Advances in Crop Science and Technology

Research Article **Open Access**

Nitrogen Uptake and Use Efficiency of Maize as Affected by Tillage, Cropping System and Nitrogen Fertilization on Cambisols and Phaeozems

Ashenafi Nigussie[1*], Wassie Haile[2], Getachew Agegnehu[2] and Alemayehu Kiflu[2]

[1]*Department of Natural Resource Management, Wondo Genet Agriculture Research Center, Shashemene, Ethiopia*

[2]*Department of Plant and Horticultural Sciences, Hawassa University College of Agriculture, Hawassa, Ethiopia*

Abstract

In the evaluation of crop production, knowledge related to nutrient use efficiency is a critical concept for sustainable agriculture. In the study areas, however, there is scant information on the influence of tillage, cropping systems and nitrogen fertilization and their interaction on nitrogen uptake and use efficiency of maize. In view of this, a field experiments were conducted in the central rift valley of Ethiopia on two different soils for two consecutive years to evaluate the effects of different soil management practices and their interaction on nitrogen uptake and use efficiencies. A three factor experiment was arranged as a split split plot arrangement randomized complete block design with three replications. Soil management practices were significantly affecting grain nitrogen content, grain nitrogen uptake, grain protein content, nitrogen harvest index and nitrogen utilization efficiency. In soils, the conventional tillage and haricot bean rotation system increased the grain nitrogen content and grain nitrogen uptake, in contrast to the minimum tillage and maize mono cropping. Application of nitrogen fertilizer was also affected the grain nitrogen content, grain nitrogen uptake, grain protein content and nitrogen harvest index. Tillage methods were significantly improved NHI and NUtE; NHI and NUtE of maize with higher in MT as compared to CT. Therefore, a conventional tillage along with haricot bean maize rotation system with the addition of integrated 46 kg N ha^{-1}+10 t compost ha^{-1} could be recommended for Cambisols and Phaeozems soils of the study areas. However, in order to ensure sustainable nitrogen utilization in the studied soils, an integrated N treatment plus MT and legume based rotation system could be recommended, which could improve NHI and NUtE.

Keywords: Fertilization; Grain quality; Harvest index; Nitrogen uptake; Utilization

Introduction

In the evaluation of crop production, knowledge related to nutrient use efficiency is a critical concept to ratify sustainable agricultural production and productivity. Nutrient Use Efficiency (NUE) is a complex and dynamic term containing a range of components. It is the product of absorption efficiency and utilization efficiency [1,2]. Nutrient use efficiency can be influenced by factors such as nutrient requirement or uptake ability of the crops, the capacity of the soil and fertilizers to supply nutrients and losses of nutrients from the soil plant systems, of which crop nutrient requirement is the major factor affecting NUE. Hence, understanding the driving factors that affect nutrient absorption, assimilation and mobilization are important to improve crop's NUE [3].

Nitrogen use efficiency can be modified through soil and plant water management practices [4,5]. Soil tillage can remarkably influence N dynamics in the soil by affecting soil aeration, microbial activities, OM decomposition and nutrient availability [6]. Other studies also confirmed that organic matter mineralization could be enhanced through CT and hence better yield and N availability [7]. However, CT has the potential to reduce SOM due to enhanced decomposition rate and hence, negatively affect long term crop productivity, nutrient uptake and soil health.

Pekrun, Ozpinar and Cay proved that adopting different tillage systems have their own effects on the delivery of both macro and micronutrients in topsoil. Among different agricultural management practices currently used, conservation tillage is a technique known to improve the uptake of soil N by the plant and to increase the content of SOM [8]. However, at the transitional time, yields, nutrient availability and uptake, particularly N, are the common problem for conservation tillage [9]. This could be due to the slower decomposition of OM and higher N-immobilization with crop residues [10].

The availability and dynamics of the key plant nutrients in soils are influenced by cropping patterns. When compared to monocropping, a legume based rotation system can improve N availability and uptake for successive cereal crops while also reducing N losses. Similarly, Fustec, Kihara and Njoroge reported that cropping systems can alter soil nutrient status and availability to succeeding crops.

