogen was determined by following the Alkaline Permanganate ($KMnO_4$) method (15). For determination of available soil phosphorus, Bray and Kurtz P-1 method has been used, as the soil samples were found to be acidic in nature (16). Lastly available soil potassium content was measured using neutral normal ammonium acetate (NH_4OAc) (17).

Statistical analysis

The data were statistically analyzed as per the method described in "Statistical Methods for Agricultural Workers" (18), using a computer program. Analysis of variance (ANOVA) has been done among the treatments. The appropriate standard error (SE) was calculated and the critical difference (C.D.) at 5 % as well as the coefficient of variation (CV) were determined. The significant differences among the treatments in different parameters have been calculated using Duncan Multiple Range Test (DMRT) in accordance with the ANOVA results. The descriptive statistics of the plant as well as the soil data

Table 1. Initial physico-chemical properties of soil under study

SL. No	Soil parameters		0-10 cm	10-20 cm	20-40 cm
1	Soil pH		5.40	5.9	6.3
2.	Soil Texture	Sand (%)	62.32	65.76	66.18
		Silt (%)	27.23	24.51	25.34
		Clay %)	10.45	9.73	8.48
3.	Bulk Density (g cm^{-3})		1.36	1.38	1.41
4.	Organic Cabon (%)		0.76	0.24	0.36
5.	Available Nitrogen (kg/ha)		123.87	101.92	62.72
6.	Available Phosphorus (kg/ha)		23.76	19.01	28.27
7.	Available Potassium (kg/ha)		89.99	41.51	50.74

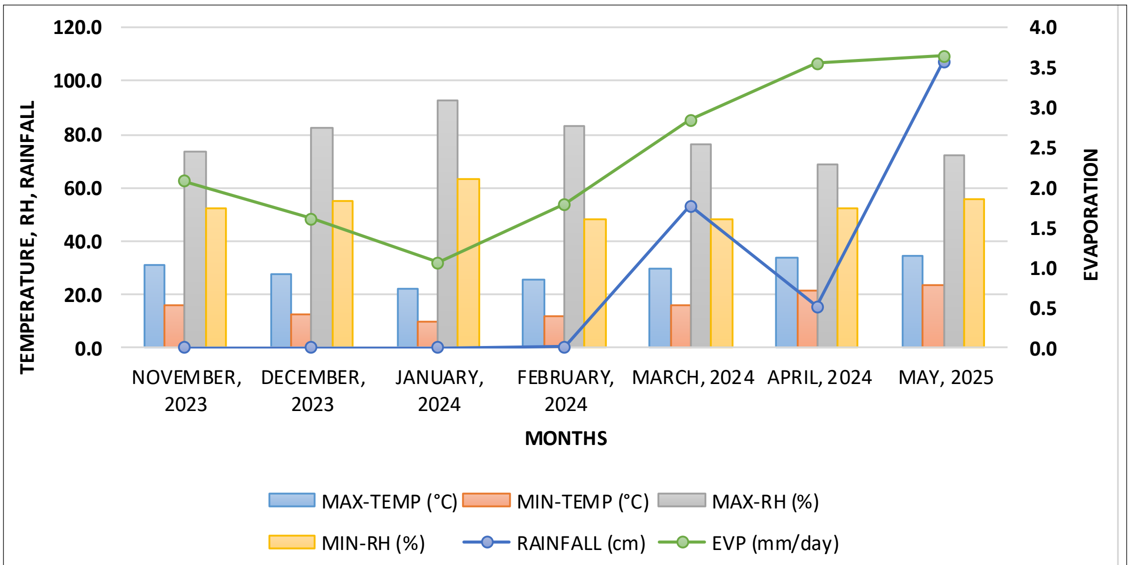

Fig. 1. Meteorological data of the area under study (2023-2024).

were carried out using IBM SPSS statistical software (version 29).

Results

Effects of conservation tillage practice on growth and yield attributing characteristics of *Zea mays* L. (Maize)

Plant height

Significant differences ($p \leq 0.05$) have been found in the plant heights of *Zea mays* L. (maize) in different treatments (Table 2). Plant height was significantly influenced by treatments, with T_6 representing the tallest plants (305.43 cm), which was significantly greater than all other treatments (Table 2).

Cob length

Cob length varied significantly ($p \leq 0.05$) among different treatments. As it can be found from Table 2, the longest cob length was recorded in treatment T_6 (18.63 cm), while it was found to be having lowest value in treatment T_7 at (15.23 cm). In the zero-tillage cultivation system, the recommended dose of fertilizer combined with residue application produced better results.

