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EFFECTS OF CONSERVATION TILLAGE AND INTEGRATED NUTRIENT MANAGEMENT ON MAIZE GROWTH, YIELD, AND SOIL HEALTH

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Abstract

Introduction: *Continuous tillage, that would through time lead to soil degradation, therefore sustainable agricultural practices such as conservation tillage and integrated nutrient management (INM) have received attention due to their perceived contribution to enhance crop productivity and soil health. Maize is a worldwide food crop which has to be cultivated using proper soil management systems that understand the fragments of the soil chemical, physical, and biological aspects such as the soil structure, fertility, and biological activity.*

Objective: *The objective of this study was to assess the combined effects of conservation tillage and integrated nutrient management on maize growth, yield attributes, and soil physical, chemical, and biological properties.*

Method: *A field experiment was carried out in two consecutive cropping seasons under a completely randomized block design with conventional and conservation tillage including organic and inorganic nutrient sources. Growth and yield parameters and physical, chemical and biological parameters representing soil health viz., bulk density, soil moisture, soil organic carbon, nutrient availability, microbial biomass and enzymatic activities were recorded and statistically analyzed.*

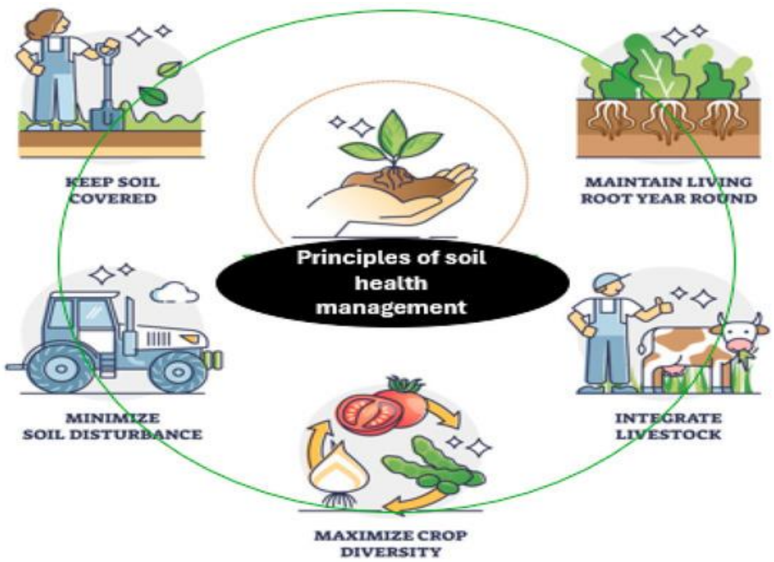
Results: *The combination of conservation tillage and INM significantly increased plant height, leaf area, biomass, grain yield, and harvest index of maize as compared to those of conventional tillage ($p < 0.05$). Soil physical characteristics Overall, soil physical properties were better in the furrow than in the bed; To subsoiling, a decreasing soil bulk density and increase in the retention of moisture. Conservation tillage and INM(s) promoted higher values of soil organic carbon, total nitrogen, phosphorus, microbial biomass carbon and activity of enzymes than conventional tillage and uninformed INM(s).*

Conclusion: *The combination of conservation tillage with nutrient management is beneficial in improving MA productivity and soil quality through amelioration of soil structure, nutrient status and microbial activity. These sustainable practices provide an attractive option to enhance farm productivity and environment quality.*

