Effect of tillage system and nitrogen fertilization on organic matter content of Nitisols in Western Ethiopia

D. Tolessa¹, C. C. Du Preez * and G. M. Ceronio²

¹Ethiopian Institute of Agricultural Research, P. O. Box 2003, Addis Ababa, Ethiopia.
²Department of Soil, Crop and Climate Sciences, University of the Free State, P. O. Box 339, Bloemfontein 9300, South Africa.

Received 30 July, 2013; Accepted 10 September, 2014

Ethiopian soils, formed from old weathered rocks, are naturally low in fertility. Moreover, crop production is constrained by non-sustainable cropping practices, particularly repeated plowing and hoeing, which enhances loss of soil organic matter. Field trials were therefore conducted to determine the integrated effects of tillage system and nitrogen fertilization on organic matter content of Nitisols at five sites using maize as test crop during 2000 to 2004 in Western Ethiopia. Three tillage systems [minimum tillage with residue retention (MTRR), minimum tillage with residue removal (MTRV) and conventional tillage (CT)] and three N levels (the recommended rate and 25% less and 25% more than this rate) were combined in factorial arrangement with three replications. After 5 years, the two measured indices of organic matter, viz. the organic carbon (C) and total nitrogen (N) content were both significantly higher in the MTRR soil compared to the CT and MTRV soils. However, the influence of tillage systems on organic C and total N was confined to the upper 0 to 7.5 cm soil layer. On average, organic C and total N in this layer were 17 and 25%, and 20 and 29% higher with MTRR than with CT and MTRV, respectively. Application of N fertilization for 5 consecutive years showed profound effects on organic C and total N. Increasing levels of N application led to higher organic C and total N irrespective of tillage system. Both organic C and total N showed however a steady (115 kg ha⁻¹ N level) to declining (69 and 92 kg ha⁻¹ N levels) trend over time. Based on these results, replacement of CT with MTRR should be beneficial and sustainable to soil quality in the study area. However, MTRV is not an option at all to replace CT from a soil quality point of view. This study’s findings may be applicable to other highland regions in Africa where cropping on Nitisols is common.

Key words: Conventional tillage (CT), crop residues, minimum tillage, organic carbon, total nitrogen.

INTRODUCTION

Western Ethiopia has a high potential for maize production due to favourable environmental conditions. This potential is seldom realized if at all because of non-sustainable cropping systems. Practices often mentioned contributing to the phenomenon are plough-based tillage resulting in soil and water loss through erosion.
(Bezuayehu et al., 2002) and insufficient fertilization resulting in poor growth and development of crops (Tolessa et al., 2002). Farmers will probably proceed with these practices for many years to come because of their financial limitations. Investigations into cropping systems comprising of alternative tillage practices are therefore justified.

Tillage plays an important role in the dynamic processes governing soil fertility (Triplett and Van Doren, 1977; Phillips et al., 1980; Mahboubi et al., 1993; Duiker and Beegle, 2006; Govaerts et al., 2009). Properly designed tillage practices usually alleviate soil-related constraints in achieving potential productivity and utility. However, improperly designed tillage practices can set in motion a wide range of degradative soil processes like organic matter depletion, aggregate deterioration, accelerated erosion, and disruption of water, carbon, nitrogen and other major nutrient cycles (Baeumer and Bakermans, 1973; Phillips et al., 1980; Lal, 1993; Bolliger et al., 2006; Du Preez et al., 2011).

