

Interactive Effects of Tillage Practices and Nitrogen Levels on Maize Growth, Yield, Nitrogen Use Efficiency, and Soil Properties.

Abstract:

The impact of soil tillage and nitrogen (N) fertilization on maize (*Zea mays* L.) productivity, growth, yield, N use efficiency, and soil quality is not comprehensively or uniformly available across environments. To determine the individual and interactive effects of tillage and nitrogen application rates on the performance of maize and selected soil properties, a field experiment was conducted at the University of Agriculture Faisalabad, Sub-Campus Depalpur, Okara, Pakistan, during the 2023-24 growing season of maize using a split-plot design with three replications. The tillages (zero tillage (ZT) and conventional tillage (CT)) and three levels of nitrogen (0% (control), 75% and 100% of the recommended dose (0, 170, and 227 kg N ha⁻¹), respectively) were set as main plots and subplots. Plant height, plant dry biomass, grain yield, 100-kernel weight, nitrogen use efficiency (NUE), and soil organic matter (SOM) were measured. Nitrogen level significantly influenced all six traits, with tillage significantly influencing plant height, grain yield, 100-kernel weight, and soil organic matter, but not plant dry biomass or NUE. Conventional tillage resulted in taller plants, higher dry biomass at higher nitrogen rates, and higher grain yield; zero tillage resulted in heavier kernels and higher soil organic matter. Both tillage regimes produced grain yields ranging from approximately 3,000 to more than 10,100 kg ha⁻¹, with the highest NUE occurring at 75% N and the lowest occurring at 100% N. The results suggest that nitrogen supply was the major factor influencing maize productivity, and a trade-off occurred between the above-ground yield and soil organic matter conservation due to the tillage effect. It is recommended that 75% of the recommended nitrogen dose is used under zero tillage as a resource-efficient and soil-conserving management approach for maize production.

Keywords: Maize, zero tillage, conventional tillage, nitrogen use efficiency, soil organic matter, grain yield

Introduction

Throughout the world, maize (*Zea mays* L.) is considered one of the most important cereal crops and plays a major role in industrial production, food, and feed (Hameed et al., 2026). Agronomic management practices, particularly soil tillage and nitrogen (N) fertilization, greatly affect its productivity. Enhancing these agronomic practices is vital for improving crop production rates and growth while preserving soil quality and efficient use of applied nutrients(Zhai et al., 2019).

One important component for maize production is tillage, because it affects seedbed conditions, water availability, soil structure, residue incorporation, nutrient availability, and aeration (Simić et al., 2020). Preexisting conventional tillage practices generally involve high soil disturbance, which provides optimum conditions for crop setting and growth, and can also play a part in soil conservation and bring positive changes in soil physical and chemical properties (Angon et al., 2023). However, soil conditions gravely affect the response of maize to various tillage practices; along with this, environmental conditions and the availability of other production inputs also play a part in this response. So there is an extensive need for the evaluation of tillage practices under different field conditions to identify optimum management strategies for maize production (Cheţan et al., 2022).

On the other hand, one more important factor influencing maize growth and production rate is nitrogen (N) (Mncube et al., 2024). Maize requires greater N amounts for proper growth and development, specifically in the vegetative growth period, reproductive development, biomass accumulation, photosynthetic activity, and grain development, which makes its optimum availability vital (Kafle et al., 2023). Inadequate N availability can limit crop development and ultimately yield parameters, while optimum N management can enhance nitrogen use efficiency and yield amounts (Govindasamy et al., 2023). But this positive effect is limited; above that limit value, N has can have negative effects, causing high production costs and nutrient losses, so that is why we need to identify an optimum value of N which supports crop growth and production while keeping production costs limited; this will aid in achieving maximum productivity of maize (Brodowska et al., 2022).

The impacts of N fertilization and tillage are not always independent (Zhang et al., 2022). Tillage can alter soil structure, which can further disturb root development and nutrient availability, having a major influence on fertilizer application and use (Tsyliuryk et al., 2025), while the availability of N to the crop has a grave part in the crop's ability to respond to changes in physical conditions of soil caused by tillage practices (Frene et al., 2024). Therefore, there is a need to evaluate N levels and tillage practices in different systems and values to create a better understanding of their combined and individual effect, and to identify the best possible way to get maximum positive combined effects. This information will greatly help in developing an efficient maize cultivation system and in recognizing optimum management practices that enhance crop productivity, supporting best possible nutrient use and preserving soil quality.

Although many studies have examined N management and tillage practices separately, their combined effects are still not well documented, and they may differ across agro-environments. Furthermore, evaluation of the combined effects of both N and tillage is one thing that is documented very little and needs more research to be done for better understanding. To evaluate the effects of zero and conventional tillage combined with different N levels, we conducted a field experiment to observe maize crop growth, nitrogen use efficiency, yield-related traits, and selected soil properties under the climatic and soil conditions of Sub-Campus Depalpur, Okara, University of Agriculture Faisalabad. The experiment was conducted to study

the main effects of N levels and tillage and their interaction on maize crop growth and soil characteristics.

