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Long-term impact of conservation agriculture practices on soil pH and electrical conductivity in a *Typic haplustept* under maize-based cropping systems

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Abstract

A decade-long field experiment was conducted and assessed (2018-2019) at the research farm of the Indian Institute of Maize Research, New Delhi, India to evaluate the effects of conservation agriculture practices on soil pH and electrical conductivity (EC) in a *Typic Haplustept* under maize-based cropping systems in a split-plot design. Three tillage and crop establishment methods (permanent beds with residue retention, zero-till flat with residue, and conventional tillage flat with residue) were assigned to main plots, while four cropping systems (maize–wheat–mungbean, maize–chickpea–sesbania, maize–mustard–mungbean, and maize–maize–sesbania) were allocated to subplots. Soil samples were collected from 0–5 and 5–15 cm depths after 10 years and analyzed for pH and EC. Results indicated that tillage practices did not significantly affect soil pH at either depth, though a numerical trend toward lower pH under permanent beds (7.47) compared to conventional tillage (7.67) was observed in the surface layer. Cropping systems also showed non-significant effects on pH, with legume-inclusive systems (MCS: 7.30) trending lower than cereal-dominated rotations (MMS: 7.81). In contrast, tillage significantly influenced EC at both depths, with conventional tillage exhibiting higher EC (0.37 and 0.29 dS m⁻¹) than conservation practices (0.32–0.33 and 0.24–0.25 dS m⁻¹). These findings suggest that long-term conservation agriculture maintains favorable soil chemical properties while preventing salt accumulation in the surface layers of soils.

Keywords: Conservation agriculture, zero tillage, permanent beds, soil pH, electrical conductivity, maize-based systems, *Typic Haplustept*

Introduction

Conservation agriculture (CA) is a sustainable approach that enhances crop productivity while maintaining soil health through minimum tillage, residue retention, and diversified crop rotations (Lal, 2015; Jat *et al.*, 2011) [7, 5]. In the Indo-Gangetic Plains, CA-based maize systems are increasingly recognized as an effective strategy for sustainable land management and resource conservation. Soil pH and electrical conductivity (EC) are important indicators of soil fertility, nutrient availability, microbial activity, and salinity status. In semi-arid alkaline soils, CA practices can help moderate soil pH and minimize salt accumulation. Conventional tillage often accelerates organic matter oxidation and soil disturbance, whereas conservation tillage with residue retention promotes organic matter accumulation and organic acid formation, which may gradually lower soil pH (Naresh *et al.*, 2018) [8]. Tillage also influences salt distribution and EC dynamics in soil. Inclusion of legumes in crop rotations further improves soil chemical properties through biological nitrogen fixation, enhanced soil organic carbon, and efficient nutrient cycling, thereby improving soil buffering capacity and overall soil quality (Rani *et al.*, 2019; Babu *et al.*, 2023) [11, 1]. Despite the growing adoption of CA in South Asian cereal systems, long-term data on soil chemical property dynamics remain limited, particularly for *Typic Haplustepts*—a dominant soil order across the semi-arid tropics. The present study was therefore undertaken with the following objectives:

1. To evaluate the long-term effects of contrasting tillage and crop establishment methods on soil pH and EC at different soil depths.

- To assess the influence of diversified maize-based cropping systems on these soil chemical properties.

Materials and Methods

Experimental Site and Climate

The long-term field experiment was initiated in 2008 at the research farm of the Indian Institute of Maize Research, New Delhi, India, to evaluate the effects of different tillage practices and maize-based cropping systems on soil properties. The experimental site is located in a semi-arid subtropical region receiving approximately 1065 mm annual rainfall, most of which occurs during the monsoon season (July–September). The soil of the experimental field is classified as *Typic Haplustept* (Inceptisol) with sandy loam texture. Initial soil characteristics (0–30 cm depth) at the start of the experiment were: sand 64.3%, silt 13.8%, clay 22.0%, pH 7.80 (1:2 soil:water), bulk density 1.65 Mg m⁻³, soil organic carbon 4.31 g kg⁻¹, available nitrogen 158 kg ha⁻¹, available phosphorus 11.6 kg ha⁻¹, and available potassium 248 kg ha⁻¹.