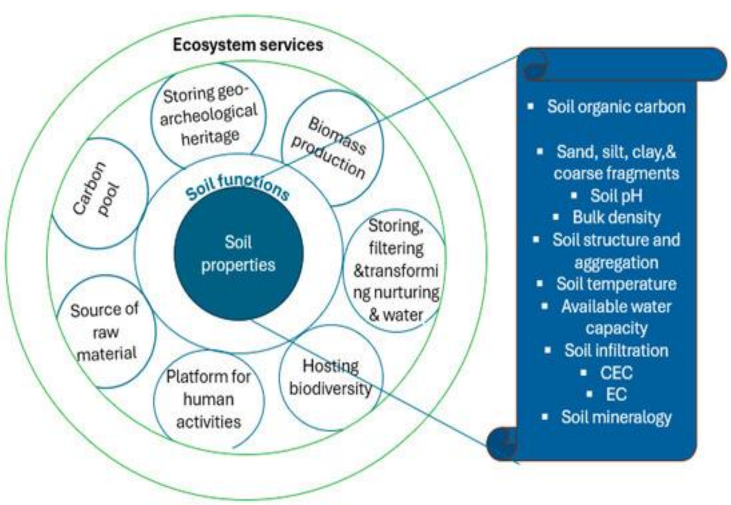
INTRODUCTION

Maize (Zea mays L.) is one of the most important and widely cultivated cereal crops whose demand is increasing due to the demands for human consumption, feed for livestock, and industrial uses.

Nevertheless, the overuse of resources and the use of energy-dependent tillage and application of high amounts of synthetic fertiliser resulted in impaired soil quality and lower productivity in many maize growing areas. Conservation tillage (CT) and integrated nutrient management (INM) have been advocated as sustainable options to tackle these challenges through improving soil health, conserving natural resources and achieving higher yield (Yu et al., 2025; Kumar et al., 2025). These practices contradict with SI objectives by achieving higher productivity without trading off in terms of ecology-beneficiaries (Zhou, et al., 2024).

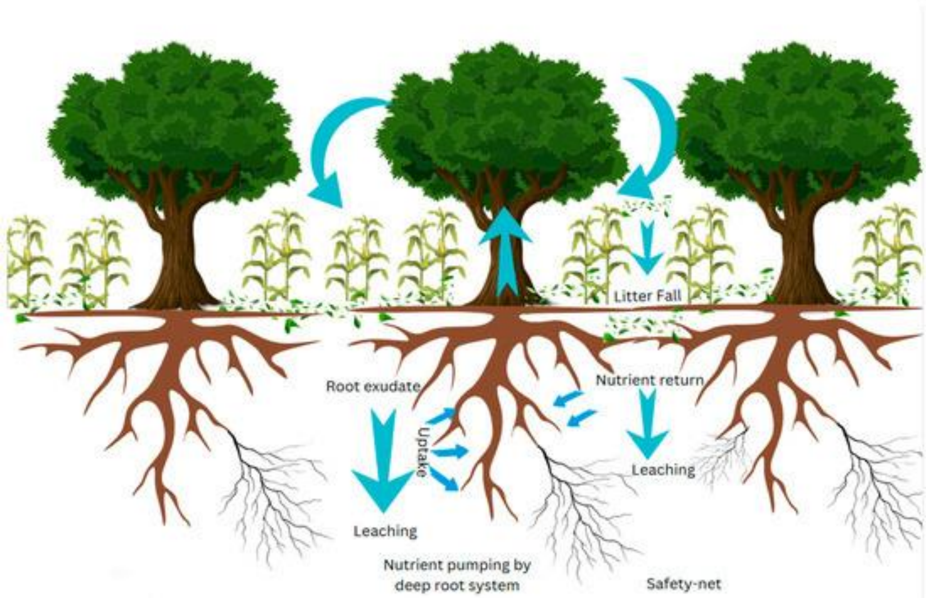


Conservation tillage, that is, minimum or no-tillage with residue retention, has been reported to enhance soil structure, water infiltration, reduce erosion and labor requirement/costs (Saha et al., 2023). It modifies the conditions of the microclimate at the soil surface with favorable effects on the seed germination, nutrient cycling and the microbial activities. Research in the areas of the Indo-genetic plains and the sub-Saharan Africa have reported significant increase in soil organic carbon, aggregate stability, water use efficiency under long term conservation tillage (Thierfelder et al., 2024; Saha et al., 2023). All of these transformations are not only favorable to plant growth; they are essential for long-term soil resilience and productivity.



