

Article

Selected Soil Physicochemical Properties under Different Tillage Practices and N Fertilizer Application in Maize Mono-Cropping

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Abstract: No-till (NT) has been said to conserve soil moisture, maintain or increase organic matter (OM), and improve crop production compared to conventional tillage (CT). However, very few studies have explored the effect of these under dry-land agriculture with occasional tillage where ploughing is performed only after several years of NT, especially in KwaZulu-Natal. The aim of this study was to assess the effect of tillage and fertilizer application on selected physicochemical soil properties under rain-fed maize production. Soil samples from NT, conventional tillage in the 5th season (CT-Y5), and annual conventional tillage (CT-A) with 0, 60, 120, 240 kg N ha⁻¹ were taken at 0–10, 10–20, and 20–30 cm and analysed for pH, EC, exchangeable acidity, exchangeable bases, C:N, gravimetric water content, bulk density, and soil texture. Results showed that NT at 0 and 60 kg N ha⁻¹ in 0–10 cm had higher bases, gravimetric water content, pH, and EC compared CT-Y5 and CT-A ($p < 0.05$). At 10–20 cm depth, CT-Y5 had higher gravimetric water content (0.17 g g⁻¹), followed by CT-A, (0.13 g g⁻¹), while NT had the least (0.11 g g⁻¹) ($p < 0.05$) in the control treatment. Again at 20–30 cm depth, NT had higher ($p < 0.05$) bases than CT-Y5 and CT-A tillage practices at 120 and 240 kg N ha⁻¹ application rate. Regression analysis of fertilizer application rate with both bases and gravimetric water content showed a strong relationship under NT. Better soil properties under both NT and CT-Y5 was attributed to residue cover and minimum disturbance of the soil, which encouraged infiltration, thus reducing runoff and evaporation from the soil surface. Accumulation of residue under conservation tillage enhances OM, which subsequently improves soil quality, whereas ploughing aerates the soil causing oxidation of OM, thus releasing H⁺ ions. Again, fertilizer application induces mineralization of OM, thus, higher fertilizer application rates result in low levels of carbon. NT is well-recommended in conserving soil quality while sustaining crop productivity.

Keywords: conventional tillage; crop residue; minimum tillage; no-till; urea fertilizer



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1. Introduction

The maintenance of optimum soil physical and chemical characteristics is integral to soil fertility management. This can be achieved through application of mineral fertilizers, retaining crop residues to soil, and reduced tillage. The improvement of physicochemical characteristics of soil would also lead to reduced erosion, improved soil water and nutrient retention, and increased crop productivity [1]. According to [2] land management practices such as tillage affect soil physicochemical and biological properties. Research has shown that crop residues under no-till (NT) conserve soil moisture, maintain or increase organic matter (OM), and improve crop production [3]. Employing proper tillage techniques combined with fertilizer application does not only improve soil quality, but results in

higher production. The high plant biomass produced by fertilizers results in increased return of organic material to the soil in the form of decaying roots, litter, and crop residues. However, threshold application must be determined to sustain soil quality, since both shortage and excess fertilizer application may be detrimental to soil physicochemical properties [4].

Conservation tillage, such as NT, increases soil organic carbon (SOC) concentration leading to enhanced soil quality and resilience [5]. [6] reported increases in soil moisture content and decreases in bulk density of tilled soils, and attributed this to increased decomposition of organic material due to tilling, which improves OM. According to [7], the benefits of NT and residue retention on crop yield is through conservation of soil moisture and improvement in soil properties (which is a slow process). In a study by [8] it was found that conventional tillage (CT) decreased SOC concentration due to breaking down of soil aggregates. Higher OM under NT would enhance soil nutrients, thus indirectly improving soil physicochemical properties. According to [2] tillage did not affect soil properties while fertilizer application significantly improved soil chemical properties.