Seed index

The seed index, representing the weight of 100 seeds, has been found to be varying non-significantly ($p \leq 0.05$) among the treatments. The seed index has been found to varying from 28.60 g to 31.20 g (Table 2).

Rows per cob

All treatments consistently produced 14 rows per cob (Table 2), indicating that this parameter was not significantly influenced by different treatments under study.

Kernels per row

The number of kernels per row has been found to be significantly different in different treatments ($p \leq 0.05$) as it can be found from Table 2. The maximum number of kernels per row was obtained in T_6 treatment and the least number of kernels were obtained in the treatment T_1 and T_7, each showing 20 kernels per row.

Cob weight (g/plant)

The Cob weight showed similar patterns as kernels per row in the Table 2. The highest cob weight in the treatment T_6(25.74 g/plant) and lowest cob weight was recorded in the treatment T_7 (18.54 g/plant)

Grain yield (t/ha)

As observed from the results of the field experiment (Table 2), significant variations ($p \leq 0.05$) in grain yield have been found within different treatments combinations. The highest grain yield has been achieved from treatment T_6 (9.77 t/ha), followed by T_3(9.07 t/ha). The lowest yield was recorded in T_7 (7.04 t/ha) (Fig. 1).

Stover yield (t/ha)

Treatment T_6 recorded the highest stover yield with 10.58 q/ha, while treatment T_7 had the lowest (7.63 t/ha) observed value (Fig. 1). The higher stover production may be due to residue management and appropriate fertilizer application better nutrient cycling, reduced soil nutrients loss and increase nutrient use efficiency of plant. The increased straw yield in conservation agriculture practices provides extra benefits including enhanced soil organic matter for next crops, improved soil health.

Effects of conservation tillage practice on physico-chemical characteristics of soil

Soil pH

The result depicted in Fig. 2 reflects the effect of different treatments on soil pH, in three different soil depths (0-10, 10-20 and 20-40 cm) on 7^{th} year of medium-term conservation agriculture plots. No significant difference has been recorded for soil pH within the different treatments in all the three soil depths. The surface soil (0-10 cm depth) in Treatment T_3had the lowest pH of 4.68, indicating a reduction from the initial soil pH. The least change was seen in the Treatment T_7, as it maintained pH closest to initial soil pH. In case of subsurface soil (10-20 cm depth), the highest pH (6.42) was observed in the treatment T_1 and lowest pH (5.81) was recorded in the treatment T_2(Fig. 2). For deeper soil depth (20-40 cm depth), the highest pH (6.71) was recorded in treatment $T_4$and the lowest pH was observed (6.40) in treatment T_6(Fig. 2). At this soil depth, all the treatments have resulted increase in soil pH than the initial value.

Soil organic carbon

The soil organic carbon (SOC) status of surface soil (0-10 cm depth) significantly changed ($p \leq 0.05$) due to conservation agriculture practices. The highest organic carbon (1.03 %) was recorded in the treatment T_4 and lowest was recorded (0.60 %) in the treatment T_7 (Table 3). No significant variation in the SOC content in the subsurface soil layer (10-20 cm) has been found. In this soil depth. the highest soil organic carbon content (0.63 %) was observed in treatment T_4 and the lowest SOC content was found in treatment T_2 which is recorded to be as low as (0.39 %) . In the deeper soil depths (20-40 cm) also, no statistically significant difference has been found within the treatments. In this soil depth, the highest soil organic carbon content has been recorded in the treatment T_6 (0.34 %) (Table 3) and both T_5 and T_7 treatments have shown minimum measured values of 0.18 % .

Table 2. Effect of medium-term conservation agriculture practice on growth and yield-attributing characteristics of maize

Treatment No	Plant height (cm)	Cob length (cm)	Seed index (g)	Rows per Cob	Kernels per Row	Cob Weight (g/plant)	Grain Yield (t/ha)	Stover Yield (t/ha)
T_1	273.88^{a}	16.86^{b}	30.17	14	20^{a}	18.99^{a}	7.21^{a}	7.81^{a}
T_2	286.33^{bc}	16.45^{b}	29.97	14	23^{b}	22.02^{b}	8.36^{b}	9.06^{b}
T_3	294.08^{cd}	17.77^{c}	30.37	14	25^{d}	23.89^{d}	9.07^{c}	9.83^{c}
T_4	290.67^{bc}	17.44^{c}	30.57	14	24^{c}	22.5^{c}	8.54^{bc}	9.25^{b}
T_5	301.63^{de}	17.46^{c}	31.20	14	24^{c}	22.65^{c}	8.6^{bc}	9.32^{bc}
T_6	305.43^{e}	18.63^{d}	31.10	14	27^{e}	25.74^{e}	9.77^{d}	10.58^{d}
T_7	283^{ab}	15.23^{a}	28.60	14	20^{a}	18.54^{a}	7.04^{a}	7.63^{a}
S.Em. (±)	3.28	0.18	0.61	0.21	0.18	0.30	0.17	0.17
C.D. ($p \leq 0.05$)	10.11	0.54	NS	NS	0.57	0.92	0.54	0.52