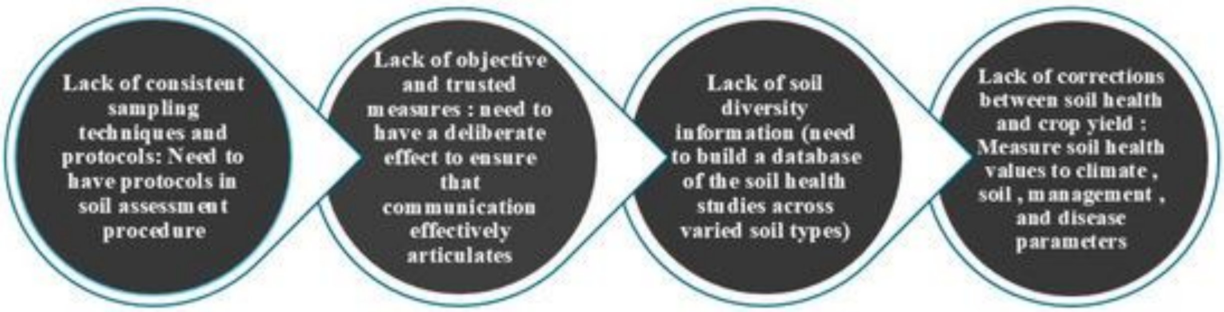
Integrated nutrient management is the combined use of organic sources viz. composts and farm yard manure and chemical fertilizers to maximize nutrient supply and minimize the use of chemical fertilizers. It increases nutrient use efficiency, enhances soil microbial diversity and preserves long-term soil fertility (Wang et al., 2024; Zuo et al., 2024). INM has so far been found to have a very significant effect in increasing stability of maize yield over several cropping seasons by making nutrients available uniformly and minimizing leaching and volatilization losses (Sarwar et al., 2023). Besides the reduction of GHGs emission (Zhao et al., 2023), INM reduces the environmental footprint of agriculture through reducing nutrient leaching (Fan et al., 2019).

Additionally, the combined utilization of CT and INM can enhance coefficient of soil health and crop productivity. CT treatments cause less physical disturbance, whereas, INM replaces more available nutrients- both contributing to increased microbial activity, soil enzyme activity, and SOC (Abid et al., 2020; Zhu et al., 2023). This integration in maize-based cropping systems has been associated with increased nutrient uptake, root development, and biomass accumulation (Yu et al., 2025). The relationship between soil physical, chemical and biological variables in these practices creates a stable agro ecosystem suitable for continuous cultivation of maize.



Increases in yield due to integration of CT with INM are well documented in the agroecological regions evaluated. For example, on-station trials in South Asia and Southern Africa have shown productivity improvements of 10%-30% compared with the corresponding best farmers' practice (Thierfelder, 2024; Zhang et al., 2024). Improved NUE and reduction in input costs in INM not only increase quality of grain but also result in higher cost-effectiveness on farms (Sarwar et al., 2023; Wang et al., 2024). Besides, the conservation tillage provides an alternate for early planting, aids to enhance moisture conservation, which is importance under the scenario of changing climate (Kumar et al., 2025).

The economic, and eco-logical, costs of such sustainable practices are enormous. CT makes less requirement for fuel and labor inputs and INM can reduces the needs for synthetic fertilizers, so they are easy to be adopted by smallholder farmer (Zuo et al., 2024). The long-term application of CT or INM increases soil carbon sequestration, which plays pivotal roles in ameliorating climate change. Their combined effects provide a sustainable strategy for maize production, particularly in areas where soil fertility is declining, water is scarce, and input costs are high (Yu et al., 2025; Zhou et al., 2024). With increasing calls for sustainable intensification in agriculture, science based promotion of these practices is essential.