The use of fertilizer, especially by well-resourced commercial farmers, is escalating in order to meet the food demand. Increase in N fertilization has generated concern about its possible negative influence on soil properties, particularly when long-term use of ammonium is involved [9]. Application of N fertilizers has sometimes been shown to have either an adverse or beneficial effect on soil aggregation [10]. This is because when NH_4^+ ion accumulates in soils in large amounts, it can become a dominant exchangeable cation, and unlike Na^+ it favours flocculation of soil colloids [11] while, in the process, it can acidify the soil. [12] argued that fertilizer application does not directly impact soil physical properties but enhances root growth, which directly remoulds the soil properties. The effect of fertilizer application and tillage is also dependent on soil depth. [13] reported higher accumulation of p under NT with application of N on the upper surface, whereas, at 7.5 cm depth pH tremendously decreased as Mn and Fe increased. This was attributed to nitrification, which caused soil acidification, increased extractable micronutrients (Fe, Cu, and Mn), and decreased available p and exchangeable bases.

Depending on the type of fertilizer, their application can have an effect on soil physicochemical properties and biological activities. Phosphate fertilizer for example can flocculate soil particles by acting as a cementing agent, while NH_4^+ fertilizers can acidify the soil [10]. In semi-arid regions where conditions are torrid, it is necessary to make sure that there is exhaustive dissolving of fertilizer by adding water through supplementary irrigation. Henceforth the fertilizer threshold under irrigated conditions is different from that under dry land conditions, which was explored in this study, when all other conditions are maintained constant. Many studies on tillage and N fertilization effects on soil properties have been under irrigation, crop rotation, annual, and pasture cropping systems. Very few studies have explored the effect of these under dry land agriculture with occasional tillage where ploughing is performed only after several years of NT, especially in KwaZulu-Natal. The aim of this study was to assess the effect of tillage and N fertilizer application on selected physicochemical soil properties under rain-fed maize production. The null hypothesis of the study was that conservation tillage had detrimental effect on soil quality compared to CT, therefore reducing crop productivity.

2. Material and Methods

2.1. Study Site

The study was done in Loskop, KwaZulu-Natal Province, South Africa, located at latitude $28^\circ 55' 26.83''$ S and longitude $29^\circ 33' 38.64''$ E. The trial was started in the 2003/2004 season; however, the sampling of the current study was performed in 2017/2018. The site had been previously utilised for dry-land maize and soybean in rotations and was NT since 1990. Thereafter, dry-land maize was planted in summer, with winter fallow under NT, annual conventional till (CT-A), and conventional tillage every 5th season (CT-Y5) since 2003/2004 season. The soil on the site was classified as Hutton [14] with clay loam

texture. The area receives approximately 643 mm of rainfall per annum which occurs mostly during summer (November–January), and has mean average midday temperatures ranging between 19.3 °C in June and 28 °C in January [15]. The field trial was arranged as a randomized split-plot design, with tillage forming whole plots and fertilizer application rate being sub-plots (S1, Annexure). Urea fertilizer was applied at four application rates of 0 (control), 60, 120, and 240 kg N ha^{−1} in each treatment, while the tillage treatment was blocked three times. The dimensions of main blocks were 48 m by 28.5 m, main plots were 48 m by 9.5 m, and sub-plots were 12 m by 9.5 m. Ploughing time was determined by rainfall, usual late November and early December. Planting was carried out through seed drill, and the banding method was used for fertilizer application. Pannar's SC701 maize seed was used with Roundup® to manage weeds. Again, cultural methods of both weed and disease control, such as winter fallowing, liming, and band application of fertilizer were integrated. Further, the yield for 2018 was calculated for all the tillage techniques.

The NT was characterised by no soil disturbance (no ploughing), with crop residues from previous year retained. CT-Y5 comprised leaving the soil unploughed for four seasons, then tilling every 5th season. Soil sampling in CT-Y5 was conducted in the 5th season. In CT-A there was annual disturbance of soil by tilling using a mouldboard plough tractor to a depth of 30 cm.

2.2. Soil Sampling Procedure

Soil was sampled after harvest to avoid plant disturbance at depths of 0–10, 10–20, and 20–30 cm. Each tillage treatment had three blocks sampled, making nine blocks in total, with each block having four N fertilizer application rates, which were all replicated three times. Cores for bulk density were sampled using a core sampler at the above-mentioned depths.