2. Materials and Methods

2.1 Experimental Site and Design

Under the climatic conditions of the University of Agriculture Faisalabad, Sub-Campus Depalpur, Okara, Pakistan, this experiment was conducted during the maize growing season of 2023–24. The effects of nitrogen (N) fertilization and tillage practices on maize growth, yield-related traits, nitrogen use efficiency, and selected soil properties were the main topics of this experiment

A split-plot design was used for this experiment, as it is best suited when we have to study soil-related properties and tillage, with 3 replications. The main plot was assigned tillage practices, while in the equivalent subplots, nitrogen levels were allocated. Two tillage practices and three nitrogen levels were used as experimental treatments; these treatments combined resulted in a 2×3 factorial arrangement

2.2 Experimental Treatments

2.2.1 Tillage Treatments

As mentioned above, 2 tillage practices were included in the study, which are given below

T₁: Zero tillage (ZT): no conventional tillage operation was performed before sowing; the field was maintained with a zero-tillage cropping system

T₂: Conventional tillage (CT): conventional tillage operations used for the maize crop were performed before sowing

2.2.2 Nitrogen Application Treatments

Three nitrogen levels were evaluated and placed in the subplot. These three treatments were designed according to recommended nitrogen doses in maize; these treatments are given below

N₁: Control (No nitrogen application).

N₂: 75% of the recommended N value (170 kg N ha^{-1}).

N₃: 100% of the recommended N (227 kg N ha^{-1}).

Using these treatments allows the evaluation of the response of the maize crop at different ranges of nitrogen application and no nitrogen applications

2.2.3 Combined treatments

Complete list with code of treatments is given in Table 1

105 Table 1 list of treatments

Treatment	Tillage practice	Nitrogen level
ZT ₁	Zero tillage	N ₁ : Control
ZT ₂	Zero tillage	N ₂ : 75% of recommended N
ZT ₃	Zero tillage	N ₃ : 100% of recommended N
CT ₁	Conventional tillage	N ₁ : Control
CT ₂	Conventional tillage	N ₂ : 75% recommended N
CT ₃	Conventional tillage	N ₃ : 100% recommended N

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107 Experimental plot is shown in figure 1

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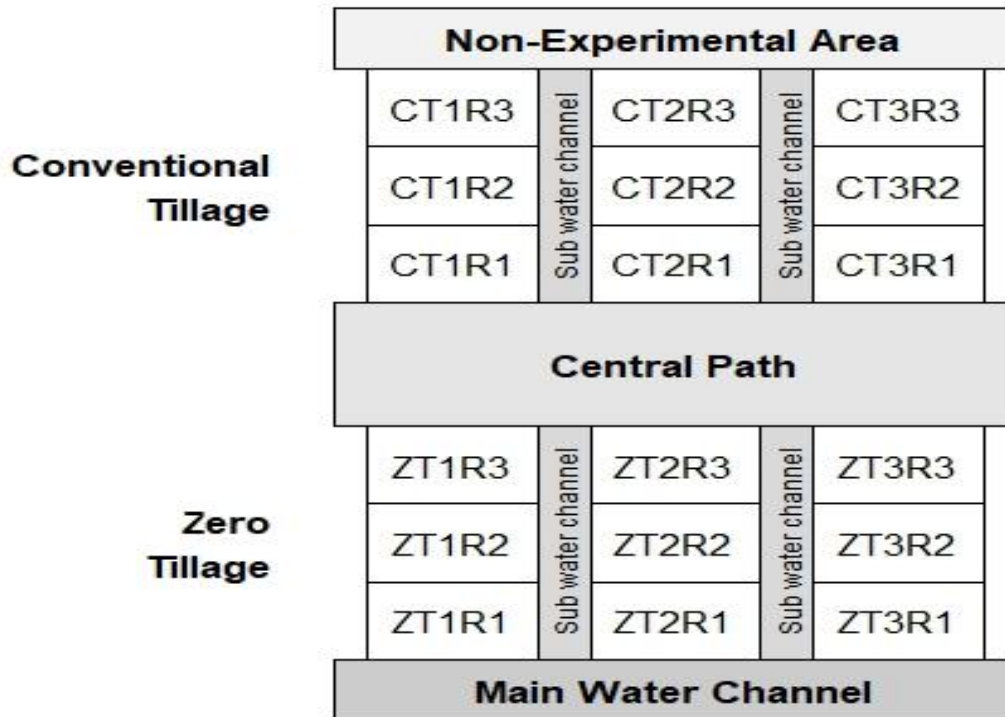


Figure 1 Experimental plot

2.3 Crop Establishment and Field Management

On 23rd of August 2023, the maize crop was sown in the experimental field of the University of Agriculture Faisalabad, Sub-Campus Depalpur, Okara. The crop was established without conventional soil preparation under zero-tillage treatment. On the other hand, the main plot was assigned to conventional tillage, was subjected to the recommended tillage treatment for maize. Nitrogen was also assigned according to the experimental design; 0%, 75% (170 kg N ha⁻¹) and 100% (227 kg N ha⁻¹) of the recommended value were applied. All the other management practices for the crop were kept uniform across the treatments to reduce variation attributable to factors other than nitrogen levels and tillage.

2.4 Soil Sampling and Analysis

Soil samples were taken according to the method described by Champion and Pratt (1978) before crop establishment. After collection, the soil samples were labelled appropriately and examined for selected soil chemical and physical properties. For the current study, as indicators, soil organic matter (SOM), pH, electrical conductivity (EC), total nitrogen, and other soil characteristics were evaluated as indicators of soil condition under the different tillage and nitrogen treatments; their recordings are mentioned in Table 2

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133 Table 2 Physio-Chemical analysis of soil from experiment site

Characteristics	Unit	Value
EC	dS/m	7.9
pH	N/A	2.12
Total nitrogen	%	0.13
Organic matter	%	0.71
Available Phosphorus	mg/kg	7.6
Extractable Potassium	mg/kg	145