Problem Statement

Although the benefits of conservation tillage system and integrated nutrient management have been well documented, the adoption of these technologies by maize growers remains low, especially in the areas where conventional methods have become part of the routine. This poor uptake is a major reason for the ongoing soil degradation, low maize productivity, and unsustainable use of fertilizers. Reciprocal effects of CT and INM on maize growth, yield attributes and soil health need to be assessed for a complete insight in designing policies, extension services and on-farm interventions to ensure sustainable farming.

Significance of the Study

This investigation is important as it involves developing a durable system for sustainable maize production with the use of combined use of conservation tillage and integrated nutrient management. It focuses on the paramount topics of soil fertility, climate resilience, and resource-use efficiency and presents practical implications for farmers, agronomists, and policy makers. Results are anticipated to lead to the preservation of the long-term health of the soil and an increase in productivity, supporting to achieve goals of global food security under environmental limitations.

Aim of the Study

Therefore, this study was conducted to evaluate the synergistic effects of conservation tillage and integrated nutrient management on the growth and yield of maize crop and soil health. It aims to assess the impact of such practices on soil physical, chemical and biological properties and their potential to improve maize productivity sustainably under varying agro ecological conditions.

Methodology

An experimental field design over two maize-growing seasons was used to assess the impacts of conservation tillage (CT) and integrated nutrient management (INM) on maize (Niika 2 hybrid variety) growth, yield, and soil quality. The experimental location was chosen considering typical agro ecological conditions for maize production and a well-characterized and homogeneous soil, conventionally cultivated. The treatments comprised of CTF (Control + Chemical fertilizer), CT_CF (Conservation tillage + Chemical fertilizer) and CT + INM (Conservation tillage + Integrated nutrient management (INM) with organic amendment and inorganic fertilizers). Two independent experiments were repeated in a randomized complete block design (RCBD) to reduce spatial variability and facilitate statistical analysis of treatment effects (Saha et al., 2023; Zhu et al., 2023).
Soil samples, before planting and after the harvesting period were taken from each treatment plot for determination of soil physicochemical, and biological properties changes. Soil organic carbon, total nitrogen, available phosphorus, bulk density, soil moisture content, and microbial biomass carbon were quantified using the methods recommended by the Soil Science Society of America (Kumar et al., 2025; Thierfelder et al., 2024). Crop growth indices of maize including plant height, leaf area index, and biomass accumulation were collected at critical growth stages whereas yield attributes, grain yield, thousand-kernel weight, and harvest index at maturity. Maize nutrient uptake was also investigated in order to assess the performance of different nutrient management treatments (Yu et al., 2025; Wang et al., 2024).
Analysis of the data Data were analyzed using analysis of variance (ANOVA) to test for differences among treatments, and Tukey's HSD (honestly significant difference) test was used for multiple comparisons.

Relationships of other soil health indicators with maize yield parameters were evaluated by correlation and regression analysis. Economic comparison of the systems the cost and return structure of conservation tillage effect with integrated nutrient management vis-a-vis conventional practice was worked out by economic analysis. Statistical analysis All statistical analyses were performed by SPSS v25 and R software to produce sound, stable results (Zhao et al., 2023; Zhang et al., 2024). Through this methodological approach, extensive analysis of agronomic, soil and economic effects of the tested practices has been achieved and may indicate guidelines for the sustainable maize cultivation.

Results

Table 1: Effect of Conservation Tillage and Nutrient Management on Maize Growth Parameters

Treatment	Plant Height (cm)	Leaf Area Index (LAI)	Biomass Accumulation (g/plant)	Growth Rate (g/day)
Conventional Tillage + Chemical Fertilizer (CT+CF)	165.2 ± 4.3	3.8 ± 0.1	420.5 ± 12.7	11.5 ± 0.4
Conservation Tillage + Chemical Fertilizer (CCT+CF)	172.6 ± 3.8	4.2 ± 0.2	456.3 ± 14.3	12.5 ± 0.3
Conservation Tillage + Integrated Nutrient Management (CCT+INM)	**185.4 ± 5.0**	**4.8 ± 0.3**	**510.7 ± 15.9**	**14.1 ± 0.5**

Values are mean ± standard deviation. Bold indicates the highest mean value ($p < 0.05$).