2.3. Laboratory Analyses

Distilled water and 1M KCl were used to determine pH at a ratio of 1:2.5, [16]. The samples with water added were also used to measure electrical conductivity. Total N and C were analyzed using LECO, from USA, TruMac CNS/NS Carbon/Nitrogen/Sulfur Determinator [17] (Corporation LECO, 2012). Air-dried soil was passed through a 0.5 mm-size sieve, then a 0.2 g sample was put into the LECO, from USA, for analysis of C and N. The procedure was based on dry combustion of air-dried samples in crucibles subjected to a 1450 °C furnace temperature for about 6 min. The C:N ratios of the soils were also calculated. Exchangeable acidity was measured using a method by [18], by extraction with 1 M KCl, followed by titration with 0.01 M NaOH. Exchangeable acidity was calculated in cmol_c/kg using the formulae by [19].

A 1 M ammonium acetate (NH₄OAc) solution buffered at pH 7 was used to measure exchangeable bases [20], while the core method by [21] was used to measure bulk density, and particle size distribution was analysed using the double-pipette method [22]. Proportions of sand, silt, and clay were calculated and expressed as percentages of the total, then used to determine soil textural class with a textural triangle. Furthermore, gravimetric water content was determined through oven-drying [23].

2.4. Statistical Analyses

An analysis of variance (ANOVA) test was done to determine the effect of tillage and fertilizer application on soil physicochemical properties. Treatment factors were tillage practice, N fertilizer application rate, and soil depth. The Fisher's protected LSD test was used as a post-hoc test to compare treatment means and their interactions at $p < 0.05$. Further, the regression analysis was done to show the relationship between N fertilizer application rates and variety. All tests were performed with GenStat 14.1 for Windows software [24].

3. Results

3.1. Soil Properties at 0–10 cm Depth

Gravimetric water content was highest at 0–10 cm depth in NT at all application rates except for 240 kg N ha^{−1} ($p < 0.05$). Table 1 shows that exchangeable acidity was highest under CT-Y5 at 240 kg N ha^{−1} (3.9 cmol_c kg^{−1}), ($p < 0.05$). Soil pH was highest at 60 kg N ha^{−1} in NT (6.4 pH_{water}), while it was lowest in CT-Y5 at 240 kg N ha^{−1} (4.4 pH_{water}), ($p < 0.05$).

Table 1. Soil characteristics under different tillage systems and N fertilizer application rates at 0–10 cm depth.

Rates (kg N ha ^{−1})	Tillage	pH _w	pH _{KCl}	Acidity (cmol _c kg ^{−1})	Bases (cmol _c kg ^{−1})	C:N	GWC (g g ^{−1})	Bulk Density (kg m ^{−3})
0	NT	5.6 ^{bc}	4.68 ^{bcd}	0.1 ^a	13.9 ^g	18.3 ^a	0.18 ^{fg}	1294 ^{abc}
	CT-Y5	6.0 ^{bc}	4.71 ^{bcd}	0.1 ^a	5.1 ^{bc}	40.4 ^{ab}	0.17 ^{efg}	940 ^a
	CT-A	6.3 ^c	5.19 ^{cd}	0.3 ^a	7.4 ^{cde}	32.7 ^{ab}	0.14 ^{cd}	1529 ^{bc}
60	NT	6.4 ^c	5.31 ^d	0.04 ^a	11.4 ^f	16.5 ^a	0.18 ^{fg}	1448 ^{abc}
	CT-Y5	6.0 ^{bc}	4.70 ^{bcd}	0.04 ^a	5.8 ^{bcd}	22.3 ^a	0.15 ^{de}	1846 ^c
	CT-A	5.9 ^{bc}	4.60 ^{bcd}	0.3 ^a	5.0 ^b	27.9 ^{ab}	0.14 ^{cd}	1307 ^{abc}
120	NT	6.3 ^c	4.71 ^{bcd}	0.1 ^a	8.5 ^e	19.7 ^a	0.16 ^{ef}	1360 ^{abc}
	CT-Y5	5.4 ^b	4.60 ^{bcd}	0.1 ^a	4.6 ^b	32.5 ^{ab}	0.19 ^g	1422 ^{abc}
	CT-A	6.4 ^c	5.15 ^{cd}	0.04 ^a	6.8 ^{bcde}	51.2 ^b	0.15 ^{de}	1339 ^{abc}
240	NT	5.4 ^b	4.33 ^{abc}	0.1 ^a	8.0 ^{de}	17.8 ^a	0.12 ^{ab}	1398 ^{abc}
	CT-Y5	4.4 ^a	3.44 ^a	3.9 ^b	0.7 ^a	24.8 ^a	0.10 ^a	1338 ^{abc}
	CT-A	5.9 ^{bc}	4.19 ^{ab}	0.2 ^a	4.8 ^b	36.4 ^{ab}	0.13 ^{bc}	1187 ^{ab}

