GRAIN YIELD AND NITROGEN UPTAKE OF MAIZE AS AFFECTED BY SOIL MANAGEMENT PRACTICES AND THEIR INTERACTION ON CAMBISOLS AND CHERNOZEM

#11250

[1]Ashenafi Nigussie
[1]Department of Soil and Water Management, Wondo Genet Agriculture Research Center, Shashemene, Ethiopia.
*e-mail: nashenafinew@gmail.com; +251 09063256

ABSTRACT

Although numerous factors contribute to wide yield gaps, low external inputs, particularly N, and poor cropping practices such as soil tillage and monocropping are among the major factors affecting low maize production. In view of this, field experiments were implemented on two sites with Cambisols and Chernozem soil types in two consecutive years to evaluate the impacts of different soil management practices on the grain yield and quality, nitrogen uptake and selected soil properties. A three-factor experiment was arranged as a split-split plot arrangement randomized complete block design with three replications. The minimum tillage (MT) and conventional tillage (CT) were used as the main plot, haricot bean-maize rotation, and maize monocropping as a subplot, and four levels of nitrogen fertilization (Control, 20 t ha^{-1} compost, 46 kg N ha^{-1} + 10 t ha^{-1} compost, and 92 kg N ha^{-1}) as the sub-sub plot. Analysis of variance showed that soil management practices were significantly affecting grain yield, N-uptake and soil properties. In sites, the conventional tillage and rotation system increased the grain yield, and N-uptake in contrast to the minimum and monocropping, respectively. Similarly, nitrogen evidently affected the grain yield, N- uptake, and selected soil properties. However, tillage methods differed in their effects on soil chemical properties; soil organic carbon and total nitrogen concentrations were improved through MT compared to CT. Grain yield was significantly associated with NDVI, grain N-content and N-uptake. Therefore, a CT plus haricot bean-maize rotation system with the addition of solely 92 kg N ha^{-1} and integrated 46 kg N ha^{-1} + 10 t compost ha^{-1} could be recommended for Hawassa Zuria (Cambisols) and Meskan (Chernozem) districts, respectively. However, to ensure sustainable maize production in the investigated areas, an integrated N-treatment with MT and a rotation system may be recommended, which could improve soil properties.

Keywords: maize, tillage, cropping systems, fertilization, grain yield and quality, nitrogen uptake

INTRODUCTION

Maize or corn (*Zea mays* L.) is one of the world's leading cereals, ranking second in production after wheat (FAO, 2019). Ethiopia is the seventh maize-producing country in Africa. It is the second in area coverage next to tef (*Eragrostis tef* (Zucc.), with total land area of 10,478,217 ha being under cereals, of which maize covered about 17.68% (2,274,305.93 ha) (CSA, 2019). Despite the large area under maize production, its current national average yield is about 4.2 t ha^{-1} (CSA, 2019), which is far below the world's average yield of 5.8 t ha^{-1} (FAO, 2019). Although numerous factors contribute to wide yield gaps, low external inputs, particularly N, poor soil fertility, reduced water-holding capacity of the soil, and poor soil infiltration problems are among the major factors paid for low maize productivity (Chimdi et al., 2012; Mourice et al., 2015; Teklewold et al., 2013). Moreover, frequent tillage, monocropping, and complete removal of crop residues are also the governing factors for low productivity (Kassie et al., 2013). However, there is scarce information about the effects of tillage, cropping systems, nitrogen fertilization and their interaction on the yield, nitrogen uptake of maize, as well as soil chemical properties. Therefore, the present study was instigated to evaluate the effects of different soil management practices on the maize grain yield and quality, nitrogen uptake and selected soil chemical properties in the central Rift valley of Ethiopia, under two soil types - Cambisols and Chernozem.

MATERIALS AND METHODS

The field experiments were conducted for two consecutive years (2019 and 2020) in Hawassa Zuria and Meskan districts of the Central rift valley of Ethiopia. The Hawassa Zuria site is geographically situated at 07° 1' 0.83" N Latitude and 38° 22' 26" E Longitude with an altitude of 1713 m above sea level (asl). The experimental site at Meskan is found at 08° 05' 33" N Latitude and 38° 26' 75" E Longitude with an altitude of 1841 m asl. The soil types for the field trial were Cambisols for Hawassa Zuria and Chernozem for Meskan, according to the WRB soil classification system (IUSS Working Group, 2015).