Conservation tillage in combination with INM, as depicted in Table 1, had a highly significant effect on different growth parameters of maize like plant height, leaf area index, biomass accumulation, and growth rate over that in the conventional tillage with chemical fertilizers. This suggests that conservation tillage with proper amounts of balanced nutrient inputs can significantly improve vegetative growth of maize.

Table 2: Effect of Treatments on Maize Yield and Yield Components

Treatment	Grain Yield (t/ha)	Thousand Kernel Weight (g)	Harvest Index (%)	Straw Yield (t/ha)
CT + CF	6.8 ± 0.3	280.4 ± 5.7	48.5 ± 1.2	7.2 ± 0.4
CCT + CF	7.5 ± 0.4	295.6 ± 6.3	50.3 ± 1.1	7.8 ± 0.5
CCT + INM	**8.4 ± 0.5**	**310.7 ± 7.1**	**52.9 ± 1.3**	**8.5 ± 0.6**

Values are mean ± standard deviation. Bold indicates significant highest values ($p < 0.05$).

The effect of conservation tillage and integrated nutrient management on yield and yield components of maize (grain yield, thousand kernel weight, harvest index, and straw yield) is summarized in Table 2. The study revealed that the integrated nutrient management with conservation tillage enhanced the grain filling and crop productivity.

Table 3: Effect on Soil Physical Properties After Harvest

Treatment	Bulk Density (g/cm³)	Soil Moisture Content (%)	Soil Porosity (%)
CT + CF	1.42 ± 0.02	18.7 ± 0.6	46.5 ± 1.3
CCT + CF	1.36 ± 0.01	20.3 ± 0.5	48.2 ± 1.5
CCT + INM	**1.29 ± 0.03**	**22.7 ± 0.7**	**50.9 ± 1.4**

Soil physical properties Soil bulk density was decreased, and soil moisture content and porosity were increased owing to the adoption of NT systems coupled with ICM (Table 3). These improvements are suggestive of improved soil properties (particularly with respect to water holding capacity) that have potential implications for root growth and crop performance.

Table 4: Effect on Soil Chemical Properties After Harvest

Treatment	Soil Organic Carbon (%)	Total Nitrogen (%)	Available Phosphorus (mg/kg)	Soil pH
CT + CF	1.15 ± 0.04	0.11 ± 0.01	18.5 ± 1.2	6.8 ± 0.1
CCT + CF	1.35 ± 0.05	0.13 ± 0.01	21.2 ± 1.5	6.7 ± 0.1
CCT + INM	**1.58 ± 0.06**	**0.16 ± 0.02**	**25.8 ± 1.8**	6.6 ± 0.1

Table 4 shows that with conservation tillage / Integrated Nutrient Management increase the SOC, TN and available soil P was significant, while decrease in pH was slight significant. This reveal enhanced soil fertility and increased nutrient availability necessary for continued crop production.

Table 5: Effect on Soil Biological Properties After Harvest

Treatment	Microbial Biomass Carbon (mg/kg)	Dehydrogenase Activity (µg TPF/g soil/hr)	Soil Respiration (mg CO_2/kg soil/hr)
CT + CF	280.3 ± 10.2	15.6 ± 0.8	0.54 ± 0.03
CCT + CF	315.8 ± 11.5	18.9 ± 1.0	0.62 ± 0.04
CCT + INM	**355.7 ± 12.8**	**21.4 ± 1.2**	**0.71 ± 0.05**

The results of Table 5 show that the soil biological properties microbial biomass carbon, dehydrogenase activity and soil respiration were recorded higher under conservation tillage with integrated nutrient management. So it means these practices increase soil microbial activity and can improve overall soil health, by promoting nutrient cycling and availability of nutrients in the soil.