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135 **2.5 Data Collection**

136 Data recording for selected growth, yield, biomass, nitrogen use efficiency, and soil parameters
 137 was done according to the recommended procedure. The analysis focused on plant dry biomass,
 138 grain yield, soil organic matter, 100-kernel weight, plant height, and nitrogen use efficiency,
 139 based on the objectives of this experiment

140 **2.5.1 Growth and Biomass-related Traits**141 **2.5.1.1 Plant Height**

142 At maturity, plant height was measured to get the best possible recordings; arandom selection of
 143 4 plants was done in each experimental unit to get the best unbiased values. A measuring scale
 144 was used to take the recordings;the height of each plant was taken from the surface to the tip of
 145 the main stem, and measurements were taken in centimeters (cm). After the recordings, mean
 146 values of the 4 recorded values were calculated; these mean valueswere subjected to statistical
 147 analysis

148 **2.5.1.2 Plant Dry Biomass**

149 Plant dry biomass was calculated after harvestingthe crop from the allocated sampling area of
 150 each experimental unit at maturity. The harvested material was subjected to drying under
 151 sunlight. Drying was done until a constant weight value was obtained; for weight recordings, a
 152 weighing balance was used. These recorded values were then expressed on the appropriate area
 153 basis.

2.5.2 Yield-Related Traits

2.5.2.1 100-Kernel Weight

After harvesting, 100-kernel weight was determined. From each experimental unit, 100 kernels were counted and then weighed using an electronic balance. The recordings were taken in grams and were then subjected to statistical analysis.

2.5.2.2 Grain Yield

Grain yield data were recorded at physiological maturity, after harvesting the crop from each experimental unit. The harvested cobs were husked, dried, and then independently threshed using a micro-thresher. After threshing, the obtained grains were weighed, and yield of grain was calculated per hectare and expressed in kilograms per hectare (kg ha^{-1})

2.5.3 Nitrogen Use Efficiency (NUE)

The NUE value was also determined separately for each experimental unit using the corresponding grain yield and nitrogen treatment. It was calculated in relation to nitrogen application and grain yield in accordance with the standard calculation procedures used in the original experimental protocol

2.5.4 Soil Organic Matter (SOM)

To calculate SOM, the collected soil samples for soil analysis were used; the calculations were made using the standard laboratory procedure followed in the original experimental protocol. The recorded values were used to evaluate differences in soil organic matter caused by different tillage and nitrogen treatments.

2.6 Statistical Analysis

Analysis of variance (ANOVA) appropriate for the split-plot design was used for statistical analysis of the collected data; according to the experimental design, tillage was taken as the main factor and N level as the subplot factor. The effects of tillage, N level, and their interaction were evaluated using the suitable main and subplot error terms for the split-plot design.

At the 5% probability level ($p \leq 0.05$), statistical significance was measured. For treatments where effects were significant, comparison of treatment means was done using a suitable post-hoc mean comparison method. The statistical methods were based on the principles defined by Steel et al. (1997).

4. Results

ANOVA was performed separately for the main effect (tillage) and subplot effect (nitrogen) as sources of variation; results showed that nitrogen level was a highly significant source of variation for all six traits under study, and the results are shown in Table 3. Results also showed that tillage significantly affected grain yield, soil organic matter, plant height, and 100-kernel weight, but had

no significant effect on nitrogen use efficiency and plant dry biomass. The tillage $\times$ nitrogen interaction effect was significant for 100-kernel weight, plant dry biomass, plant height, and soil organic matter, showing that the response to nitrogen fertilization was not the same under the two tillage treatments for traits under study. Means of treatments for the six tillage $\times$ nitrogen combinations (T1–T6) are presented in Table 4.

Table 3. Analysis of variance(ANOVA) (F-ratios) for tillage, nitrogen level and their interaction on maize yield, growth, soil organic matter and nitrogen use efficiency.

Source of variation	df	Plant height (cm)	Plant dry biomass (g)	Grain yield (kg ha ⁻¹)	100-kernel weight (g)	NUE (%)	Soil organic matter (%)
Tillage (T)	1	37.75*	0.06	14.57*	99.27**	4.10	85.94*
Nitrogen (N)	2	272.23**	85.03**	162.98**	99.72**	45.50**	164.80**
T $\times$ N	2	14.68**	4.81*	0.84	8.09*	0.42	9.33**

*Significant at $P \leq 0.05$; **significant at $P \leq 0.01$

Table 4. Mean values of nitrogen use efficiency, plant height, plant dry biomass, grain yield,soil organicmatter, and 100-kernel weight as affected by tillage $\times$ nitrogen treatment combinations.