Two tillage methods (TM) were evaluated: conventional tillage (CT) and minimum tillage (MT). The two tillage practices were combined with two cropping systems (CS): haricot bean-maize rotation (RCS) and maize monocropping (MCS). In addition, four levels of nitrogen fertilization (NF) (0, 20 t compost ha^{-1}, 46 kg N ha^{-1} + 10 t compost ha^{-1}, and 92 kg N ha^{-1}) were combined with tillage practices and cropping systems. Treatments were arranged as Split-split plot arrangement randomized as a RCBD (randomized complete block design), with tillage methods as the main (whole) plots, cropping systems as sub-plots, and nitrogen fertilization treatments as sub-sub-plots, with three replicates: making 48 sub-sub-plots for each experimental site.

Yield and yield related data were collected from a net plot area of 4 m^2 (1.25 m x 3.2 m) by rejecting the border rows, from three replications. The harvested grain yield was adjusted to a 12.5% moisture level (Nelson et al., 1985) and it was converted into hectare bases. Twenty grams of grain samples were taken from each experimental unit. The grains were oven-dried to constant weight thereafter; and the samples were ground and passed through a 0.5 mm sieve. The nitrogen content in the grain was analyzed using the Kjeldahl procedure after wet digestion by H_2SO_4/H_2O_2 (Nelson and Sommers, 1982).

Before the analysis of variance (ANOVA), the normality of the data was checked using the Shapiro-Wilk normality test. Despite the two experimental sites were distinctly different in their soil fertility status, subsequently the statistically analysis was done independently for each location, using the SAS 9.3 software package (SAS Institute, 2014), considering the experimental treatment as a fixed factor and replication as a random factor. At a probability level of $P \leq 0.05$, differences between treatments means were separated using the protected Fisher's least significant difference (LSD) (Steel and Torrie, 1980). The LSD differences for the main factors and interaction effects comparisons were calculated using the appropriate standard error terms.

RESULTS AND DISCUSSION

Effects of tillage methods, Cropping systems and nitrogen fertilization on NDVI, grain yield, grain N-content and uptake and grain protein content

Tillage had revealed a statistically significant ($P < 0.05$) effect on maize grain yield At Hawassa Zuria, but not Meskan site, despite the higher yield which was gained from the CT (3855.5 kg ha^{-1}) and (7094.9 kg ha^{-1}) for Hawassa Zuria and Meskan, respectively (Table 1). In this study, grain yield increased by 5.2 and 0.1% in CT over MT at Hawassa Zuria, and Meskan. The positive result of CT on maize grain yield was possibly due to improved soil physical conditions, root growth, infiltration of water, nutrient mineralization and suppressing weed growth. Correspondingly, Simić et al. (2020); Salem et al. (2015); Wang et al. (2015) reported that CT in a short-term study increased corn grain yield compared to a minimum or zero tillage due to less soil compaction, which improved soil aeration and organic matter mineralization. In both locations, the N-content and N-uptake parameters responded positively to CT, possibly due to the stimulation of N-mineralization from organic matter and thereby improved soil mineral N-availability for crop uptake. Similarly, Simić et al. (2020) verified the benefit of conventional tillage for better maize grain yield and enhancement in grain protein content.

At Hawassa Zuria, the cropping system had a significant ($P < 0.05$) effect on grain yield, grain nitrogen content, nitrogen uptake, and protein content. However, at Meskan, while grain yield was affected, the other parameters did not show statistically significant differences (Table 1). The haricot bean-maize rotation system increased maize grain yield, N-content, N-uptake and protein content by 1.1, 2.7, 17.8, 21.1 and 17.9% in Hawassa Zuria and 1.3, 0.25, 10, 12.1 and 13.7% in Meskan, respectively, compared to maize monocropping (Table 1). This was possibly due to the change in inorganic N-availability in the soil solution caused by previous atmospheric N_2 fixation and legume residue decomposition since legume residues had better quality and a narrow C:N ratio, which results in rapid release of N from the residues (Adesoji et al., 2015; Lupwayi et al., 2011; Tolera et al., 2009). Our result is in covenant with Lafond et al. (2006) who stated that legumes offer a positive contribution to soil TN and thus improved its availability.