Rates—different UREA fertilizer application rates; NT—zero tillage; CT-Y5—ploughing on the 5th season; CT-A—annual ploughing; GWC—gravimetric water content. Similar letters in the same column means there is no significance ($p < 0.05$) whereas different letters indicates significant difference ($p < 0.05$).

3.2. Soil Properties at 10–20 cm Depth

NT had higher bulk density than the other tillage treatments in the control, while at 240 kg N ha^{−1} CT-Y5 had the lowest density ($p < 0.05$). The C:N ratio was highest in NT at 240 kg N ha^{−1} ($p < 0.05$), while it did not significantly differ in all the other treatments at 10–20 cm soil depth (Table 2). However, NT had the highest level of exchangeable bases in all treatments, while CT-Y5 had a lower base concentration than the other tillage treatments at most N application rates ($p < 0.05$). The exchangeable acidity, on the other hand, was highest in CT-A (1.0 cmol_c kg^{−1}) at 120 kg N ha^{−1} ($p < 0.05$), (Table 2).

Table 2. Soil characteristics under different tillage systems and N fertilizer application rates at 10–20 cm depth.

Rates (kg N ha ^{−1})	Tillage	pH _w	pH _{KCl}	Acidity (cmol _c kg ^{−1})	Bases (cmol _c kg ^{−1})	C:N	GMC (g g ^{−1})	Bulk Density (kg m ^{−3})
0	NT	6.4 ^{bc}	5.28 ^{bc}	0.1 ^a	7.8 ^{bcd}	24.2 ^a	0.11 ^a	1860 ^b
	CT-Y5	6.1 ^{bc}	4.72 ^{abc}	0.2 ^a	5.0 ^{abc}	35.4 ^a	0.17 ^b	1416 ^{ab}
	CT-A	6.4 ^{bc}	5.17 ^{bc}	0.3 ^a	7.2 ^{bcd}	32.2 ^a	0.13 ^{ab}	1772 ^{ab}
60	NT	6.4 ^{bc}	5.30 ^{bc}	0.01 ^a	9.1 ^d	25.2 ^a	0.16 ^b	1560 ^{ab}
	CT-Y5	6.4 ^{bc}	5.21 ^b	0.03 ^a	8.4 ^{cd}	28.0 ^a	0.16 ^{ab}	1626 ^{ab}
	CT-A	5.8 ^{bc}	4.59 ^{abc}	0.03 ^a	6.5 ^{abcd}	35.1 ^a	0.15 ^{ab}	1704 ^{ab}
120	NT	6.2 ^{bc}	5.04 ^{bc}	0.05 ^a	7.3 ^{bcd}	25.3 ^a	0.15 ^{ab}	1633 ^{ab}
	CT-Y5	5.7 ^{bc}	4.56 ^{abc}	0.1 ^a	4.9 ^{ab}	31.0 ^a	0.17 ^b	1663 ^{ab}
	CT-A	4.8 ^a	3.85 ^a	1.0 ^b	5.1 ^{abc}	26.8 ^a	0.15 ^{ab}	1526 ^{ab}
240	NT	6.3 ^{bc}	5.26 ^{bc}	0.1 ^a	7.8 ^{bcd}	80.8 ^b	0.14 ^{ab}	1706 ^{ab}
	CT-Y5	5.6 ^{ab}	4.37 ^{ab}	0.2 ^a	3.3 ^a	34.0 ^a	0.15 ^{ab}	1343 ^a
	CT-A	5.9 ^{bc}	4.78 ^{bc}	0.02 ^a	5.8 ^{abcd}	35.9 ^a	0.14 ^{ab}	1415 ^{ab}

Rates—different UREA fertilizer application rates; NT—zero tillage; CT-Y5—ploughing on the 5th season; CT-A—annual ploughing; GWC—gravimetric water content. Similar letters in the same column means there is no significance ($p < 0.05$), whereas different letters indicates significant difference ($p < 0.05$).