Different letters at each column represents significant differences within treatments according to DMRT test (at $p \leq 0.05$)

ns: Non-significant

Table 3. Impact of medium-term conservation agriculture practice on soil organic carbon and available nitrogen in different depth of soil

Treatment No	Treatment details	Organic Cabon (%)			Available Nitrogen (kg/ha)		
		Soil Depth (cm)					
		0-10	10-20	20-40	0-10	10-20	20-40
T_1	R1 + RDF	1.01	0.50	0.28	162.02	90.89	56.44
T_2	R1 + FD-1	0.94	0.39	0.21	189.26	99.18	56.53
T_3	R1 + FD-2	0.71	0.42	0.29	195.47	97.21	54.36
T_4	R2 + RDF	1.03	0.63	0.30	165.09	114.12	59.45
T_5	R2 + FD-1	0.98	0.46	0.18	190.83	127.53	45.79
T_6	R2 + FD-2	0.82	0.47	0.34	200.70	103.57	66.21
T_7	R0+RDF	0.60	0.43	0.18	142.95	85.31	50.61
S.Em. (±)		0.052	0.06	0.05	2.09	5.54	1.48
CD (at $p \leq 0.05$)		0.16	NS	NS	6.44	17.07	4.57
C.V. %		10.44	25.17	38.12	2.04	9.36	4.62

ns: Non-significant

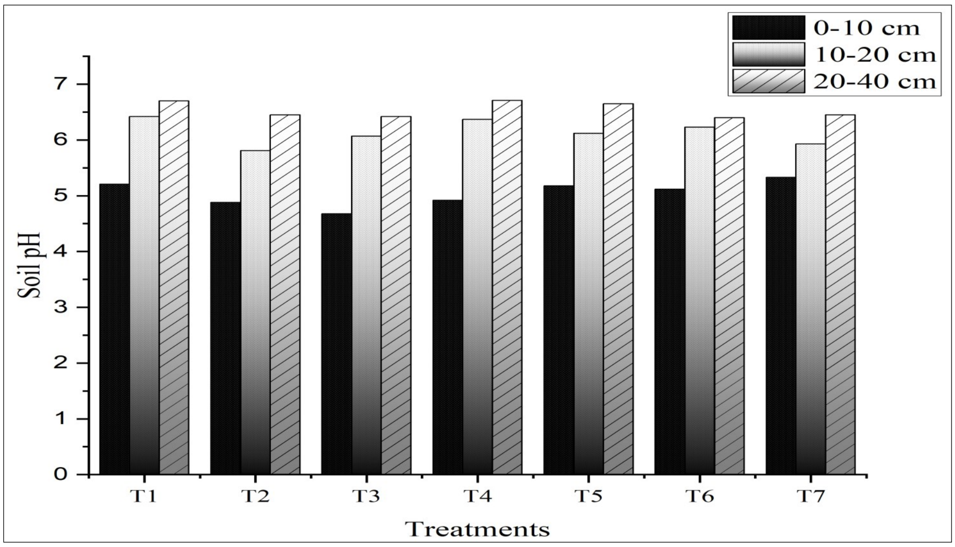

Fig. 2. Impact of medium-term conservation agriculture practice on soil pH at different depths.

Soil available nitrogen

The data on Table 3 reflects that available nitrogen on surface soil (0-10 cm depth) shows significant changes in the aforesaid treatments. The highest soil nitrogen status was recorded (260.70 kg/ha) in treatment T_6 and lowest nitrogen was recorded (142.95 kg/ha) in the treatment T_7(Table 3). In case of the subsurface soil (10-20 cm depth) significant differences were found in soil available nitrogen levels. The highest available nitrogen in soil was recorded (127.53 kg/ha) in the treatment T_5 and lowest nitrogen level was observed (85.31 kg/ha) in the treatment T_7. Statistically significant differences in available nitrogen level were also found in deeper soil depths (20-40 cm). The highest soil available nitrogen was recorded (66.21 kg/ha) in case of the treatment T_6 and lowest value was observed (50.61 kg/ha) in the treatment T_7 (Table 3).