The most critical nutrient for maize is nitrogen (N), which regulates grain yield through its participation in photosynthesis and other biological activities. To produce the optimum grain and biomass yields, maize needs a lot of nitrogen. Despite the huge amount of N-fertilizers used globally to achieve optimal grain yields, its RE is lower, ranging from 35% to 55% [11,12]. However, a better

***Corresponding author:** Ashenafi Nigussie, Department of Natural Resource Management, Wondo Genet Agriculture Research Center, Shashemene, Ethiopia, Tel: 913278860; E-mail: nashenafinew@gmail.com

Received: 27-October-2022, Manuscript No. ACST-22-76305; **Editor assigned:** 31-October-2022, PreQC No. ACST-22-76305; **Reviewed:** 14-November-2022, QC No. ACST-22-76305; **Revised:** 06-March-2023, Manuscript No. ACST-22-76305; **Published:** 13-March-2023, DOI: 10.4172/2329-8863.1000561

Citation: Nigussie A, Haile W, Agegnehu G, Kiflu A (2023) Nitrogen Uptake and Use Efficiency of Maize as Affected by Tillage, Cropping System and Nitrogen Fertilization on Cambisols and Phaeozems. Adv Crop Sci Tech 11: 561.

Citation: Nigussie A, Haile W, Agegnehu G, Kiflu A (2023) Nitrogen Uptake and Use Efficiency of Maize as Affected by Tillage, Cropping System and Nitrogen Fertilization on Cambisols and Phaeozems. Adv Crop Sci Tech 11:561.

understanding of NUE mechanisms, such as the utilization of appropriate N fertilizer sources, application rate and time, soil and water management and cropping system, can aid in maize NUE improvement.

Crop production with minimum input application is viewed as an alternative strategy in modern agriculture for achieving sustainable agricultural production. The judicious uses of N fertilizers have a remarkable consequence to produce sustainable agricultural outputs. Earlier studies distinguished that an increase in N input above a certain level, neither leads to an increase in grain production nor N-uptake; rather it might be a cause for environmental problems such as eutrophication and greenhouse gases emissions and also result in lodging, susceptibility to disease and pest attacks. Moreover, with an increase in N rates, an index of NUE (AE and RE) tends to decreases. Conversely, underutilization of N fertilizers contributes to the depletion of organic matter and be the prime cause for low crop productivity. Therefore, optimum N management is important to improve yield and N uptake and subsequently to reduce environmental concerns.

Urea is the most widely used N fertilizer in agriculture. Most crops utilized about 30%-70% of the applied inorganic N fertilizer; the rest is subject to losses through different ways such as leaching, surface run-off, volatilization, denitrification and the fixation mechanism in soil. Mineral nitrogen loss from the soil plant system not only reduces soil fertility and plant yield but also has a negative effect on the environment. To revert such phenomena, integrated organic and inorganic inputs application is imperative to enhance nutrient use efficiency of the plants particularly N. Previous studies also confirmed that amending soils with organic inputs like manure or compost along with mineral fertilizer improved soil air exchange, water holding capacity and infiltration rate in contrast to sole mineral fertilizers application and subsequently improved NUE.

There is a need to integrate efforts on the judicious use of different soil management practices to improve NUE and reduce environmental concerns [13]. In the study areas, however, information pertaining to the influence of tillage, cropping systems and nitrogen fertilization and their interaction on nitrogen uptake and use efficiency of maize is scant. Therefore, field experiments were carried out at Hawassa Zuria and Meskan district to evaluate the effect of different soil management practices and their interaction on nitrogen uptake and use efficiency of maize. The integrated use of organic and inorganic nitrogen fertilizers, along with crop rotation and minimum tillage, were expected to improve maize nitrogen uptake and use efficiency.

Materials and Methods

Description of experimental locations

The field experiments were carried out during two growing seasons (2019 and 2020) at Hawassa Zuria and Meskan districts of the central rift valley of Ethiopia. The Hawassa Zuria site is geographically located at 07°1’0.83"N Latitude and 38°22’26"E Longitude with an altitude of 1713 m above sea level (asl) is found 287 km south of Addis Ababa. Mainly characterized by a semi-arid climate with long term an average annual rainfall of 957.5 mm, of which 81% falls during the growing season (April to October) and an annual mean temperature of 21°C. The trial site at Meskan is found at 08°05'33"N Latitude and 38°26’75"E Longitude with an altitude of 1841 masl, 135 km south of Addis Ababa. The experimental site is mostly categorized under a semi-arid climate with a long term average annual rainfall of 987 mm, of which 84% falls during the growing season (April to October) and an annual mean temperature of 20.4°C.