3.3. Soil Properties at 20–30 cm Depth

Gravimetric water content was highest in NT in the control and at 60 kg N ha⁻¹, while at 120 and 240 kg N ha⁻¹, it was highest in CT-Y5, ($p < 0.05$). Exchangeable bases were highest at 60 kg N ha⁻¹ in NT (6.45 cmol_c kg⁻¹) and CT-A (6.11 cmol_c kg⁻¹) treatments, while they were lowest in all CT-Y5 treatments ($p < 0.05$). Exchangeable acidity, on the other hand, was highest in NT and CT-A in the control, as well as in CT-A at 120 kg N ha⁻¹, but lowest in NT at 120 kg N ha⁻¹ compared to all the other treatments ($p < 0.05$). Table 3 shows that soil pH_{water} was highest in NT (6.46) at 60 kg N ha⁻¹ compared to CT-A (5.15), at 120 kg N ha⁻¹ ($p < 0.05$).

Table 3. Soil characteristics under different tillage systems and N fertilizer application rates at 20–30 cm depth.

Rates (kg N ha ⁻¹)	Tillage	pH _w	pH _{KCl}	Acidity (cmol _c kg ⁻¹)	Bases (cmol _c kg ⁻¹)	C:N	GWC (g g ⁻¹)	Bulk Density (kg m ⁻³)
0	NT	5.31 ^{ab}	4.08 ^{ab}	0.96 ^f	4.29 ^{abcde}	60.52 ^a	0.18 ^d	1918 ^{ab}
	CT-Y5	5.47 ^{abc}	4.27 ^c	0.34 ^{abcd}	3.59 ^{abcd}	46.40 ^a	0.17 ^{cd}	1762 ^{ab}
	CT-A	5.86 ^{abcd}	4.61 ^d	0.95 ^{ef}	4.74 ^{bcde}	57.80 ^a	0.17 ^{cd}	1602 ^{ab}
60	NT	6.46 ^d	5.04 ^f	0.09 ^a	6.45 ^e	27.79 ^a	0.17 ^{cd}	1994 ^b
	CT-Y5	5.64 ^{abc}	4.33 ^c	0.38 ^{bcd}	2.77 ^{ab}	33.30 ^a	0.15 ^{abc}	1779 ^{ab}
	CT-A	5.57 ^{abc}	4.76 ^e	0.39 ^{bcd}	6.11 ^e	50.57 ^a	0.15 ^{abc}	1734 ^{ab}
120	NT	5.91 ^{bcd}	4.85 ^e	0.03 ^a	5.75 ^{de}	24.11 ^a	0.15 ^{abc}	1878 ^{ab}
	CT-Y5	5.27 ^{ab}	3.98 ^a	0.56 ^{de}	1.91 ^a	77.18 ^a	0.17 ^{cd}	1516 ^a
	CT-A	5.15 ^a	4.21 ^{bc}	0.88 ^{ef}	2.86 ^{ab}	81.40 ^a	0.15 ^{abc}	1523 ^a
240	NT	5.48 ^{abc}	4.61 ^d	0.11 ^a	5.35 ^{cde}	104.34 ^a	0.13 ^a	1746 ^{ab}
	CT-Y5	5.34 ^{abc}	4.34 ^c	0.46 ^{cde}	2.31 ^a	37.07 ^a	0.16 ^{bcd}	1648 ^{ab}
	CT-A	6.06 ^{bcd}	5.00 ^f	0.10 ^a	3.20 ^{abc}	72.98 ^a	0.14 ^{ab}	1737 ^{ab}

Rates—different UREA fertilizer application rates; NT—zero tillage; CT-Y5—ploughing on the 5th season; CT-A—annual ploughing; GWC—gravimetric water content. Similar letters in the same column means there is no significance ($p < 0.05$) whereas different letters indicates significant difference ($p < 0.05$).

3.4. Relationship between Fertilizer Application Rates and Soil Properties

A regression analysis was performed to establish a relationship between fertilizer application rates and both the bases and gravimetric water content under different tillage techniques. Figure 1 depicts the outcome of the linear regression analysis in all three tillage techniques, with gravimetric water content having a strong relationship (correlation coefficient of 0.8096) with fertilizer application rate under both NT and CT-A. The relationship between the bases and fertilizer application rates was weak under all the tillage techniques, with NT having the strongest relationship, at 0.485 (Figure 1).