Experimental Design and Treatments

The experiment was laid out in a split-plot design with three replications. Main plot treatments comprised three tillage and crop establishment (TCE) methods:

- **Permanent Beds (PB):** Zero tillage on permanent raised beds with residue retention
- **Zero-Till Flat (ZT):** Zero tillage on flat land with residue retention
- **Conventional Till Flat (CT):** Conventional tillage on flat land with residue incorporation

Subplot treatments consisted of four diversified maize-based cropping systems

- MWMB: Maize–Wheat–Mungbean
- MCS: Maize–Chickpea–Sesbania (green manure)
- MMuMB: Maize–Mustard–Mungbean
- MMS: Maize–Maize–Sesbania (green manure)

All treatments received recommended doses of fertilizers and irrigation as per standard agronomic practices for the respective crops.

Soil Sampling and Analysis

After completion of 10 cropping cycles (2018–19), soil samples were collected from two depths: 0–5 cm and 5–15 cm. Samples were air-dried, ground, and passed through a 2-mm sieve before analysis. Soil pH was determined in a 1:2 soil: water suspension using a digital pH meter following Jackson (1973) [3]. Electrical conductivity was measured in the same suspension using a conductivity meter.

Statistical Analysis

Data were subjected to analysis of variance (ANOVA) appropriate for split-plot design using standard statistical procedures. Treatment means were compared using the Least Significant Difference (LSD) test at $p = 0.05$ probability level (Gomez K A and Gomez A A, 1984) [2]. Non-significant interactions between tillage and cropping systems allowed for independent interpretation of main effects.

Results

Effect of Tillage Practices on Soil pH

Tillage and crop establishment methods did not significantly

influence soil pH at either the 0–5 cm or 5–15 cm depths after 10 years of continuous management (Table 1). However, a consistent numerical trend was observed across depths, with pH values decreasing in the order: CT-flat > ZT-flat > PB. At the 0–5 cm depth, permanent beds recorded the lowest mean pH (7.47), followed by zero-till flat (7.55) and conventional tillage (7.67). A similar pattern persisted at the 5–15 cm depth, where PB (7.54) remained lower than CT (7.74). Compared to the initial pH of 7.80, all treatments showed a declining trend after a decade, with conservation practices demonstrating greater acidification than conventional tillage.

Effect of Cropping Systems on Soil pH

Cropping system diversification did not produce statistically significant differences in soil pH (Table 2). Nevertheless, notable numerical variations were evident, with legume-inclusive systems generally exhibiting lower pH values than cereal-dominated rotations. The maize–chickpea–sesbania (MCS) system recorded the lowest pH values at both depths (7.30 and 7.38), whereas the maize–maize–sesbania system exhibited the highest pH values (7.81 and 7.90).

Effect of Tillage Practices on Electrical Conductivity

Tillage practices significantly affected soil EC at both sampled depths (Table 3).

At the 0–5 cm depth, conventional tillage recorded significantly higher EC (0.37 dS m⁻¹) compared to both PB (0.32 dS m⁻¹) and ZT-flat (0.33 dS m⁻¹). A similar pattern was observed at the 5–15 cm depth, where CT (0.29 dS m⁻¹) was significantly higher than both PB (0.24 dS m⁻¹) and ZT (0.25 dS m⁻¹).

Effect of Cropping Systems on Electrical Conductivity

Cropping systems did not significantly affect EC at either sampled depth (Table 4).

Numerically, the MCS system exhibited the lowest EC values across both depths, while MMS showed the highest values.