The soil types for the field trial were Cambisols and Phaeozems, according to the WRB soil classification system. The soil at Hawassa Zuria has loam textural class, medium organic carbon and total nitrogen as rated by Landon, very low available P and medium CEC as rated by Hazelton and Murphy. Whereas the soil at Meskan has a clay textural class with high OC, medium TN, high available P and CEC as presented.

Treatment and experimental design

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 (RC) and Maize Monocropping (MM). In addition, four nitrogen levels (0, 20 t ha^{-1} compost, 46 kgNha^{-1}+10 t compost ha^{-1} and 92 kgNha^{-1}) were combined with tillage practices and cropping systems. The treatments were arranged in a split plot with tillage practice as the main plot, the cropping system as a subplot and the nitrogen levels as sub plot factor, RCBD, with three replications, making 48 sub plots for each experimental location. Three times and single ox-draw local plowing was used as conventional and minimum tillage practices, respectively. Moreover, minimum tillage plots received one application of roundup (glyphosate) herbicide 3 liters per hectare to control weeds before seed emergence.

Experimental procedures and management practices

Tillage practices as the main and cropping systems as subplots were arranged in a randomized complete block design with three replications during the 2019 main cropping season. During the field experiment, three and single ox-draw local plowing was used as a conventional and minimum tillage practice, respectively. Moreover, minimum tillage plots received one application of roundup (glyphosate) herbicide 3 liters per hectare to control weeds before seed emergence. A recently released hybrid maize variety (BH 546) and haricot bean variety (Hawassa Dume) were sown following optimum planting time, which is adapted to the agro ecologies of the study areas. Maize and haricot beans were sown at a space of 80 cm × 25 cm and 40 cm × 10 cm, respectively. Each main and sub Plot had an area of 15 m × 9 m=135 m^2 and 15 m × 4 m=60 m^2, respectively and the total experimental area was 31.5 m × 30 m=945 m^2. Phosphorus fertilizer was applied to all plots at planting as Triple Superphosphate (TSP) at the recommended rate (20 kgPha^1), in a band in the row. To minimize losses and increase the efficiency of N, Urea fertilizer was applied at the rate of 92 kgNha^{-1} in split form. Half at planting time and the remaining half at 35 days after sowing when the maize seedling reached a knee height stage, to all plots except the sole bean, which is in bean maize rotation treatment, assuming the bean benefited from its N fixation. Recommended agronomic practices were performed uniformly in all experimental units as per required. Furthermore, thirty percent (30%) of the crop residues were retained after harvesting in minimum tilled plots.

During the 2020 main cropping season, the experiment was laid out in a 2 × 2 × 4 factorial arrangement in a randomized complete block design with three replications. Each main plot (conventional and minimum tillage practices) had eight treatment combinations, *i.e,* two cropping systems with four levels of nitrogen fertilizer rates. According to the treatment, ten days before seed sowing, compost was applied in the upper 20 cm soil depth, based on inorganic N equivalency. Similarly, the hybrid maize variety (BH 546) was used as the test crop. The pathway between blocks and plots were 1.5 m and 1 m, respectively. Each sub sub plot had a size of 4.8 m × 3 m (14.4 m^2) and accommodated six maize rows with inter and intra row spacing of 80 cm and 25 cm, respectively. Each row and plot had 12 and 72 plants, respectively. The phosphorus fertilizer was applied to all plots at planting as Triple Superphosphate (TSP) at the recommended rate (20 $kgPha^1$), in a band in the row. However, the N fertilizer (urea) was applied in the split form: Half at planting and the other half at a knee height stage of the maize according to the treatments. Other agronomic practices were operated uniformly to all experimental units as per recommendation.

Grain yield and stover yield measurements

Samples of grains and stover of maize were collected at physiological maturity, which corresponds to 173 and 175 days after sowing at Hawassa Zuria and Meskan experiment sites, respectively. The samples were collected from a net plot area of 4 m^2 (1.25 m × 3.2 m) by excluding the border rows with three replications. Grain yield and stover DM yield were measured using a high capacity precision balance. The harvested grain yield was adjusted to a 12.5% moisture level and it was converted into hectare bases. A 20 gram of grain and stover samples was taken from each experimental unit. The grain and stover samples were oven dried at 70°C to constant weight thereafter; the samples were ground and passed through a 0.5 mm sieve. The nitrogen content in grain and stover were analyzed using the Kjeldahl procedure after wet digestion by H_2SO_4/H_2O_2. The grain and stover nitrogen contents analysis were executed at Kulumsa, soil chemistry laboratory.