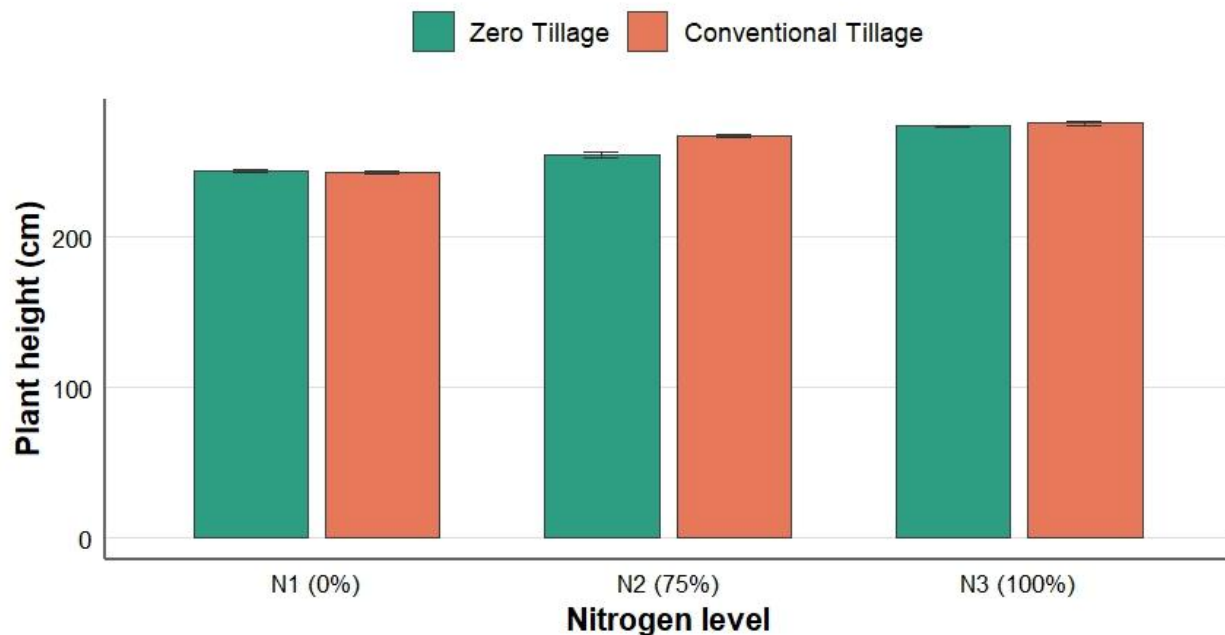
Treatment	Plant height (cm)	Plant dry biomass (g)	Grain yield (kg ha ⁻¹)	100-kernel weight (g)	NUE (%)	SOM (%)
ZT1	243.80 $\pm$ 1.27	660.00 $\pm$ 23.33	2991.6 $\pm$ 125.7	35.17 $\pm$ 1.58	39.60 $\pm$ 1.26	0.99 $\pm$ 0.01
ZT2	254.47 $\pm$ 1.67	816.67 $\pm$ 8.82	9382.3 $\pm$ 148.8	48.77 $\pm$ 1.04	71.01 $\pm$ 2.12	1.07 $\pm$ 0.01
ZT3	273.45 $\pm$ 0.40	873.33 $\pm$ 14.53	10250.3 $\pm$ 670.4	49.17 $\pm$ 1.09	63.05 $\pm$ 2.21	1.24 $\pm$ 0.01
CT1	242.87 $\pm$ 0.90	586.67 $\pm$ 35.12	3024.6 $\pm$ 163.2	30.23 $\pm$ 1.09	42.20 $\pm$ 4.04	0.91 $\pm$ 0.01
CT2	267.37 $\pm$ 0.99	863.33 $\pm$ 6.67	9494.5 $\pm$ 117.5	40.00 $\pm$ 0.65	75.57 $\pm$ 0.96	1.01 $\pm$ 0.01

Treatment	Plant height (cm)	Plant dry biomass (g)	Grain yield (kg ha ⁻¹)	100-kernel weight (g)	NUE (%)	SOM (%)
CT3	275.60 ± 1.49	916.67 ± 27.28	10103.5 ± 209.2	44.67 ± 0.60	67.21 ± 3.18	1.09 ± 0.02

198 NUE = nitrogen use efficiency; SOM = organic soil matter.

199 4.1 Plant Height

Nitrogen level affected plant height highly significantly ($F = 272.23$, $P = 0.0002$), and tillage affected plant height significantly; along with both these, the tillage $\times$ nitrogen interaction also



had a significant effect ($F = 14.68$, $P = 0.0015$). By average among all nitrogen levels, conventional tillage delivered the tallest plants (261.95 cm), with average plant height under zero tillage being relatively lower (257.24 cm). On the other hand, an increase in height was seen to progress with each nitrogen rate under both systems, showing a positive relation between height and N levels. Under conventional tillage, with the control N level, plants reached 242.87 cm, at 75% N it was 267.37 cm, and at 100% N it was 275.60 cm (CT1-CT3). Under zero tillage, the subsequent means were 243.80, 254.47, and 273.45 cm (ZT1-ZT3). Both tillage systems showed the maximum gap at control and 75% nitrogen levels, but the difference narrowed down at the 100% N level; at this level, plants of both tillage systems reached similar height. Results are visualized in Figure 2

Figure 2 Mean comparison of plant height at different treatments

4.2 Plant Dry Biomass

There was no significant effect of tillage on plant dry biomass ($F = 0.06$, $P = 0.8266$), but on the other hand, N levels showed highly significant results ($F = 85.03$, $P = 0.0004$), and the

interaction effect of tillage $\times$ nitrogen was significant ($F = 4.81$, $P = 0.0488$). Dry biomass rose from 586.67 g at the control to 863.33 g at 75% N and 916.67 g at 100% N under conventional tillage; the corresponding values under zero tillage were 660.00, 816.67, and 873.33 g. Higher biomass was produced at the N control level under zero tillage, but when nitrogen was applied (75%, 100%) conventional tillage overtook it