3.5. Amount of Yield

In all the application rates the CT-A had less yield compared to both NT and CT-Y5 (Figure 2). Further, Figure 2 shows that there was no significant difference of yield between 0 and 240 kg N ha⁻¹ in NT and CT-Y5 whereas under 60 and 120 kg N ha⁻¹ NT had higher amount of yield compared CT-Y5.

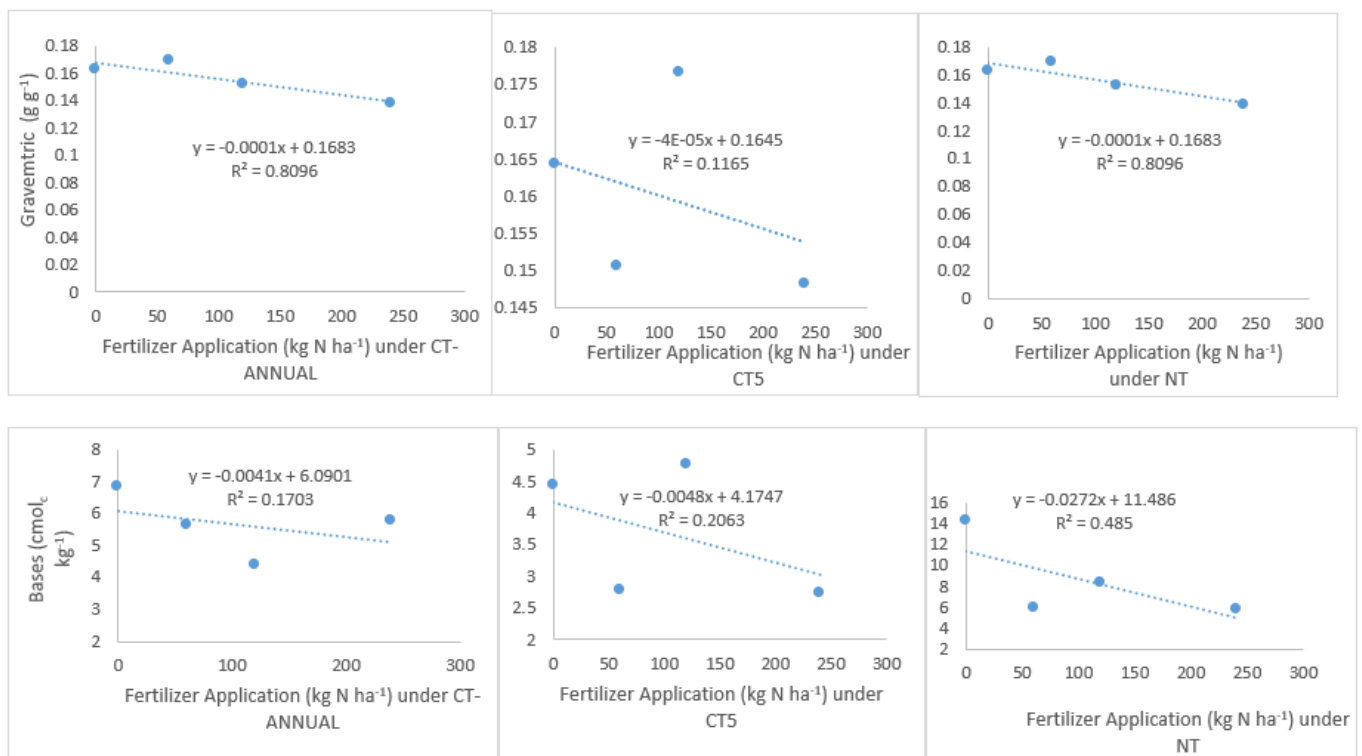


Figure 1. Relationship between fertilizer application rates under different tillage techniques and gravimetric water content and bases.