Soil available phosphorus (kg/ha)

Variation in soil available phosphorus level was found within the treatments as presented in the Table 4. In case of the surface soil (0-10 cm depth), available phosphorus (P_2O_5) was recorded statistically significant (48.73 kg/ha) in the treatment T_5 followed by T_1 and T_2 and the lowest value was found (29.63 kg/ha) in T_7. In the subsurface soil (10-20 and 20-40 cm soil depths) availability of phosphorous was found to be reduced with increasing depth in all the treatments. The range of available phosphorus was found, 7.47 to 13.48 kg/ha and 8.27 to 18.78 kg/ha for the soil depth of 10-20 cm and 20-40 cm respectively. Previous study also showed similar results (19).

Soil available potassium (kg/ha)

Significant changes were found in available soil potassium levels in different treatments and it is shown in Table 4. In case of the surface soil (0-10 cm depth), available potassium (K_2O) was

Table 4. Impact of medium-term conservation agriculture practice on soil available phosphorus and potassium in different depth of soil

Treatment No	Treatment details	Available Phosphorus (kg/ha)			Available Potassium (kg/ha)		
		Soil Depth (cm)					
		0-10	10-20	20-40	0-10	10-20	20-40
T_1	R1 + RDF	47.08	8.37	10.56	138.19	53.67	74.67
T_2	R1 + FD-1	46.14	11.43	17.91	134.25	99.64	108.86
T_3	R1 + FD-2	37.61	9.39	16.44	128.66	64.91	79.40
T_4	R2 + RDF	32.01	10.64	18.78	140.62	74.83	87.84
T_5	R2 + FD-1	48.73	10.39	10.95	177.58	73.94	74.81
T_6	R2 + FD-2	34.67	13.48	17.12	184.62	82.17	92.47
T_7	R0+RDF	29.63	7.47	8.27	122.70	49.24	68.97
S. Em. (±)		3.41	1.02	1.37	3.16	3.26	6.43
CD (at $p \leq 0.05$)		10.53	3.12	4.22	9.73	10.03	19.83
C.V. %		15.02	17.3	16.62	3.73	7.92	13.3

ns: Non-significant

recorded the highest (184.62 kg/ha) in the treatment $T_6$and lowest value was found in T_7 122.70 kg/ha (Table 4). In subsurface soil available potassium content ranged from 49.24 to 99.64 kg/ha and in deeper soil (20-40 cm depth) it was found from 74.67 to 108.86 kg/ha.

Discussion

The application of crop residue in combination with fertilizer significantly increased plant height, indicated that effective residue management enhances plant growth by improving soil moisture retention, promoting beneficial microbial activity and increasing nutrient availability in the soil. Similar results were reported by one previous study (20). In the zero-tillage cultivation system, the recommended dose of fertilizer combined with residue application led to greater cob length, likely due to improved soil nutrient availability and enhanced nutrient use efficiency by the crop (21). The uniformity observed in seed index and number of rows per cob suggests that these traits are primarily governed by genetic factors rather than agronomic practices (22). A notable increase in both grain and stover yield was observed in treatment T_6, likely due to the synergistic effects of zero tillage, residue management and appropriate fertilizer application. Zero tillage reduces soil disturbance, conserves moisture, minimizes erosion and maintains soil structure and organic matter, thereby promoting stronger plant growth through better water retention, reduced evaporation and enhanced infiltration. As per one previous report, also reported that zero tillage increases *Zea mays* L. (maize) yield and net income while lowering cultivation costs and labour inputs compared to conventional tillage (23). Furthermore, as residues decompose, they enrich the soil with organic matter and minerals, boosting microbial activity and soil fertility (24). When integrated with zero tillage and residue management, fertilizer application becomes more efficient due to improved soil structure and a more favourable microbial environment that supports better nutrient uptake in *Zea mays* L. (maize) plants. T6 (ZT + R2 + FD-2) outperformed the other treatments as the combination of zero tillage, high residue retention (5 t ha^{-1}) and higher nitrogen (200 kg N ha^{-1}) created optimal soil conditions for crop growth. The high residue improved soil moisture retention and microbial activity, while the additional nitrogen balanced the high carbon input, maintaining a favourable C:N ratio and preventing nitrogen immobilization. This balance enhanced nutrient mineralization and synchronized nutrient release with crop demand, leading to higher yields. In contrast, T4 (ZT + R2 + RDF; 180:75:75 NPK kg ha^{-1}) had high SOC due to residue retention but lower nitrogen, which slowed residue decomposition and limited nutrient availability during crop growth. Therefore, T6 achieved better nutrient cycling and yield performance by combining high residue with adequate nitrogen under zero tillage.