Analysis of variance depicted that the grain yield differed significantly ($P < 0.001$) among N-treatments in both sites. The highest grain yields of 1180.5 kg ha^{-1} and 8169.1 kg ha^{-1} were obtained from the application of 92 kg N ha^{-1} and 46 kg N ha^{-1} + 10 t ha^{-1} compost at Hawassa Zuria and Meskan sites, respectively. Similarly, Kaplan et al. (2019) proved that the grain yield increased with increasing the N level. Like grain yield, N-fertilization had revealed significant effects on GNC, GNU, and GPC (Table 1). In both locations, the integrated use of inorganic nitrogen and compost at a rate of 46 kg N ha^{-1} + 10 t ha^{-1} remarkably increased GNC, GNU and GPC by 35.1, 61.6 and 35.3% at Hawassa Zuria and 23.2, 68.2 and 21.6% at Meskan, respectively, when compared to the unfertilized treatment. Our result is in covenant with findings of Dunjana et al. (2012); Negassa et al. (2005); Rusinamhodzi et al. (2013), who stated that integrated application of organic and mineral fertilizers at appropriate rates can be an effective approach to improve maize N uptake.

Table 1. The effects of tillage methods, cropping systems, and N-fertilization on NDVI, grain yield, N-content, N-uptake and grain protein content of maize at the two sites

Investigated factors	**Hawassa Zuria**				**Meskan**			
	GY kg ha^{-1}	GNC g kg^{-1}	GNU kg ha^{-1}	GPC %	GY kg ha^{-1}	GNC g kg^{-1}	GNU kg ha^{-1}	GPC %
Tillage methods								
MT	3662.6^{b}	9.6	35.6^{b}	6.0	7061.0	12.1	89.0	7.8
CT	3855.5^{a}	9.9	39.1^{a}	6.2	7091.9	12.5	89.7	7.8
LSD (0.05)	112.6	ns	1.89	ns	ns	ns	ns	ns
Cropping systems								
RCS	3835.1^{a}	10.6^{a}	10.9^{a}	6.6^{a}	7101.0	13.2^{a}	91.5^{a}	8.3^{a}
MCS	3683.5^{b}	9.0^{b}	33.7^{b}	5.6^{b}	7083.2	12^{b}	81.3^{b}	7.3^{b}
LSD (0.05)	128.8	0.1	3.8	0.21	ns	0.03	5.6	0.2
Nitrogen fertilization								
Control	3273.3^{d}	8.2^{d}	26.8^{c}	5.1^{d}	5987.9^{d}	11.2^{d}	66.9^{d}	6.9^{d}
20 t ha^{-1} Compost	3628.2^{c}	9.1^{c}	31.2^{b}	5.9^{c}	6169.2^{c}	11.8^{c}	75.8^{c}	7.1^{c}
46 kg N ha^{-1} +10 t ha^{-1} Compost	3951.1^{b}	11.1^{a}	11.1^{a}	6.9^{a}	8169.1^{a}	13.8^{a}	112.5^{a}	8.6^{a}
92 kg N ha^{-1}	1180.5^{a}	10.5^{b}	11.1^{a}	6.6^{b}	7711.8^{b}	13^{b}	102.1^{b}	8.3^{b}
LSD (0.05)	113.7	0.6	2.62	0.35	310.1	0.01	1.2	0.25

Values of a parameter means followed by the same letter did not differ significantly across the tillage methods, cropping systems and N-fertilization at $P \leq 0.05$ according to LSD test.