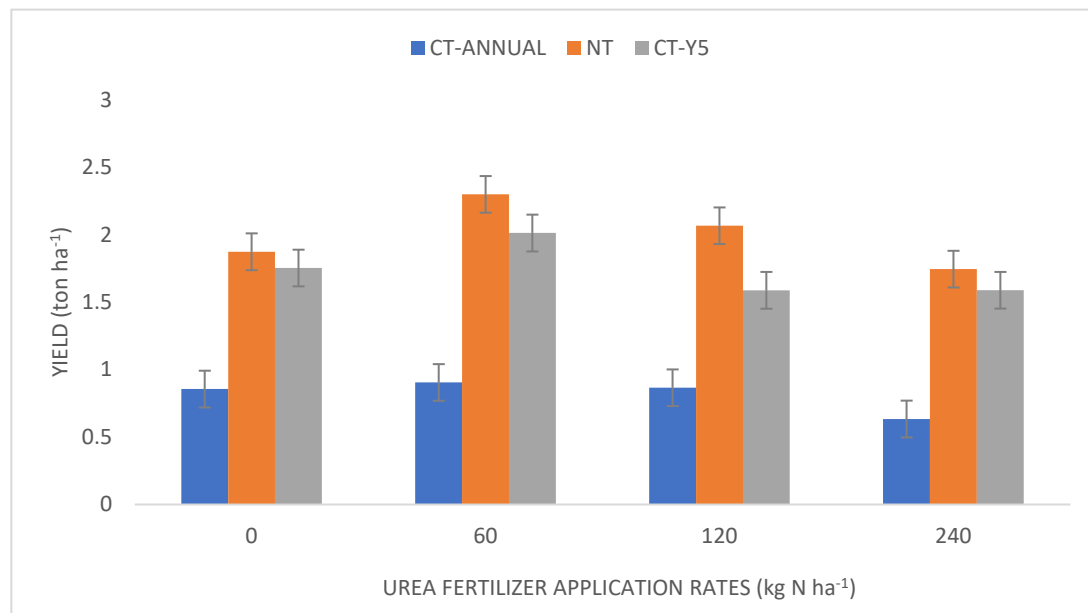


Figure 2. Maize yield of different tillage and N application treatments.

4. Discussion

Low soil bulk density under CT-Y5 treatment in 0–10 cm depth may be attributed to the increase in OM. Unlike NT and CT-A, which may have high penetration resistance and less organic material accumulation, respectively, in CT-Y5 there was incorporation of plant residues during tillage in the 5th season, which would reduce compaction and promote aggregation of soil particles. The mixing of organic materials with more dense mineral fractions of soils causes a decrease in bulk density [25]. Bulk density of the soil

in NT may increase due to lack of the loosening action of tillage [26]. [27], also reported that continuous conservation tillage may increase bulk density and soil strength, thereby inhibiting plant root growth. Furthermore, bulk density under CT-Y5 at 0–10 cm depth was lower in the control treatment compared to fertilized treatment. This concurs with the findings of [28] where mineral fertilizer application resulted in greater bulk density than that of unfertilized soil because fertilizers cement soil particles. [29] also observed higher bulk density in sub-surface layers of 10–20 and 20–30 cm depths of NT compared to CT, which is similar to the current findings.

Residue accumulation under NT increased gravimetric water content, which was in association with improved pore spaces and reduced water evaporation from the soil surface. Both NT and CT-Y5 had residue cover, which encourages infiltration, thus reducing runoff and evaporation from the soil surface, which concurs with the findings of [7]. Many studies have shown that crop residues under NT conserve soil moisture, maintain or increase OM, and improve crop production [3,30,31]. High gravimetric water content in the control compared to fertilized treatments may be due to more abundant crop biomass under fertilized treatments, which extract more water for plant biochemical processes. Abundant maize yield under NT compared to both CT-A and CT-Y5, in the current study, agrees with previous findings, while ploughing of soil under CT-A improves aeration, which accelerates decomposition of organic material and mineralization of organic N into soluble forms that can be easily lost through leaching. The reduced oxygen availability below the surface of NT systems also reduces decomposition rates, causing SOM to be retained in conservation tillage systems.