Nitrogen uptake and use efficiency

The grain and stover nitrogen uptake were computed by multiplying N content with the respective grain and stover yields, respectively. The total N uptake was calculated by adding the N uptake in grain and N uptake in stover ($kgha^1$).

$$\text{Grain N uptake}\left(\frac{kg}{ha}\right)=\frac{\left(\text{Grain N content}\,\frac{g}{kg}\times\text{grain yield}\,\frac{kg}{ha}\right)}{1000}\quad(1)$$

$$\text{Stover N uptake}\left(\frac{kg}{ha}\right)=\frac{\text{Stover N content}\,\frac{g}{kg}\times\text{stover DM}\,\frac{kg}{ha}}{1000}\quad(2)$$

$$\text{Total N uptake}\left(\frac{kg}{ha}\right)=\text{Grain N uptake}\left(\frac{kg}{ha}\right)+\text{Stover N uptake}\left(\frac{kg}{ha}\right)\quad(3)$$

Agronomic Efficiency (AE) is defined as the economic production obtained per unit of nutrient applied. It was calculated by dividing the grain yield to the applied N.

$$AE\ (kg\ grain\ per\ kg\ N\ applied)=\frac{GYn-GYo}{FN\ applied}\quad(4)$$

Where GYn=Grain Yield of N fertilized plot, GYo=Grain Yield of N unfertilized plot and FN=amount of N applied per plots.

Agro Physiological Efficiency (APE) is defined as the economic production obtained per unit of nutrient uptake. It was calculated by dividing the grain yield produced per unit of total N uptake.

$$APE\ (kg\ grain\ per\ kg\ N\ uptake)=\frac{GYn-GYo}{TNUn-TNUo}\quad(5)$$

Where, GYn=Grain Yield from N fertilized plot, GYo=Grain Yield from N unfertilized plot, TNUn=Total N Uptake from N fertilized plot and TNUo=Total N Uptake from N unfertilized plot.

Apparent N Recovery Efficiency (ANRE) is calculated by dividing N uptake difference to kg N applied as described by Azizian and sepaskhah.

$$ANRE\ (kg\ N\ uptake\ per\ kg\ N\ applied)=\frac{TNUn-TNUo}{FN\ applied}\quad(6)$$

Where, TNUn=Total N uptake from N fertilized plot and TNUo=Total N Uptake from N unfertilized plot and FN=amount of N applied.

Nitrogen Utilization Efficiency (NUtE) was calculated according to using the following equations:

$$NUtE=\frac{Grain\ yield\ (\frac{kg}{ha})}{TNU\ (\frac{kg}{ha})}\quad(7)$$

Nitrogen Harvest Index (NHI) was computed using the following formula:

$$Nitrogen\ harvest\ index\ (\%)=\frac{\left(grain\ N\ uptake\,\frac{kg}{ha}\right)}{Total\ N\ uptake\ kg/ha}\times 100\quad(8)$$

$$Grain\ protien\ content\ (\%)=Grain\ N\ content\ (\%)\times 6.25\quad(9)$$

Data analysis

Prior to Analysis of Variance (ANOVA), the normality of the data was tested using the Shapiro Wilk normality test. Analysis of variance was done for each location independently using the SAS 9.3 software package, considering the experimental treatments as a fixed factor and replication as a random factor. Differences among treatments was separated with the protected Least Significant Difference (LSD) at $P<0.05$ probability level. Pearson correlation coefficient (r) was done using SAS software 9.3. All graphs were designed using Origin 2021 procedures.

The statistical model for three way design is:

$$Y_{ijkl}=\mu+ \alpha_i +\beta_j + \Theta_k + (\alpha\beta_{ij} + \alpha\Theta_{ik} + \beta\Theta_{jk}) + (\alpha\beta\Theta_{ijk}) +\varepsilon_{ijkl}$$

Where Yijkl denotes the cell's first score at the ith level of factor A, the j^{th} level of factor B and the K^{th} level of factor C.