Several studies indicated that minimum tillage increased organic matter on or near the soil surface mainly due to crop residues that are not mechanically mixed into the soil and hence decompose slower compared to conventional tillage (CT) (Lal, 1976; Barber, 1979; Elevins et al., 1983; White, 1990; Rasmussen and Collins, 1991; Unger, 1991; Ismail et al., 1994; Loke et al., 2012). This increase of organic matter has on account of its nature long-term beneficial effects on a number of soil properties and processes. In the broadest context, organic matter may be referred to as the total complement of organic substances in soil, including living organisms of different sizes, organic residues in various stages of decomposition and dark-coloured humus consisting of non-humic and humic substances (Stevenson and Cole, 1999; Powlsen et al., 2013). Claims are therefore that organic matter is a major source of nutrients and microbial energy, holds water and nutrients in available forms, promotes soil aggregation and root development, and improves water infiltration and water-use efficiency (Allison, 1973; Brady and Weil, 2008). Cropping usually benefits from the mentioned properties and processes influenced by organic matter.

Another benefit often attributed to minimum tillage is the sequestration of carbon (C) in the soil through higher organic matter contents (Kern and Johnson, 1993). This sequestered C results in less CO$_2$ in the atmosphere and therefore reducing the rate of global warming. CT in comparison with minimum tillage releases more CO$_2$ to the atmosphere on account of enhanced biological oxidation of soil organic matter (Reicosky et al., 1995; Govaerts et al., 2009). However, Baker et al. (2007) cautioned against the widespread belief that minimum tillage favours C sequestration since it may simply be an artifact of sampling depth. In line with this view, Chaplot et al. (2012) mentioned that the impact of minimum tillage on CO$_2$ emissions is still a matter of debate because research results are often not complementary.

Nevertheless, minimum tillage is widely recognized for its role in conservation of the natural resources soil, water and air. Minimum tillage however often necessitates higher nitrogen (N) fertilization to maintain crop yields during its initiation phase until a gradual build-up of the organic N pool could compensate for sustainable production (Larson et al., 1972; Phillips et al., 1980; Rice et al., 1986; Smith and Elliot, 1990; Bakht et al., 2009). This additional N will be unaffordable for most Ethiopian farmers if not subsidized in one way or another.

Experiments were therefore conducted on Nitisols in Western Ethiopia to examine the integrated effects of tillage system and N fertilization on the performance of the maize crop and the change in soil properties.

The ultimate aim with this research was to obtain substantiated information on whether minimum tillage can be introduced successfully into the current cropping systems practiced in the region. Some of the results are already reported, viz. the effects on yield and yield components (Tolessa et al., 2007) and efficacy of applied nitrogen (Tolessa et al., 2009). In this paper, the response of soil organic matter is presented.

MATERIALS AND METHODS

Experimental sites

The field trials for this study were conducted under rainfed conditions at Bako Agricultural Research Center, and on farmers’ fields at Shoboka, Tibe, Ijaji and Gudar. These five sites were selected to be representative of the major maize producing areas of Western Ethiopia in terms of climate and soil. Bako is located at 09°01'N and 37°02'E, Shoboka at 09°06'N and 37°21'E, Tibe at 09°29'N and 37°32'E, Ijaji at 09°43'N and 37°47'E, and Gudar at 08°09'N and 38°08'E latitude and longitude, respectively.

The altitudes for Bako, Shoboka, Tibe, Ijaji and Gudar are 1650, 1695, 1730, 1820 and 2000 m above sea level, respectively. Only climatic data of the Bako site with the lowest altitude and the Gudar site with the highest altitude as obtained from nearby weather stations is given in Table 1 since there are no weather stations close to the other three sites. Based on these data the mean annual rainfall over a 15-year period (1990 to 2004) ranged from 1042.2 mm at the higher lying Gudar site to 1239.6 mm at the lower lying Bako site, viz. a difference of 197.4 mm. For the cropping season (May to October) the average minimum temperature was 3.5°C lower and maximum temperature 0.9°C higher at the Bako site compared to that of the Gudar site.

At all five sites the soil was classified as a Nitisol (FAO, 1998). Some physical and chemical topsoil characteristics of these Nitisols before commencement of the trials are summarized in Table 2. The textural class of the Nitisols differed from loam at the Ijaji site to clay at the Shoboka site. Similar differences of 0.61 units in pH, 1.08% in organic C, 0.04% in total N, 3.9 mg kg$^{-1}$ in extractable P and 85 mg kg$^{-1}$ in exchangeable K were recorded between the five sites.