However, higher N application rates resulted in higher exchangeable acidity and lower bases (especially in the top layer), which may have a detrimental effect on crop productivity. This result was supported by the findings of [7], who postulated that root mass and straw yield increases with the first and second increment of 40 kg N ha^{-1} due to increase in acidity with higher fertilizer increment, which elucidates the high gravimetric water content in the current study, which can be due to increased crop residue retention under low N application rates. Furthermore, NT can increase water storage replenishment of deeper layers compared with CT [32], which was observed between NT and CT-A, in the present study, in 20–30 cm depth. At deeper soil levels, CT-Y5 had higher gravimetric water content compared to NT. This agrees with the findings of [33] which showed that minimum tillage often improved the capacity of soil to store water. Continuous practice of NT may have a detrimental effect on soil infiltration, however, as penetration resistance might increase. Hence, tilling after a few seasons may further enhance gravimetric water content, as was the case under CT-Y5 at higher N rates.

Tillage and N fertilization is associated with a decrease in soil pH and depletion of bases, in the current study. Lower soil pH under CT-Y5, especially at 0–10 cm depth, may be attributed to the formation of organic acids during decomposition of organic material, nitrification of NH_4^+ fertilizer, and mineralization of crop residues [34]. The electrical conductivity (EC) trend is similar to the gravimetric water content on the surface, whereas at lower depth the trend is different to gravimetric water content, which concurs with the findings of [35]. This may be due to high concentration of soluble ions on the surface, which water cannot dilute because of abundance of organic compounds, whereas at lower depth few available soluble ions were fully diluted by water. According to [36] N fertilizers, unlike manure and composts, tended to have the lowest EC and least residual effect after application. Different equation of regression analysis explicitly shows that the NT technique strengthened the relationship between the application rates and both bases and gravimetric water content. By contrast, the correlation coefficient of fertilizer application and gravimetric water content indicated a strong relationship under CT-A technique, but the relationship with bases was weak. These findings may be attributed to an accumulation of crop residues under NT, which led to a significant increase in OM and subsequent improvement in water- and base-holding capacity, whereas frequent breakdown of soil under CT-A attenuated bases and improved infiltration capacity due to macro pores. The

current findings are supported by the study by [37], conducted at the same study site, in which NT had significantly higher organic C compared to both CT-Y5 and CT-A.

5. Conclusions

The lower bulk density of CT-Y5 in the control at 0–10 and 10–20 cm depths than in NT and CT-A, may be due to incorporation and intensified decomposition of crop residue during tillage after four seasons of omitting tillage. Mixing of organic material with soil during ploughing might have played a salient role in lowering bulk density under CT-Y5 at 0–10 and 10–20 cm depths and under CT-A at 20–30 cm. The lack of soil loosening under NT increases bulk density, soil resistivity, and penetration at 10–20 and 20–30 cm, in some treatments. This may be attributed to continuous accumulation of residual load and use of heavy machineries in planting without loosening the soil.

Concentration of bases was higher under NT across all application rates and soil depths because of accumulation of crop residues, while the control under NT had higher gravimetric water content at all depths (except at 10–20 cm), than CT-Y5 and CT-A, which may be attributed to reduced mineralization of organic compounds compared to fertilized treatments. Hence, it has heavier surface cover by crop residue, which in turn reduces evaporation and increases infiltration. High rate of N fertilization mostly led to a decrease in pH and reduction in bases. The pH decrease could be a result of acidification created during N nitrification. Also, the improvement of crop productivity under conservation tillage compared to traditional practices stimulated better soil physicochemical properties. Therefore, the null hypothesis of the study that conservation tillage had a detrimental effect on soil quality compared to CT, leading to reduction in crop productivity, was rejected. It is recommended to practise NT and apply an optimum fertilizer rate of 60 kg N ha^{−1}, particularly in areas of homogeneous soil and climatic conditions with the study area, to avoid the depletion of soil physicochemical characteristics, especially in the 0–10 cm depth. The maize yield of the current study substantiates the notion of NT being the intermediate between CT-Y5 and CT-A, whereby NT promotes higher soil nutrient content than CT-Y5 and subsequently, far more abundant maize yields. This occurred because soil moisture, bases, exchangeable acidity, and pH of this combination treatment (NT at 60 kg N ha^{−1}) had better results at 0–10 cm depth. However, because of site-specificity, tillage, and N fertilizer, investigations need to be carried out under different soil and climatic conditions on a long-term basis.

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