Effects of tillage, cropping systems and nitrogen fertilization on soil organic carbon and total nitrogen

There were no significant changes in organic carbon concentrations across tillage methods and cropping systems in either location (Table 2). This could be because the samples were gathered two years after the field trial, which is a short time to oversee the effect of tillage on soil OC. A similar observation was reported by Geisseler and Horwath (2009). Conversely, organic carbon content was significantly affected by N fertilization (Table 2). The addition of 20 t ha^{-1} compost provided the higher OC at Hawassa Zuria, which was statistically comparable with the integrated N-treatment. The increase in soil OC after the application of compost is due to the composting material and the rich microbial community, which contributes to the formation of soil organic carbon (Deepak et al., 2017; Dhillon et al., 2018; Lorenz and Lal., 2016).

Tillage practices had a significant effect on soil total N in both locations, with minimum tillage contributing more to total N than the conventional tillage (Table 2). This could be owing to enhanced N protection inside micro and macro aggregates, resulting in lower N losses due to leaching and organic matter decomposition (Wyngaard et al., 2012). Likewise, the cropping systems was significantly affected the soil total N at Meskan, but remarkable variation not observed at Hawassa Zuria. However, in both sites there was a tendency for better soil total N in the RCS compared to MCS (Table 2). The findings of this study agree with those of Kirkegaard et al. (2008) and Lupwayi et al. (2011). Total nitrogen content was significantly affected by nitrogen fertilization (Table 2). The integrated N treatment had the highest TN (0.26% and 0.39% for Hawassa Zuria and Meskan, respectively), indicating that more N was released through mineralization of the compost added to the soil and due to the existence of high levels of respective total N in the compost. Our findings are in line with those of Ashenafi et al. (2021) and Yan et al.

(2007), who found that inorganic nitrogen influences most soil biological processes by promoting microbial carbon use, which is critical for mineralization and nutrient transformation activities.

Table 2. Main effects of tillage, cropping systems and nitrogen fertilization on soil reaction, organic carbon and total nitrogen contents of the surface layer of soils (0-20 cm)

Treatments	Hawassa Zuria (Cambisols)				Meskan (Chernozem)			
	pH	OC (%)	TN (%)	C: N	pH	OC (%)	TN (%)	C: N
Tillage methods								
MT	6.1^{b}	2.61	0.25^{a}	10.52^{b}	6.8	1.00	0.36^{a}	11.31^{b}
CT	6.2^{a}	2.59	0.23^{b}	11.18^{a}	6.8	3.98	0.33^{b}	12.11^{a}
LSD (0.05)	0.06	ns	0.01	0.33	ns	ns	0.02	0.83
Cropping systems								
RCS	6.1	2.61	0.25	10.72	6.8	3.99	0.35^{a}	11.18^{b}
MCS	6.2	2.60	0.21	10.97	6.8	3.99	0.31^{b}	11.97^{a}
LSD (0.05)	ns	ns	ns	ns	ns	ns	0.01	0.37
Nitrogen fertilization								
Control	6.0^{b}	2.51^{c}	0.21^{c}	11.81^{a}	6.6^{d}	3.83^{d}	0.32^{c}	11.91^{b}
20 t ha^{-1} Compost	6.3^{a}	2.68^{a}	0.21^{b}	10.73^{b}	7.0^{a}	1.11^{b}	0.32^{c}	13.02^{a}
16 kg N ha^{-1} +10 t ha^{-1} Compost	6.2^{a}	2.66^{a}	0.26^{a}	10.19^{c}	6.9^{b}	1.11^{a}	0.39^{a}	10.57^{d}
92 kg N ha^{1}	6.1^{b}	2.58^{b}	0.25^{ab}	10.63^{bc}	6.7^{c}	3.88^{c}	0.31^{b}	11.37^{c}
LSD (0.05)	0.1	0.01	0.01	0.17	0.08	0.03	0.01	0.53

Within the columns, means followed by the same letters are not significantly different at $P < 0.05$ according to LSD test.