The aforementioned differences in climate and soil justified therefore the selection of the five sites for this investigation.

Field trial layout

At each of the sites a field trial was laid out in a randomized
Table 1. Climatic data for the Bako and Gudar sites as obtained from nearby weather stations.

<table>
<thead>
<tr>
<th></th>
<th>Bako</th>
<th></th>
<th></th>
<th></th>
<th></th>
<th></th>
<th>*CS</th>
<th>Annual</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>May</td>
<td>June</td>
<td>July</td>
<td>August</td>
<td>September</td>
<td>October</td>
<td>*CS</td>
<td>Annual</td>
</tr>
<tr>
<td>Rainfall (mm)</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>1990 - 1999</td>
<td>146.1</td>
<td>214.1</td>
<td>254.1</td>
<td>231.7</td>
<td>141.4</td>
<td>70.8</td>
<td>1058.2</td>
<td>1243.7</td>
</tr>
<tr>
<td>2000</td>
<td>135.1</td>
<td>278.2</td>
<td>236.9</td>
<td>289.6</td>
<td>162.0</td>
<td>103.4</td>
<td>1205.2</td>
<td>1345.5</td>
</tr>
<tr>
<td>2001</td>
<td>161.3</td>
<td>219.3</td>
<td>328.9</td>
<td>264.3</td>
<td>96.7</td>
<td>92.7</td>
<td>1163.2</td>
<td>1354.2</td>
</tr>
<tr>
<td>2002</td>
<td>68.3</td>
<td>236.0</td>
<td>239.2</td>
<td>205.9</td>
<td>42.1</td>
<td>0.0</td>
<td>791.5</td>
<td>1040.9</td>
</tr>
<tr>
<td>2003</td>
<td>5.7</td>
<td>265.1</td>
<td>420.6</td>
<td>434.4</td>
<td>39.9</td>
<td>11.5</td>
<td>1177.2</td>
<td>1355.1</td>
</tr>
<tr>
<td>2004</td>
<td>14.1</td>
<td>268.6</td>
<td>225.5</td>
<td>257.8</td>
<td>85.2</td>
<td>43.5</td>
<td>894.7</td>
<td>1061.3</td>
</tr>
<tr>
<td>2000 - 2004</td>
<td>76.9</td>
<td>253.4</td>
<td>290.2</td>
<td>290.4</td>
<td>85.2</td>
<td>50.2</td>
<td>1046.3</td>
<td>1231.4</td>
</tr>
<tr>
<td>Temperature (°C)</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Minimum</td>
<td>15.0</td>
<td>14.7</td>
<td>14.6</td>
<td>14.5</td>
<td>14.0</td>
<td>12.6</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Maximum</td>
<td>28.6</td>
<td>25.9</td>
<td>23.9</td>
<td>24.1</td>
<td>25.1</td>
<td>27.2</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Mean</td>
<td>21.8</td>
<td>20.3</td>
<td>19.3</td>
<td>19.3</td>
<td>19.6</td>
<td>19.9</td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