Results and Discussion

Effects of experimental factors and their interactions on grain and stover N contents and uptakes of maize

The main effects of CS, NF and the interaction of TM × CS and CS × NF and TM × CS × NF showed significant ($P<0.05$) effects on gain N-content, N-uptake and protein content at Hawassa Zuria. Whereas at Meskan, gain N content, N uptake and protein content were significantly influenced by the main effects of CS and NF and the interaction of CS × NF. At Hawassa Zuria, the main factors of TM, CS and NF and the interaction of CS × NF had a significant effect on NUtE. Likewise, the NUtE of the Meskan site was significantly affected by the main factors of TM, CS and NF and the interaction of CS × NF and TM × CS × NF.

The main effects of tillage methods, cropping systems and N fertilization on grain and stover N contents and uptakes of maize grown at the two sites

Tillage methods had no significant effect on grain N content in both sites. This result is at par with the findings of Habbib who indicated no significant effect of tillage on grain N content [14]. Tillage methods at Hawassa Zuria showed significant variation in stover N content, grain N uptake, stover N uptake and Total N Uptake (TNU), with CT achieving the higher values compared to MT. However, at Meskan, SNU and TNU only revealed significant ($P<0.05$) variation with higher values of 80.8 $kgha^{-1}$ and 170.5 $kgha^{-1}$, respectively. Although there were no significant variations observed in grain N content, stover N content and N uptake at Meskan, CT in general, offered higher values compared to MT.

In both soils, 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. Significantly higher N content and total N uptake under conventionally tilled plots of maize might be due to improved root growth, density and soil moisture availability [15]. Similarly, Masvaya reported that crop yields and N uptake were superior in CT as compared to MT. Tilling soils through the conventional method usually improves the soil aeration and organic matter decomposition. Similarly, Simic verified the benefit of conventional tillage for better maize grain yield and enhancement in grain protein content [16]. Conversely, minimum soil disturbance resulted in reduced available soil N, which is largely due to an increase in N immobilization. A similar finding was reported by Malhi. describing the shifting of CT to MT tends to decrease nutrient concentrations in the soils and thereby uptake, particularly N, which could be improved through the addition of optimal N and inclusion of legume, crops as a precursor. Based on the existing information, MT seems to have lower N uptake efficiency compared to CT, which is positively coincided with the yield and yield components and higher value was obtained from CT. Therefore, application of optimum N is advisable to overcome the effect of N immobilization under MT to enhance N mineralization.

At Hawassa Zuria, cropping systems had significant ($P<0.05$) effects on GNC, GNU, SNC, SNU and TNU; higher values were achieved from the haricot bean maize rotation system than maize monocropping. The haricot bean maize rotation system increased maize GNC, SNC, GNU, SNU and TNU by 17.8, 21.4, 17.6, 28.8 and 25.1% in Hawassa Zuria, respectively, compared to maize monocropping. Similarly, cropping systems used at Meskan had significant effects on GNC, SNC, GNU, SNU and TNU. In comparison to maize monocropping, the haricot bean maize rotation system improved GNC and GNU by 10% and 12.1%. This was possibly due to the change in inorganic N availability in the soil caused by previous atmospheric N_2 fixation and legume residue decomposition since legume residues have better quality and a narrow C:N ratio, which results in rapid release of N from the residues [17]. Similarly, Adesoji, found improved N content and uptake in maize following soybean rotation system due to enhanced soil N [18].

In this study, the mean grain N content, N uptake, stover N content and related components were higher in the Meskan than in Hawassa Zuria at all treatments of nitrogen fertilization. The differences in N contents and uptakes in grain and stover between locations were associated with grain and stover yields, whereby Meskan yields were higher than that of Hawassa Zuria. This could be due to the higher initial soil TN and fertility status of the soil at Meskan as compared to the Hawassa Zuria.

Analysis of variance depicted that nitrogen fertilization had significant effects on GNC, SNC, GNU, SNU and TNU in both sites (Table 1). In both locations, higher stover and total N uptake at higher inorganic N levels could be due to more N available for plant uptake [19]. When compared to the unfertilized plot, the combined application of inorganic nitrogen and compost at a rate of 46 $kgNha^{-1}$+10 t ha^{-1} improved GNC, SNC, GNU, SNU and TNU by 35.4, 46.4, 64.5, 67 and 65.7% in Hawassa Zuria and 24.3, 12.2, 68.2, 23.1 and 46.5% in Meskan, respectively. Our result is in covenant with the findings of Dunjana, Negassa and Rusinamhodzi which indicated that integrated application of organic and mineral fertilizers at appropriate rates can be an effective approach to improve maize N uptake [20-22]. In the present study, the grain, stover and total N uptake of maize treated with sole organic input (compost) was lower than that of maize treated with sole inorganic N fertilizer, possibly due to the slow release nature of the nutrients from organic input as was also reported by Makinde and Ayoola [23].