The pH of the surface soil decreased, likely due to the surface application of crop residues, which release organic acids during the decomposition process (25). The effect of different treatments on soil pH varied with depth, with surface soils becoming more acidic while sub-surface layers remained relatively neutral. However, residue management and fertilizer application did not significantly alter the overall soil pH dynamics (26). Soil organic carbon on surface soil improved in residue incorporated treatment, it may be residue retention in soil increases external addition of organic matter in the soil and subsequent increased decomposition that results in more SOC content in the soil (27). The current study clearly indicates that with progressing soil depth, the organic carbon content in the soil decreases. As compared to the top soil, the deeper layers receive less amounts of organic residues that results in less SOC build up in the soil. Some previous studies also suggested that the lower soil depths receive less organic input and more heterogenous status in this region (28, 29). In case of soil available nitrogen, it was observed that application of residue increased both the soil organic carbon and available nitrogen levels compared to no residue application treatments T_7. Incorporation of residue results in increase of Soil organic matter which ultimately enhances soil microbial activities, favouring nitrogen mineralization in soil thus improving the levels of soil available nitrogen (30). Most of the treatments showed that the soil available phosphorus improved as compared to the initial value. The incorporation of chemical fertilizers along with the residue results in lower c/p ratio favouring rapid mineralization of phosphorus in the soil. Along with this production of organic acids during the decomposition of residues, reduces the fixation of phosphorus with soil minerals favouring higher availability in the surface soil.

In case of soil available potassium depth-wise nutrient distribution in different treatment showed typical patterns with higher concentrations in surface soil (0-10 cm), but conservation practices maintained reasonable nutrient levels in subsurface soil, indicating effective nutrient cycling in the soil. Some studies also reported similar findings (31-33). Application of residue and their subsequent decomposition promote organic matter levels in the soil which ultimately improves soil structure and enhances the cation exchange capacity. It is especially very important in high rainfall areas with sandy to sandy-loam soils, as significant potassium loss by run off can happen. Improved soil structure along with increased CEC reduces loss of soil available potassium by holding them on the exchangeable sites and later releasing them in the soil (34).

Conclusion

The integration of crop residue management with fertilizer application under zero-tillage conditions was found to be of great importance to *Zea mays* L. (maize) production and soil health. Apart from boosting parameters of plant growth like plant height and cob length, the system also highly increased the yield of grain and stover. Synergistic combination of zero tillage, residue retention and balanced fertilizer application helped in better conservation of soil moisture and nutrient availability. Residue decomposition also provided organic matter enrichment of the soil, thus improving microbial activity, nutrient cycling and fertility of the soil.

Soil analysis indicated residue incorporation enhanced the organic carbon status of surface soil, available nitrogen, phosphorus and potassium and helped in sustaining nutrient distribution at different soil depths. Even as surface soil pH was slightly lowered through the release of organic acids during residue decomposition, general soil pH dynamics were unaffected. The results emphasize how conservation measures not only maintain soil fertility but also improve efficiency in nutrient utilization, especially in rainfed and sandy loam soils with the risk of nutrient loss.

Hence, implementing zero tillage with residue management and fertilizer application is a resource-effective and sustainable way of enhancing *Zea mays* L. (maize) yield, soil quality and long-term agricultural production. This may help policy makers in the further implementation of sustainable crop and soil management like implementation of site-specific nutrient management through soil testing and advisory services to ensure efficient fertilizer use and maintain soil fertility, integration of CA practices into regional agricultural policies to enhance climate resilience, water-use efficiency and sustainable intensification and facilitating long-term field experiments to monitor the effects of CA on soil health, carbon sequestration and productivity under different cropping systems.

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Authors' contributions

The present work has been carried out in coordinated efforts of all the authors. MS has conducted field trial, did laboratory analysis and contributed to the manuscript writing. SP has contributed to manuscript writing and statistical analysis. AC and AKS have conceptualized the work and did data curation. SS has contributed to statistical analysis and manuscript formatting. All authors have read and approved the final manuscript.

Compliance with ethical standards

Conflict of interest: Authors do not have any conflict of interest to declare.

Ethical issues: None

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