|          | Gudar          |               |               |               |               |               | *CS | Annual |
|          | May | June | July | August | September | October | *CS | Annual |
| Rainfall (mm) |     |      |      |        |           |            |     |        |
| 1990 - 1999 | 111.4 | 150.4 | 258.5 | 163.3 | 100.7 | 74.6 | 858.9 | 1069.0 |
| 2000 | 109.9 | 123.8 | 207.5 | 237.5 | 166.6 | 19.4 | 864.7 | 994.4 |
| 2001 | 194.0 | 166.6 | 301.5 | 209.7 | 61.0 | 17.8 | 950.6 | 1139.4 |
| 2002 | 29.5 | 216.2 | 211.6 | 131.0 | 30.2 | 17.8 | 636.3 | 881.8 |
| 2003 | 2.0 | 185.9 | 167.3 | 153.2 | 55.9 | 7.5 | 571.8 | 975.9 |
| 2004 | 37.4 | 110.0 | 293.5 | 172.1 | 147 | 28.9 | 788.9 | 951.5 |
| 2000 - 2004 | 74.6 | 160.5 | 236.3 | 180.7 | 92.1 | 18.3 | 762.5 | 988.6 |
| Temperature (°C) |     |      |      |        |           |            |     |        |
| Minimum | 11.6 | 11.1 | 11.1 | 11.2 | 10.3 | 9.6 |       |        |
| Maximum | 28.4 | 25.3 | 23.1 | 22.6 | 24.5 | 25.7 |       |        |
| Mean | 20.0 | 18.2 | 17.1 | 16.9 | 17.4 | 17.7 |       |        |

*CS = Cropping season.

Table 2. Some physical and chemical topsoil characteristics of the Nitisols at the study sites before commencement of the trials.

<table>
<thead>
<tr>
<th>Sites</th>
<th>Sand</th>
<th>Silt</th>
<th>Clay</th>
<th>pH (H₂O)</th>
<th>Organic C</th>
<th>Total N</th>
<th>P</th>
<th>K</th>
</tr>
</thead>
<tbody>
<tr>
<td>Bako</td>
<td>35.1</td>
<td>31.6</td>
<td>33.3</td>
<td>5.59</td>
<td>1.77</td>
<td>0.15</td>
<td>12.6</td>
<td>192</td>
</tr>
<tr>
<td>Shoboka</td>
<td>34.7</td>
<td>23.3</td>
<td>42.0</td>
<td>5.52</td>
<td>1.65</td>
<td>0.14</td>
<td>11.5</td>
<td>155</td>
</tr>
<tr>
<td>Tibe</td>
<td>26.7</td>
<td>35.2</td>
<td>38.1</td>
<td>5.41</td>
<td>1.46</td>
<td>0.12</td>
<td>8.7</td>
<td>146</td>
</tr>
<tr>
<td>Ijaji</td>
<td>44.7</td>
<td>32.3</td>
<td>23.0</td>
<td>5.69</td>
<td>1.93</td>
<td>0.16</td>
<td>10.3</td>
<td>231</td>
</tr>
<tr>
<td>Gudar</td>
<td>18.8</td>
<td>42.5</td>
<td>38.7</td>
<td>6.02</td>
<td>1.69</td>
<td>0.14</td>
<td>9.6</td>
<td>159</td>
</tr>
</tbody>
</table>

complete block design. The layout consisted of two factors namely, three tillage systems: minimum tillage with residue retention (MTRR), minimum tillage with residue removal (MTRV) and CT and three N fertilization levels (69, 92 and 115 kg ha⁻¹) replicated three times in a complete factorial combination. Every field trial had therefore 27 plots. An application of 92 kg N ha⁻¹ is the recommended fertilization rate for conventional maize production at the study sites, implicating the two other rates are 25% less and 25% more than this recommended rate. These experiments were conducted from 2000 until 2004. The experimental plots were kept permanent to observe the carry-over effects of the treatments for the five cropping seasons.

Agronomic practices

Before the initiation of the trials the fields at all sites had been under conventional maize production for many years. During the
entire trial period immediately after harvesting, the plants were cut at ground level and uniformly spread on the CT and MTRR plots, and removed from the MTRV plots. For the MTRR and MTRV treatments, soil disturbance was restricted to the absolute minimum, viz. the soil was disturbed only to place the seed in the soil at the time of sowing. In contrast, the soil was ploughed three times with the local oxen-plough ‘maresha’ prior to sowing to obtain a suitable seedbed for the CT treatments.