Treatments	**Hawassa Zuria**					**Meskan**				
	GNC	**SNC**	**GNU**	**SNU**	**TNU**	**GNC**	**SNC**	**GNU**	**SNU**	**TNU**
	(%)		**($kgha^{-1}$)**	**(%)**	**($kgha^{-1}$)**					
Tillage methods										
MT	0.96	0.33^b	35.6	36.4^b	71.9^b	1.24	0.48	89.03	72.6^b	161.8^b
CT	0.99	0.41^a	39.1	46.9^a	86.5^a	1.25	0.49	89.7	80.8^a	170.5^a

LSD (0.05)	ns	0.05	ns	6.53	4.46	ns	ns	ns	4.76	6.36
Cropping systems										
RCS	1.06^{a}	0.40^{a}	40.9^{a}	47.2^{a}	88.08^{a}	1.32^{a}	0.38^{b}	94.5^{a}	59.8^{b}	154.3^{b}
MCS	0.90^{b}	0.34^{b}	33.7^{b}	36.7^{b}	70.41^{b}	1.2^{b}	0.59^{a}	84.3^{b}	93.6^{a}	177.8^{a}
LSD (0.05)	0.09	0.01	3.8	2.6	6.03	0.03	0.01	5.6	9.26	11.9
Nitrogen fertilization										
Control	0.82^{d}	0.28^{d}	26.8^{c}	28.8^{d}	55.65^{c}	1.11^{c}	0.41^{c}	66.9^{d}	61.1^{c}	128.1^{d}
20 t ha^{-1} Compost	0.94^{c}	0.36^{c}	34.2^{b}	38.5^{c}	72.75^{b}	1.18^{c}	0.49^{b}	75.8^{c}	75.8^{b}	151.6^{c}
46 kgNha^{-1} +10 t ha^{-1} Compost	1.11^{a}	0.41^{a}	44.1^{a}	48.1^{b}	92.21^{a}	1.38^{a}	0.46^{b}	112.5^{a}	75.2^{b}	187.7^{b}
92 kgNha^{1}	1.05^{a}	0.43^{a}	44.1^{a}	52.2^{a}	96.37^{a}	1.3^{b}	0.59^{a}	102^{b}	94.7^{a}	198.4^{a}
LSD (0.05)	0.06	0.02	0.06	3.33	4.56	0.07	0.04	4.2	5.14	4.8
Note: 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 ≤ 0.05 according to LSD test. GNC: Grain N-Content; SNC: Stover N-content; GNU: Grain N-Uptake; SNU: Stover N-Uptake; TSU: Total N-Uptake										

Table 1: The effects of tillage methods, cropping systems and N fertilization on grain and stover N concentrations and uptakes of maize at the two sites.

According to Xu, Grain Protein Content (GPC) is an important quality parameter for cereal crops. The present study showed that tillage practice had no considerable effect on GPC in both sites, with maximum values of 6.25 and 8.83 at Hawassa Zuria and Meskan, respectively. Similarly, Sabo reported a non-significant effect of tillage systems on GPC. However, cropping systems had a significant effect on GPC [24]. Maize after haricot bean contained more GPC as compared to maize after maize cropping system. Higher grain protein contents in the legume based rotation system of the present study might be due to more N-uptake by maize grain compared to maize monocropping.

Similarly, nitrogen fertilization increased GPC, as nitrogen plays a vital role in enhancing protein content due to the existence of the amino group, which is a protein building block [25]. The unfertilized plot gave the lowest result at both locations, with values ranging from 5.12 to 6.92% at Hawassa Zuria and 6.99 to 9.25% at Meskan. When compared to the unfertilized plot, the integrated usage of mineral N and compost enhanced GPC by 35.7 and 18.5% for Hawassa Zuria and Meskan, respectively. At both sites, the increase in grain protein content corresponded to an increase in the nitrogen levels. Nitrogen Harvest Index (NHI) is the proportion of N in grain relative to total aboveground biomass and is an indicator of N translocation efficiency [26]. Tillage methods had a significant effect on Nitrogen Utilization Efficiency (NUtE) but not on NHI at Hawassa Zuria, whereas tillage methods had significant impacts on both NHI and NUtE at Meskan. In both sites, MT had higher NHI and NUtE than CT, implying that MT aided in the efficient utilization of supplied nitrogen. Different cropping systems had significant effects on NHI and NUtE at Meskan, while NUtE only showed a significant variation due to cropping systems at Hawassa Zuria. However, maize cultivated after haricot bean had higher NHI and NUtE values than maize grown after maize.