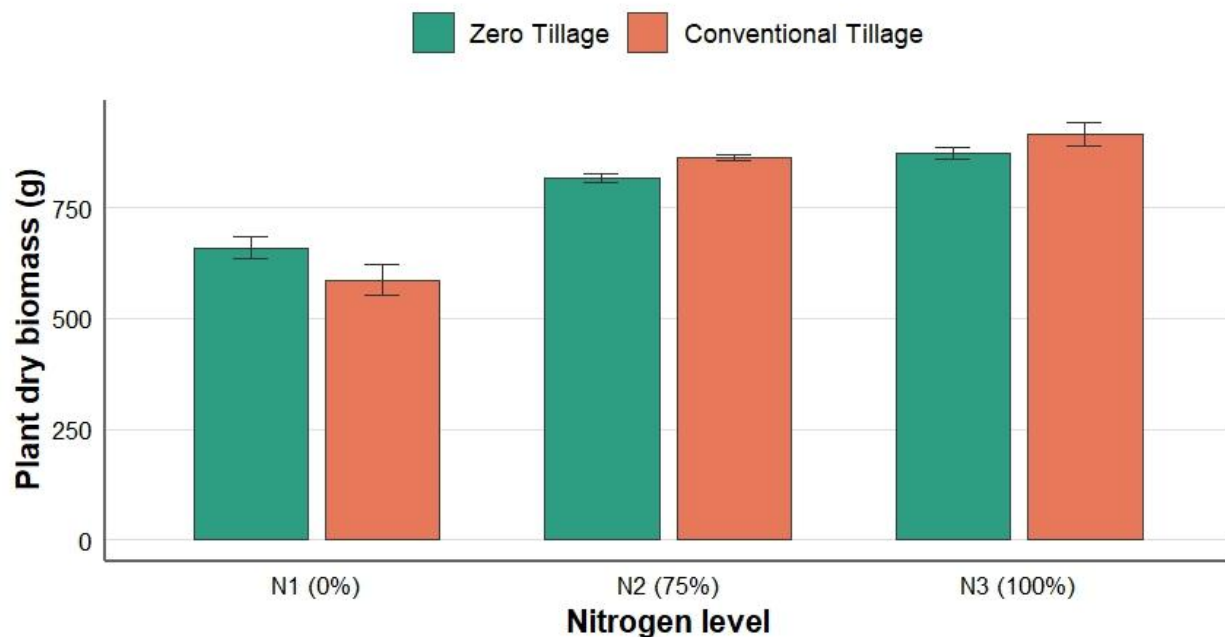


Figure 3 Mean comparison of Plant dry biomass

4.3 Grain Yield

Grain yield was significantly affected by tillage ($F = 14.57$, $P = 0.0457$). Nitrogen level showed a highly significant effect ($F = 162.98$, $P = 0.0001$); and grain yield was not significant ($F = 0.84$, $P = 0.4549$). Conventional and zero tillage produced almost identical mean yields when values were averaged over N levels (7540.9 and 7541.4 kg ha⁻¹, respectively). This tells us that the significant effect shown by tillage was due to the variations within nitrogen levels; this kills the claim of advantage of any tillage system. With nitrogen supply, grain yield improved sharply. The recorded values went from 3000 kg ha⁻¹ at the control to more than 9,300–9,500 kg ha⁻¹ at 75% N level, and at 10,100–10,250 kg ha⁻¹ at 100% N. The highest yield was recorded at 100% N level and zero tillage, which was 10,250.3 kg ha⁻¹; this value was closely followed by

conventional tillage at the same nitrogen level (10,103.5 kg ha⁻¹). Means are visualized in Figure 4

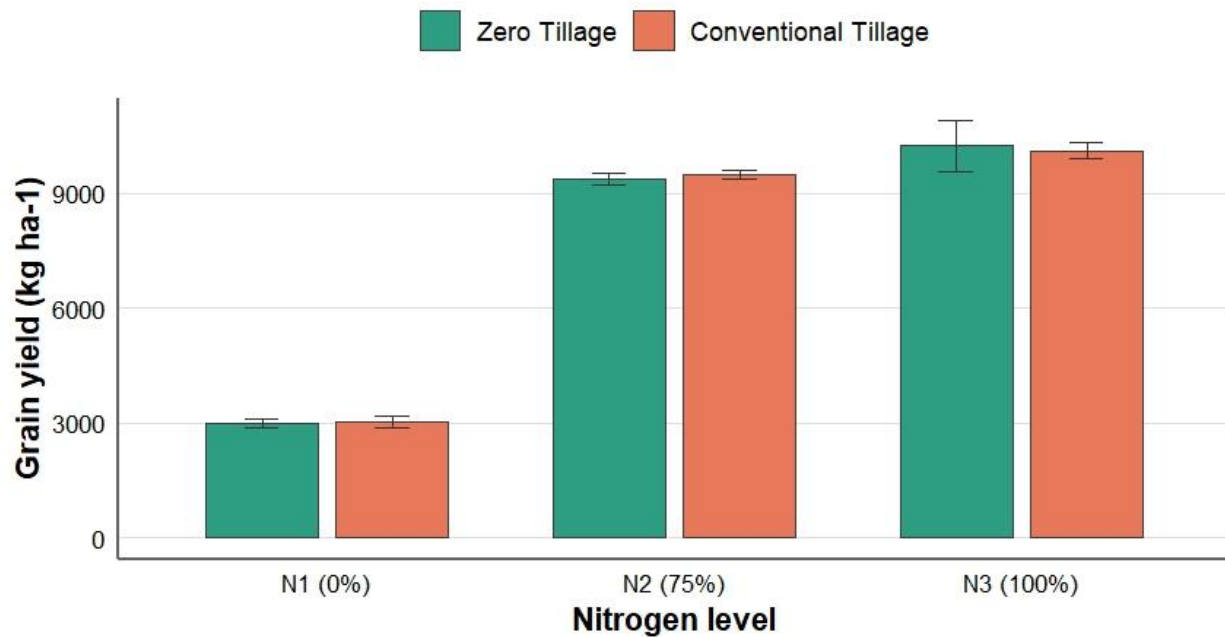


Figure 4 Mean comparison of grain yield

4.4 100-Kernel Weight

Both nitrogen level ($F = 99.72$, $P = 0.0001$) and tillage ($F = 99.27$, $P = 0.0099$) had highly significant effects on 100-kernel weight; the tillage $\times$ nitrogen interaction was also significant ($F = 8.09$, $P = 0.0120$). In contrast, plant dry biomass, grain yield, and plant height results for zero tillage showed higher 100-kernel weight as compared to conventional tillage at all the N levels. 100-kernel weight rose from 35.17 g at the control to 48.77 g at 75% N and reached its highest at 49.17 g at 100% N under zero tillage (ZT1-ZT3). On the other hand, the corresponding values were 30.23, 40.00, and 44.67 g under conventional tillage (CT1-CT3). Figure 5 shows the graphical representation of mean values of 100-kernel weight.