Discussion

Tillage Effects on Soil pH

The numerical decline in pH under conservation tillage practices, though non-significant, aligns with findings of Rattan Lal (2015) [6] and Naresh *et al.* (2018) [8], who reported that residue retention and reduced soil disturbance enhance soil organic matter accumulation and organic acid production, leading to gradual acidification in alkaline soils. Under PB and ZT systems, minimal disturbance and continuous residue addition likely promoted these processes. With initial pH at 7.80, the soil possesses considerable resistance to pH change. The non-significant response may be due to the high buffering capacity of *Typic Haplustepts*. Nevertheless, the observed decline under conservation practices indicates progressive movement toward neutrality.

Cropping System Effects on Soil pH

The comparatively lower pH values under legume-inclusive systems, especially MCS and MWMB, may be attributed to biological nitrogen fixation and decomposition of low C:N ratio residues. Similar observations were reported by Babu *et al.* (2023) [1], who noted improved soil chemical properties under diversified cereal–legume rotations. Legume residues enhance organic carbon dynamics and organic acid formation, thereby contributing to pH moderation (Rakshit *et al.*, 2015) [10]. The nearly 0.5-unit lower pH under MCS compared with MMS may improve micronutrient availability in alkaline soils.

Tillage Effects on Electrical Conductivity

The significantly higher EC under conventional tillage indicates greater salt accumulation in surface layers due to increased evaporation and soil disturbance. Conservation practices with residue retention likely reduced evaporative losses and restricted upward salt movement. Similar reductions in EC under CA systems were also observed by Rani *et al.* (2019) [11] and Jat *et al.* (2013) [4]. Improved aggregation, infiltration, and soil organic matter under PB and ZT systems may further reduce salt build-up. The 13-17% lower EC under conservation practices highlights their importance in mitigating secondary salinization in semi-arid irrigated systems.

Cropping System Effects on Electrical Conductivity

Although cropping systems did not significantly influence EC, lower values under MCS suggest positive effects of legume integration on soil chemical balance and nutrient cycling. Enhanced organic matter turnover and better soil structure under legume-based systems may have contributed to reduced salt accumulation, as also reported by Palm *et al.* (2014) [9] and Babu *et al.* (2023) [1].

Table 1: Long-term effect of tillage and crop establishment methods on soil pH

Treatment	0-5 cm	5-15 cm
PB	7.47	7.54
ZT-flat	7.55	7.61
CT-flat	7.67	7.74
LSD ($p=0.05$)	NS	NS

Table 2: Long-term effect of cropping systems on soil pH

Cropping System	0-5 cm	5-15 cm
MWMB	7.38	7.47
MCS	7.30	7.38
MMuMb	7.75	7.78
MMS	7.81	7.90
LSD ($p=0.05$)	NS	NS

Table 3: Long-term effect of tillage and crop establishment methods on electrical conductivity (dS m^{-1})

Treatment	0-5 cm	5-15 cm
PB	0.32b	0.24b
ZT-flat	0.33b	0.25b
CT-flat	0.37a	0.29a
LSD ($p=0.05$)	0.03	0.03

Means followed by the same letter within a column are not significantly different at $p = 0.05$.

Table 4: Long-term effect of cropping systems on electrical conductivity (dS m^{-1})

Cropping System	0-5 cm	5-15 cm
MWMB	0.33	0.25
MCS	0.31	0.23
MMuMb	0.35	0.28
MMS	0.36	0.28
LSD ($p=0.05$)	NS	NS

Conclusions

After decade long conservation agriculture practices, especially permanent beds and zero tillage with residue retention, improved soil chemical health compared to conventional tillage. Soil pH showed a lower trend under permanent beds (7.47) and maize–chickpea–sesbania rotation (7.30) than conventional tillage (7.67). Electrical conductivity was significantly lower under

conservation practices ($0.32\text{--}0.33 \text{ dS m}^{-1}$) compared to conventional tillage (0.37 dS m^{-1}), indicating reduced salt accumulation. Legume-inclusive rotations further enhanced soil quality in *Typic Haplustepts*.

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