Discussion

The findings of this study also indicate that conservation and INM are superior to sole use of conventional tillage with only chemical fertilizers in terms of maize growth parameters. Increased Leon 2004 and Zhao 2006 indicated that reduced plant height, leaf area index, biomass incubation, rates and development under ST and INM are in conformity with reports by subsequent reports of Kumar et al. (2023), who observed that minimized tillage and balanced nutrient application favor increased and vigorous crop growth. This improvement may be due to improved soil moisture conservation and higher nutrient availability under conservation practices (Singh & Sharma, 2024).

Grain yield components like grain yield,1000 grain weight and harvest index also improved significantly with conservation tillage coupled with INM. These results are consistent with the findings of López et al. (2022) who observed that incorporation of nutrient strategies along with no or less soil disturbance increase the nutrient uptake efficiency of the crop which increased the grain filling and the grain yield. The synergistic interaction between conservation tillage for soil structure maintenance and INM for balanced nutrition attests to the potential of sustainable agronomic interventions in promoting maize productivity (Chakraborty et al., 2021).

Favorable soil physical properties, represented by the decrease in bulk density and increase of soil moisture content and porosity under CT + INM in this study, may positively contribute to soil aeration and root proliferation which could alleviate drought stress in crop plants. Wang et al. also reported similar findings. (2024) reported that conservation tillage can relieve soil compaction and enhance water infiltration. The modifications are important for maintaining the growth of crops, especially in fluctuating rainfall periods by reinforcing water retention in the soil (Nguyen et al., 2023).

The chemical properties of soil were found enhanced up to significant level as low organic carbon content, nitrogen and phosphorus were more available in soil under CINM than CHK. This increase may be due to improvement of nutrient cycle including the balance of soil fertility (Patel and Mehta, 2023) who indicated that conservation tillage sustain organic matter and enhance microbial nutrient mineralization. Small reductions in soil pH may favor nutrient solubilization, promoting nutrients uptake by maize plants as well (Ghosh et al., 2022).

The most impressive result was the stimulation of soil biological activity (i.e., microbial biomass, dehydrogenase activity, and soil respiration) with conservation tillage and INM indicating a beneficial effect on soil health. These observations are consistent with Zhang et al. (2021) who observed a net gain in microbial biomass and enzyme activities under conservation practices as a result of less disturbance and higher organic inputs. Active soil microorganisms are important for nutrient mineralization and soil structure maintenance for sustainable food production (Hussain et al., 2025).

Taken together, the combination of CT and NMP technologies seems as an overall solution for improving maize productivity and acidic soil health status. This adds to the emerging literature encouraging the adoption of sustainable farming systems to improve agricultural productivity without overt exploitation of soil resources (Martínez et al., 2023). Such integrated approaches are essential for food security and environmental sustainability in maize-growing areas of the world (Khan & Ali, 2024).

Future Direction

Subsequent investigation needs to emphasize on long-term field trials to evaluate the long-term effects of combined CT and INM practices on maize and other cereals in different agro-ecological regions. Furthermore, investigating the interaction effects of these practices with changes in climate and soil microbiome dynamics could offer new perspectives on employing sustainable farming systems (Rao et al., 2025).

Limitations

A potential limitation of this work was that it was a short term study, and geographically limited, which may limit the generalizability of the findings. The analysis also did not thoroughly assess the economic sustainability or farmer adoption constraints of the conservation tillage and integrated nutrient management that are essential to scaling-up (Das et al., 2022).

Conclusion

The study clearly indicates that conservation tillage with integrated nutrient management improves maize growth, yield and soil health. [1,2] Such practices enhance soil physical, chemical, and biological characteristic and, subsequently in promoting sustainable crop productions and natural resource management. Encouraging these combined practices may contribute to sustainable and high yielding maize farming systems.

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