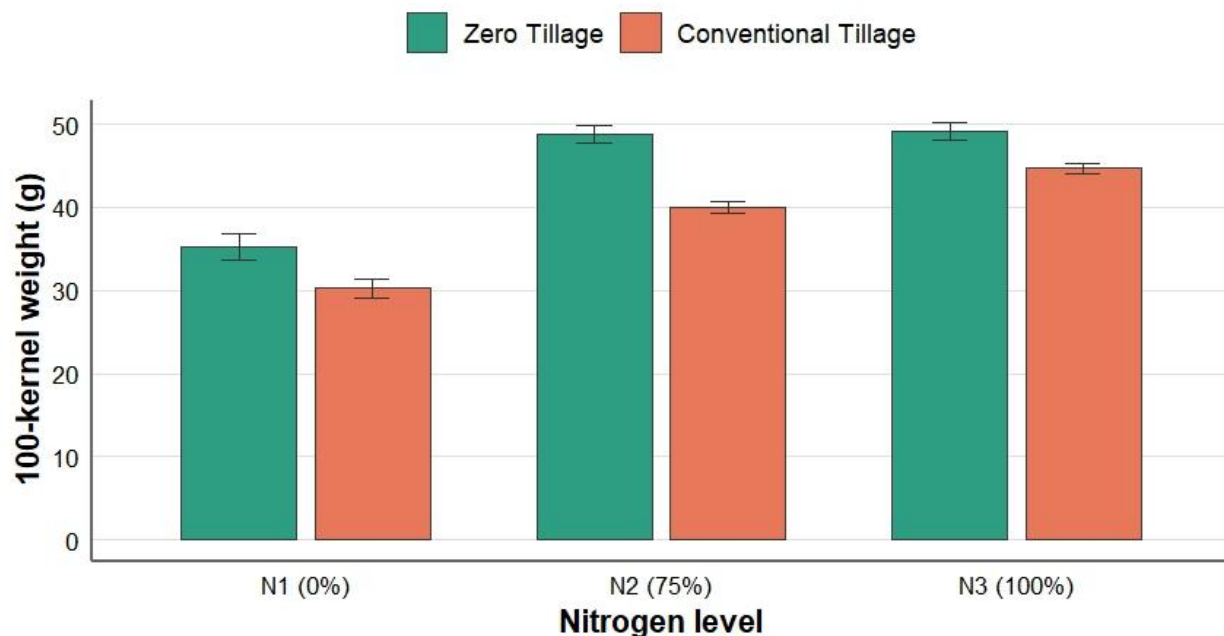


Figure 5 Mean comparison of 100-kernel weight

4.5 Nitrogen Use Efficiency

No significant effect was observed due to Tillage practices on NUE ($F = 4.10$, $P = 0.1803$), but N levels had a highly significant effect ($F = 45.50$, $P = 0.0001$); the interaction effect (tillage $\times$ nitrogen) was also non-significant ($F = 0.42$, $P = 0.6686$). There was no uniform increase in NUE with nitrogen rate. NUE increased from 42.20% at the control; it was highest at 75.57% at 75% N before decreasing to 67.21% at 100% N under conventional tillage (CT1-CT3). Zero tillage also showed a similar pattern, with NUE values increasing from 39.60% at the control up to 71.01% at 75% N and then dropping to 63.05% at 100% N (ZT1-ZT3). Conventional tillage practices showed a relatively higher value of NUE than zero tillage; mean comparisons are shown in Figure 6