Urea and triple super phosphate were used as the sources of N and P, respectively. The application of urea was split, and therefore half of the urea and all of the triple super phosphate were band placed 5 cm below the seed at sowing. At 35 days after sowing when maize was at knee-height the other half of the urea was band placed next to the row at 5 cm depth. The fertilizer in the small furrows was covered with soil soon after application. All treatments received the recommended phosphorus rate of 20 kg ha\(^{-1}\) annually.

Weed control in the MTRR and MTRV treatments was done by applying Round-up (glyphosate-isopropylamine 360 g a.i. L\(^{-1}\)) at a rate of 3 L ha\(^{-1}\) prior to planting and Lasso/Atrazine (alachlor/atrazine 336/144 g a.i. L\(^{-1}\)) at a rate of 5 L ha\(^{-1}\) as a pre-emergence application. The recommended weed control practice for CT in Ethiopia is hand weeding at 30 and 55 days after sowing followed by slashing at milk stage.

The standard cultural practices as commonly recommended to the farmers were adopted for the study. Therefore, from 2000 to 2004 the planting dates varied from 5 May to 5 June at all the sites. A late maturing commercial maize hybrid, BH-660 was planted. The plant density aimed for was 50 000 plants ha\(^{-1}\) as the 5.0 × 4.8 m plots consisted of six rows, 5.0 m in length and the inter- and intra-row spacing was 0.8 and 0.25 m, respectively.

Data collection

Soil samples were collected, just before the trials commenced, from the 0 to 30 cm layer of all five sites for their characterization. A 5 cm auger was used to sample 20 randomly selected spots per site. These subsamples were thoroughly mixed, dried at room temperature, sieved through a 2 mm screen and stored until analysis.

Since the trials started soil samples were collected annually after harvesting from the 0 to 30 cm layer of all plots at each site. At the end of the trial period, the 0 to 7.5 cm, 7.5 to 15 cm, 15 to 22.5 cm and 22.5 to 30 cm layers were sampled additionally. In both instances an auger with a 2 cm diameter was used to sample five randomly selected spots per plot. These sub-samples were prepared for analysis as described earlier.

Standard procedures (The Non-affiliated Soil Analysis Work Committee, 1990) were used to determine particle size distribution (Hydrometer), organic C (Walkley-Black), total N (Kjeldahl), extractable P (Bray 2) and exchangeable K (NH\(_{4}\)OAc) of the relevant composite soil samples.

Statistical analysis

Experimental data were analyzed through analyses of variance using the MSTATC statistical package (Michigan State University, 1989). Means for each parameter were compared by the least significant difference (LSD) test at \(P = 0.05\).

RESULTS AND DISCUSSION

Organic carbon

The effect of tillage system on organic C in the 0 to 30 cm soil layer is displayed in Figure 1 for the year 2000 to 2004. Clear differences in the organic C development on account of the three tillage systems as the experiments progressed from 2000 to 2004 were observed. This phenomenon is attributed to the fact that organic C increased with MTRR and decreased with MTRV. In the case of CT the organic C at Tibe and Gudar remained almost constant, and at Bako, Shoboka and Ijaji it declined but to a lesser degree as compared to MTRV.

The change of organic C in the 0 to 30 cm layer resulting from the application of N fertilization at different levels is illustrated in Figure 2. Organic C increased with higher levels of N application though not significant in many instances. These differences in organic C become more apparent as the experimental period progressed from 2000 to 2004. Over this period it appears that there is a decreasing trend in organic C, especially with the lowest and intermediate rates of N application. This is a cause of concern for the long-term organic matter content.

The organic C differences evolved in the upper 30 cm of the Nitisols from tillage system and N fertilization had their origin mainly in the upper 0 to 7.5 cm layer as shown in Figures 3 and 4. In general the highest organic C in this layer was recorded with MTRR, followed by CT and then MTRV. Organic C also increased significantly with higher levels of N application at three of the five sites, viz. Bako, Ijaji and Gudar.