CONCLUSION

Soil management practices play a crucial role in influencing grain yield, nitrogen content, nitrogen uptake, and grain protein content, as well as certain soil chemical properties. At both sites, the conventional tillage and crop rotation system resulted in higher grain yield, nitrogen content, uptake, and protein content compared to minimum tillage and monocropping systems. Additionally, nitrogen fertilization had a significant impact on grain yield, nitrogen content, and uptake, with the application of 92 kg N ha^{-1} and 46 kg N ha^{-1} + 10 t compost ha^{-1} showing superior results at the Hawassa Zuria and Meskan sites, respectively. Consequently, a conventional tillage combined with a haricot bean-maize rotation system, supplemented with either 92 kg N ha^{-1} alone or 46 kg N ha^{-1} + 10 t compost ha^{-1}, is recommended for the Hawassa Zuria (Cambisols) and Meskan (Chernozem) districts, respectively, to achieve optimal yield and nitrogen uptake. However, for sustainable maize production in these areas, it is advisable to adopt an integrated nitrogen treatment along with minimum tillage and legume-based crop rotation to enhance soil properties, ultimately improving yields and nitrogen uptake.

REFERENCES

Adesoji, A.G., Abubakar, I.U. and Labe, D.A. 2015. Influence of incorporated legumes and nitrogen fertilization on maize (Zea mays L.) nutrient uptake in a Semi-Arid environment. Journal of Agriculture and Veterinary Science 8(3): 01-08.

Ashenafi, N., H. Wassie, A. Getachehu, and K. Alemayehu. 2021. Growth, Nitrogen Uptake of Maize (Zea mays L.) and Soil Chemical Properties, and Responses to Compost and

Nitrogen Rates and Their Mixture on Different Textured Soils: Pot Experiment. Applied and Environmental Soil Science. Pp. 12 https://doi.org/10.1155/2021/9931763

Benton, J.J. 2003. Agronomic handbook: Management of crops, soils, and their fertility. CRC Press LLC, 2000 N.W. Corporate Blvd., Boca Raton, Florida.

Chimdi, A., Gebrekidan, H., Kibret, K., Tadesse, A. 2012. Status of selected physio-chemical properties of soil under different land use system of Western Oromia, Ethiopia. Journal of Biological and Environmental Sciences 2(3):57-71.

CSA (Central Statistics Agency). 2019. Agricultural Sample Survey 2018/2019. Volume I. Report on Area and Production of Major Crops (Private Peasant Holdings, Meher Season). Statistical Bulletin 586. Addis Ababa.

Deepak, K.G., M.B. Roshan and K.S. Bishal. 2017. Effects of Biochar and Farmyard Manure on Soil Properties and Crop Growth in an Agroforestry System in the Himalaya. Sustainable Agriculture Research Journal 6: 1.

Dhillon, J., M. R. Del Corso, B. Figueiredo, E. Nambi, and W. Rau. 2018. Soil organic carbon, total nitrogen, and soil pH in a long-term continuous winter wheat (Triticum Aestivum L.) experiment. Communications in Soil Science and Plant Analysis. 19:803–13.

Dunjana, N.; Nyamugafata, P.; Shumba, A.; Nyamangara, J.; Zingore, S. 2012. Effects of cattle manure on selected soil physical properties of smallholder farms on two soils of Murewa, Zimbabwe. Soil Use Manag. 28: 221–228.

FAO (Food and Agricultural Organization) 2019. FAOSTAT statistical database and data sets of the Food and Agriculture Organization of the United Nations. Available at: http://www.faostat.fao.org.

Geisseler, D., W.R. Horwath. 2009. Short-term dynamics of soil carbon, microbial biomass, and soil enzyme activities as compared to longer-term effects of tillage in irrigated row crops. Biol. Fertil. Soils 16:65-72.

Hazelton P and Murphy B. 2007. Interpreting soil test results: What do all numbers mean? CSIRO publishing: Melbourne.

Kaplan, M., Karaman, K., Kardes, Y.M., Kale, H. 2019. Phytic acid content and starch properties of maize (Zea mays L.): Effects of irrigation process and nitrogen fertilizer. Food Chem. 283: 375–380.

Kassie, B.T., Hengsdijk, H., Rötter, R.P., Kahiluto, H., Asseng, S., and Ittersum, M.K.V. 2013. Adapting to climate variability and change: Experiences from cereal-based farming in the Central Rift and Kobo valleys, Ethiopia. Environ. Manag. 52:1115–1131.

Kirkegaard, J.A., O. Christen, J. Krupinsky, D. B. Layzell. 2008. Break crop benefits in temperate wheat production. Field Crops Research 107, 185–195. doi:10.1016/j.fcr.2008.02.010.