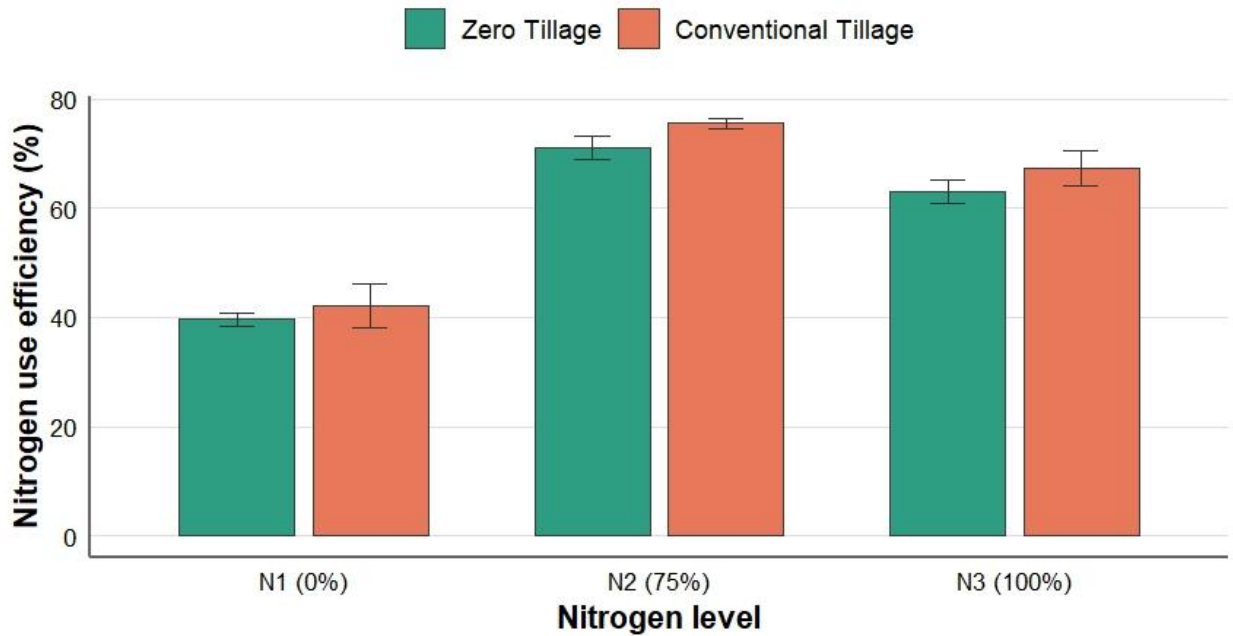


Figure 6 Meancomparison of NUE

4.6 Soil Organic Matter

Tillage had a significant effect on soil organic matter (SOM) ($F = 85.94$, $P = 0.0114$), while nitrogen levels showed a highly significant effect ($F = 164.80$, $P = 0.0001$), highly significant effect of the tillage $\times$ nitrogen interaction was also observed ($F = 9.33$, $P = 0.0081$). Higher SOM values were observed in zero tillage at all the nitrogen levels; the values of SOM increased from 0.99% at the control to 1.07% at 75% N and 1.24% at 100% N (ZT1-ZT3), while the corresponding values under conventional tillage increased from 0.91% at the control to 1.01% at 75% N and 1.09% at 100% N (CT1-CT3). With increasing nitrogen rate, the gap between the two tillage systems widened gradually, reaching a maximum at the 100% N level. Mean comparisons are given in Figure7

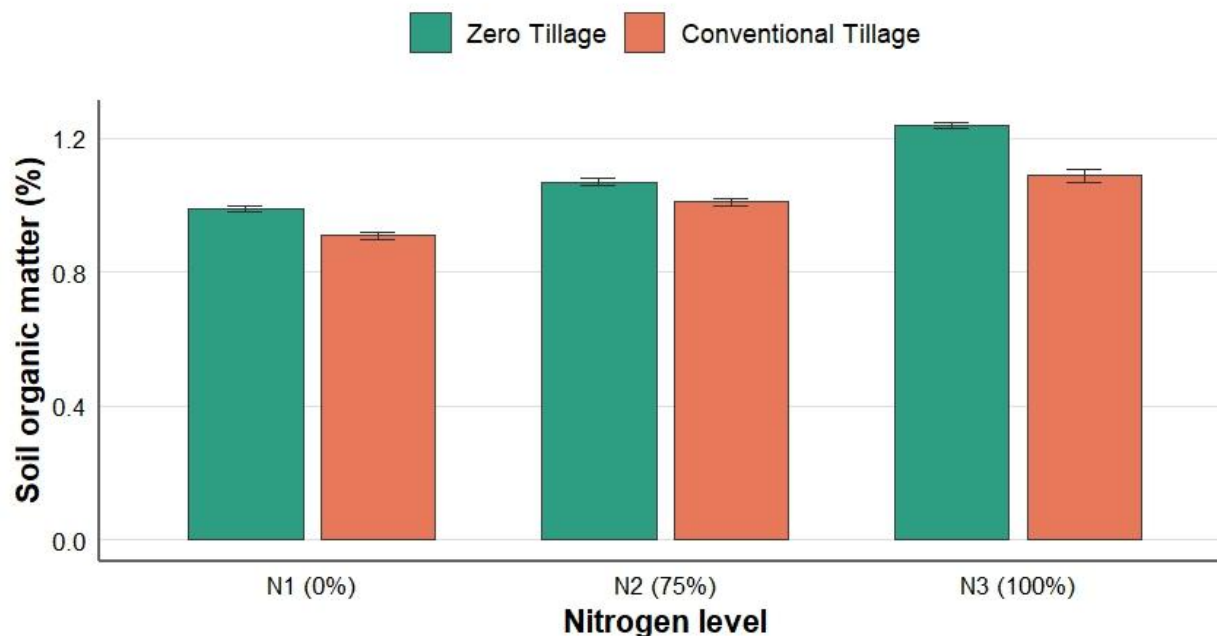


Table 3 Mean comparison of SOM

5. Discussion

5.1 Plant Height

Under conventional tillage, taller plants were observed, as it is linked to a better-aerated, loosened seedbed that conventional tillage typically creates with its land alteration practices; this aids in root formation, root proliferation, and also helps in efficient water and nutrient uptake in the early growth stages. Alletto et al. (2011) and Lampurlanes et al. (2016) also observed that with intensive tillage, greater vegetative growth can be attained; hence, these results agree with both of these studies. However, the results go against Yang et al. (2017), who reported an increased plant height in a zero-tillage system; these contradictions can be due to changes in the application timeline of nitrogen, cultivar used, dose rate, and climatic conditions (Liu et al., 2018). The obvious almost linear increase in plant height due to nitrogen application shows us that nitrogen has a central role in chlorophyll synthesis, overall photosynthetic capacity, and cell elongation; the significance of the interaction effect shows that the loss in height due to the undisturbed, more compact seedbed of zero tillage was compensated when the full N dose was applied. This effect states that some of the early physical constraints can be managed with adequate nitrogen supply (Wasaya et al., 2017).