The application of the particular three tillage systems on the Nitisols for 5 consecutive years caused tremendous changes of organic C in the upper 7.5 cm layer. Organic C in this layer was on average for all sites with MTRR 17 and 25% more than with CT and MTRV, respectively. This finding is consistent with results reported by several other researchers (Baeumer and Bakermans, 1973; Hamblin and Tennant, 1979; Griffith et al., 1986; Mahboubi et al., 1993; Franzluebbers, 2004; Baker et al., 2007; Luo et al., 2010; Loke et al., 2012). They attributed the difference in organic C between MTRR and CT to the fact that crop residues and the organic matter originated from it are oxidized faster in CT than MTRR soils due to a higher microbial activity. The significance of retaining crop residues was emphasized by the difference of organic C between the MTRR and MTRV soils. Sufficient crop residues for retention to ensure organic C maintenance or increase can only be realized with proper N fertilization as was the case in this study.

Total nitrogen

As could be expected the effect of tillage system on total N in the 0 to 30 cm soil layer (Figure 5) was almost similar to that of organic C (Figure 1). The total N increased with MTRR and decreased with MTRV resulting in large differences after 5 years. In the case of CT, the total N also decreased but to a lesser degree.
than with MTRV. The change of total N in the 0 to 30 cm soil layer resulted from the application of N fertilizer at different rates is shown in Figure 6. Total N increased with higher rates of N application though not always significant. It seems however when the recommended rate of N or less is applied that total N like organic C
Figure 2. Effect of nitrogen fertilization on organic C measured after harvesting in the 0-30 cm layer of Nitisols at the five experimental sites in 2000 to 2004.

shows a declining trend from 2000 to 2004. Thus, maintenance of organic matter content could be in question over the long-term.

Inspection of Figures 7 and 8 show that the differences of total N in the 0 to 30 cm layer which resulted from tillage system and N fertilization are mainly attributable to
changes in the 0 to 7.5 cm layer. At all sites the lowest total N recorded in this layer was observed in MTRV, followed by CT and then MTRR. Total N increased also with higher rates of N application though only significant at Bako and Ijaji.

After 5 consecutive years of application, the three
Figure 4. Effect of nitrogen fertilization on organic C measured after harvesting in the 0-7.5 cm, 7.5-15 cm, 15-22.5 cm and 22.5-30 cm layers of Nitisols at the five experimental sites in 2004.

tillage systems resulted in large changes of total N in the upper 7.5 cm layer of the Nitisols. The average total N in this layer for all sites was 20 and 29% higher with MTRR than with CT and MTRV, respectively. Similar results were reported by various other researchers (Tripplet and Van Doren, 1969; Phillips and Young, 1973; Lal, 1976; Blevins et al., 1983; White, 1990; Bakht et al., 2009). The fate of total N was therefore almost similar to that of organic C for the same reasons given earlier. This phenomenon is supported by the C/N ratios (Data not
shown) that indicated no significant differences between the treatments. Thus, either organic C or total N can be used as an index to monitor the change of organic matter content in the Nitisols.

Figure 5. Effect of tillage system on total N measured after harvesting in the 0-30 cm layer of Nitisols at the five experimental sites in 2000 to 2004. Y = year and T = tillage system.

The replacement of CT with MTRR could be considered therefore to increase the organic matter content of degraded Nitisols in Western Ethiopia on the condition that the change in tillage system coincide with at least the
Figure 6. Effect of nitrogen fertilization on total N measured after harvesting in the 0-30 cm layer of Nitisols at the five experimental sites in 2000 to 2004.

recommended N fertilization rate of 92 kg ha\(^{-1}\). An increase of organic matter in these degraded soils should improve their quality tremendously because Weil and Magdoff (2004) stated that organic matter influences the properties of mineral soils disproportionately to the quantity of organic matter present. Soil of good quality has according to Doran and Parkin (1994) the capacity to sustain biological productivity, maintain environmental

\(\text{LSD}_{(0.05)}\)
Figure 7. Effect of tillage system on total N measured after harvesting in the 0 to 7.5 cm, 7.5 to 15 cm, 15 to 22.5 cm and 22.5 to 30 cm layers of Nitisols at the five experimental sites in 2004.

quality and promote plant, animal and human health which is essential for enhancing the sustainability of the rural community in the region.