Lafond, G.P., May, W.E., Stevenson, F.C., Derksen, D.A. 2006. Effects of Tillage Systems and Rotations on Crop Production for a Thin Black Chernozem in the Canadian Prairies. Soil Tillage Res. 89: 232–215.

Lorenz, K. and R. Lal. 2016. Environmental Impact of Organic Agriculture. Adv. Agron. 139: 99-152.

Lupwayi, N. Z., A. C. Kennedy, and R. M. Chirwa. 2011. Grain legume impacts on soil biological processes in sub-Saharan Africa. Afr. J. Plant Sci. 5(1): 1-7.

Mourice, S.K., Tumbo, S.D., Nyambilila, A., Rweyemamu, C.L. 2015. Modeling potential rain-fed maize productivity and yield gaps in the Wami River subbasin, Tanzania. Acta Agriculturae Scandinavica, Section B: Soil and Plant Science, 65(2):132-110.

Negassa, W., Gebrekidan, H., Friesen, D.K. 2005. Integrated use of farmyard manure and NP fertilizers for maize on farmers' fields. J. Agric. Rural Dev. Trop. Subtrop. 106: 131–111.

Nelson, D.W. and Sommers, L.E. 1982. Total carbon, organic carbon, and organic matter. In: A. L. Page, R. H. Miller & D. R. Keeney, (eds.). Methods of Soil Analysis, Part 2 Chemical and microbiological properties. Agronomy monograph 9, Am. Society of Agronomy and Soil Science Society of America, Madison, Wisconsin, USA, pp. 539-591.

Nelson, L.A., Voss, R.D. and Pesek, J. 1985. Agronomic and statistical evaluation of fertilizer response. Pp. 89.

Rusinamhodzi, L., Corbeels, M., Zingore, S., Nyamangara, J., Giller, K.E. 2013. Pushing the envelope? Maize production intensification and the role of cattle manure in the recovery of degraded soils in smallholder farming areas of Zimbabwe. Field Crop. Res. 117: 10–53.

Salem, H.M., Valero, C., Muñoz, M.A., Rodríguez, M.G. and Silva, L.L. 2015. Short-term effects of four tillage practices on soil physical properties, soil water potential, and maize yield. Geoderma 237-238: 60-70.

SAS (Statistical Analysis System) 2001. SAS/STAT Software Syntax, Version 9.0. SAS Institute, Cary, NC. USA. 751pp.

Simić M, Dragičević V, Mladenović Drinić S, Vukadinović J, Kresović B, Tabaković M, Brankov M. 2020. The Contribution of Soil Tillage and Nitrogen Rate to the Quality of Maize Grain. Agronomy. 10(7):976. https://doi.org/10.3390/agronomy10070976.

Steel, R.G.D. and Torrie, J.H. 1980. Principles and Procedures of Statistics: a Biometrical Approach. 2nd Edition. McGraw-Hill. New York. Pp. 631.

Teklewold, H., Kassie, M., Shiferaw, B. 2013. Adoption of multiple sustainable agricultural practices in rural Ethiopia. J. Agric. Econ. 61: 597–623.

Tolera, A., Daba, F. and Friesen, D.K. 2009. Effects of Crop rotation and N-P Fertilizer Rate on Grain Yield and related characteristics of Maize and Soil Fertility at Bako Western Oromia, Ethiopia. East African Journal of Science 3: 70-79.

Wang, X., Zhou, B., Sun, X., Yue, Y., Ma, W., Zhao, M. 2015. Soil Tillage Management Affects Maize Grain Yield by Regulating Spatial Distribution Coordination of Roots, Soil Moisture and Nitrogen Status. Plops ONE 10 e0129231.

Wyngaard, N., H. Echeverrıa, H. R. Sainz Rozas, and G. A. Divito. 2012. Fertilization and tillage effects on soil properties and maize yield in a Southern Pampas Argiudoll. Soil and Tillage Research. 119: 22–30.

Yan D, Wang D and Yang L, 2007. Long-term effect of chemical fertilizer, straw, and manure on labile organic matter fractions in paddy soil. Biol. Fertil. Soils, 11(1):93-101.