5.2 Plant Dry Biomass

The main effect of tillage was non-significant, while the interaction effect was significant; this showed that the dry matter accumulation was not determined by tillage only but was influenced by tillage interaction with different N levels applied. These results are supported by many other studies, like Wasaya et al. (2017), who stated that tillage practices do have an effect on nutrient availability and soil structure with positive affiliation with both; this effect can be exploited by applying optimum nitrogen to the land under use. As with plant height, nitrogen availability is very crucial for dry biomass as well, as the results showed a sharp rise in biomass between the control and 75% N treatments, but this increase was followed by a small increase when moving from 75% to 100% N levels; this elaborates the significance of nitrogen application on vegetative growth, with diminishing marginal returns from the highest dose (Wasaya et al., 2017).

5.3 Grain Yield

The interaction results were non-significant, showing that the response of the maize crop to nitrogen application remains consistent across both tillage applications; this further confirms that the main driver of grain yield in this case is nitrogen availability rather than seedbed preparation method. This claim is supported by evidence reviewed for this study, which states that nitrogen application is mainly the leading driver of maize grain yield, with tillage effects becoming effective only under specific climatic, soil, or management conditions (Shahzad et al., 2015). The sharp, almost three-fold gain in yield between the control and the 75% N treatments, followed by a relatively modest further increase from 75% to 100% N, is characteristic of the weakening-returns response typical of nitrogen-yield curves in maize crops (Qiu et al., 2015), and indicates that the 75% nitrogen rate already resulted in most of the attainable yield gain in the environment.

5.4 100-Kernel Weight

The kernels with more weight were obtained under zero tillage treatment. Despite this system usually producing short, lower-height plants and lower yield at low nitrogen levels, this suggests that integrating division to individual grains was more effective under zero tillage, possibly offering improved conservation of soil moisture during the period of grain-filling. The plateau in kernel weight beyond 75% N level under zero tillage, compared with the still-rising response under conventional tillage, is the clearest expression of the significant interaction and indicates

that once soil-moisture conservation under zero tillage had already supported near-maximal grain filling, additional nitrogen produced little further gain, whereas under the more disturbed, potentially drier profile of conventional tillage, the crop continued to respond to nitrogen up to the highest rate tested.

5.5 Nitrogen Use Efficiency

The highest point in NUE was at 75% of N application, the intermediate treatment; this was followed by a slight decrease in NUE at the full recommended dose. This behavior is well documented in several papers, such as Qiu et al. (2015). This paper stated that partial factor productivity, agronomic efficiency, and NUE all decreased once the N application went above the maize crops' limit for efficient use, with almost all of the surplus nitrogen becoming susceptible to denitrification, volatilization, or leaching rather than helping the crop or soil. Thenon-significant recording of tillage and interaction showcased that NUE is completely determined by N supply alone and that both tillage practices do not affect it. The slight increase in NUE under conventional tillage practice is supported by Eivazi and Habibi (2013), who made a connection between enhanced nitrogen recovery when intensive tillage of the land was done, due to better root proliferation and nitrogen uptake in loosened soil. Overall, these records show that 75% of the recommended dose of N is best for efficient use of nitrogen, since the remaining 25% made near to zero gain in yield, while reducing the NUE.

5.6 Soil Organic Matter

The uniform increase in SOM under zero tillage demonstrates that low soil physical alteration was linked to this increase in SOM. Physical disturbance of soil through tillage practices limits the oxidation and exposure of soil organic material and reduces the mineralization that typically complements conventional tillage operations; recorded results are supported by Chaudhari et al. (2023) and Asenso et al. (2018), both of whom stated that higher SOM accumulation occurs under zero or minimum tillage. The increasing gap between tillage systems at higher nitrogen application levels recommends that nitrogen fertilization aided in greater biomass return to the soil, and that this additional organic input was retained more efficiently where soil disturbance was the least, strengthening the case for zero tillage as a soil-conserving practice when integrated with adequate nitrogen management.

6. Conclusion

The most important factor in this study was the level of nitrogen input, which accounted for the greatest proportion of the variation of the treatments for each measurement of maize performance made, and exerted significant effects on all the measurements tested, including plant height, plant dry biomass, grain yield, 100 kernel weight, N use efficiency and soil OM. The second factor, tillage practice, was second in importance and influenced only certain traits, with conventional tillage having a beneficial effect on plant height, plant dry biomass at higher nitrogen rates, and yield, and zero tillage consistently having a beneficial effect on kernel weight and soil organic matter. The difference here shows that there is a compromise between above-ground productivity and below-ground soil quality when deciding on a tillage system, and not a clear preference of one system over the other.

Practically, the attainment of 100% of the recommended rate of nitrogen application was associated with the maximum grain yield, plant height, plant dry matter, and 100 kernel weight for both tillage systems, while 75% of the recommended rate of nitrogen application resulted in maximum N use efficiency with little yield penalty, and was the more nitrogen-efficient application level when input costs or environmental losses of nitrogen were considered. Zero tillage, coupled with a sufficient nitrogen supply, is a viable approach to maintaining grain yield similar to conventional tillage and to promote it as a more sustainable maize production system, which can also help the conservation of soil organic matter. Additional multi-season trials are suggested to better define the consistency of these relationships between tillage and nitrogen application for various soil types and agro-climatic zones and to help adjust nitrogen recommendations specific to the region for zero-till.

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