The initiation phase of MTRR when additional N fertilization is usually needed seems favourably short based on recorded grain yield (Tolessa et al., 2007) and fertilization efficacy (Tolessa et al., 2009) over the 5 years trial period. During the final 2 years there was no
significant difference in grain yield between MTRV and CT and both were significantly inferior to MTRR (Table 3). The agronomic and recovery efficient use of applied N were also higher with MTRR than with either MTRV or CT. In 2004, MTRR, MTRV and CT had an agronomic efficiency of 16.0, 11.8 and 9.4 kg grain kg N applied\(^{-1}\) and a recovery efficiency of 47.7, 34.8 and 33.2%, respectively.

The replacement of CT with MTRV is not an option at all if the aim is to increase organic matter in the degraded Nitisols of Western Ethiopia. This is because MTRV exhausted the organic matter of these soils even more than CT, probably due to the removal of the crop residues.

We believe that the findings of this study could be extrapolated to the remaining highland regions of
cropping on Nitisols is common, notably at altitudes of more than 1200 m above sea level. The estimated area of Nitisols in the highlands of Africa is 100 million ha.

Conclusions

Tillage systems and concomitant crop residue management significantly affected organic C and total N. This change in organic C and total N was confined to the upper 0 to 7.5 cm layer. Both organic C and total N increased steadily over the trial period with MTRR and decreased with MTRV, and that of CT was intermediate to MTRR and MTRV. Higher contents of organic C and total N were recorded with higher fertilizer N applications irrespective of tillage system. There was however over time a steady (115 kg ha\textsuperscript{-1} N level) to decreasing (69 and 92 kg N levels) trend in organic C and total N. Based on these results CT can be replaced with MTRR and in addition proper fertilization, especially N is of utmost importance to improve soil quality and secure sustainable crop production in Western Ethiopia. These findings may be applicable also to the remaining highland regions of Ethiopia as well as those of other African countries where cropping on Nitisols is common.

Conflict of Interest

The authors have not declared any conflict of interest.

ACKNOWLEDGEMENTS

Financial support from International Maize and Wheat Improvement Center (CIMMYT), Sasakawa Global 2000 and Ethiopian Agricultural Research Organization (EARO) is gratefully acknowledged.

REFERENCES


Table 3. Effect of tillage system [minimum tillage with residue retention (MTRR), minimum tillage with residue removal (MTRV) and conventional tillage (CT)] on mean maize grain yield of the five sites for each year.

<table>
<thead>
<tr>
<th>Tillage system</th>
<th>2000</th>
<th>2001</th>
<th>2002</th>
<th>2003</th>
<th>2004</th>
</tr>
</thead>
<tbody>
<tr>
<td>MTRR</td>
<td>7538\textsuperscript{a}</td>
<td>6249\textsuperscript{a}</td>
<td>6307\textsuperscript{b}</td>
<td>5898\textsuperscript{b}</td>
<td>6374\textsuperscript{b}</td>
</tr>
<tr>
<td>MTRV</td>
<td>7499\textsuperscript{a}</td>
<td>6545\textsuperscript{a}</td>
<td>5787\textsuperscript{a}</td>
<td>4955\textsuperscript{b}</td>
<td>5577\textsuperscript{b}</td>
</tr>
<tr>
<td>CT</td>
<td>6724\textsuperscript{b}</td>
<td>5832\textsuperscript{a}</td>
<td>5410\textsuperscript{b}</td>
<td>5125\textsuperscript{b}</td>
<td>5752\textsuperscript{b}</td>
</tr>
</tbody>
</table>

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

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