Nitrogen fertilization had significant effects on NHI and NUtE in both sites. The combined N treatment produced the highest NHI, with average values of 48.7% and 60.3% for Hawassa Zuria and Meskan, respectively (Table 2). This finding showed that using an organic N source in conjunction with mineral N fertilizer could improve the inorganic N utilization efficiency. Similarly, the N application had a significant impact on NUtE. However, the unfertilized plot had the highest NUtE, whilst the maximum N levels had the lowest N utilization efficiency. This result is consistent with previous findings by Qiao and Wassaya who reported the lowest NUtE in rice and maize were recorded in maximum N levels [27,28].

Treatments	**Hawassa Zuria**			**Meskan**		
	GPC	**NHI**	**NUtE**	**GPC**	**NHI**	**NUtE**
	(%)			**(%)**		
Tillage methods						
MT	6.02	49.9	53.0^{a}	7.8	55.65^{a}	44.67^{a}
CT	6.25	45.5	46.4^{b}	7.3	52.72^{b}	42.07^{b}
LSD (0.05)	ns	ns	3.5	ns	2.16	2.33
Cropping systems						
RCS	6.72^{a}	48	53.4^{a}	8.3^{a}	61.24^{a}	46.38^{a}

MCS	5.65^{b}	47.3	45.9^{b}	7.3^{b}	47.14^{b}	40.36^{b}
LSD (0.05)	0.55	ns	3.78	0.21	2.87	2.01
Nitrogen fertilization						
Control	5.12^{d}	48.2^{ab}	59.8^{a}	6.99	52.89^{b}	47.04^{a}
20 t ha^{-1} Compost	5.88^{c}	47.1^{ab}	50.4^{b}	7.4^{c}	50.99^{b}	42.95^{b}
46 kgNha^{-1}+10 t ha^{-1} Compost	6.95^{a}	48.7^{a}	44.4^{c}	8.6^{a}	60.27^{a}	43.68^{b}
92 kgNha^{1}	6.57^{a}	45.9^{b}	44.2^{c}	8.3^{b}	52.59^{b}	39.81^{c}
LSD (0.05)	0.35	2.16	2.6	0.25	2.49	1.73

Note: Means followed by the same letter did not differ significantly across the tillage methods, cropping systems and N-fertilization at P ≤ 0.05 according to LSD test. GPC: Grain Protein Content; NHI: Nitrogen Harvest Index; NUtE: Nitrogen Utilization Efficiency

Table 2: Means for the main effects of tillage, cropping systems and nitrogen fertilization on GPC, NHI and NUtE of maize grown at the two sites.

Effects of tillage, cropping systems and N fertilization on nitrogen use efficiency components of maize grown at the sites

Agronomic Eficiency (AE) is one of the components of NUE, which mainly depends on soil and crop management practices. It ranges from 10 kg to 30 kg yield per kg of nutrient applied [29]. In our study, insignificant variation in AE was detected between the MT and CT in both sites. At Hawassa Zuria, the cropping systems showed a statistically significant variance in AE, but not at Meskan. However, higher AE in both sites was recorded in the haricot bean maize rotation system than in maize mono cropping. Nitrogen fertilization had a significant effect on AE at Meskan but not at Hawassa Zuria. Despite the insignificant difference observed in AE at Hawassa Zuria, the highest value was recorded from the integrated N-treatment in both sites. This result is consistent with Vanlauwe, who found maximum AE of N with co-addition of mineral fertilizer with compost (36 kg maize grain kg^{-1}N).

Fageria and Baligar define Apparent Nitrogen Recovery Efficiency (ANRE) as the crop's ability to remove nitrogen from the soil. Under current farming practices, its value in cereal crops ranged from 0.17 to 0.33, 0.25 to 0.49 in research plots and 0.55 to 0.96 in well managed research plots. In the present study, tillage methods had no significant effect on ANRE in either location. Similarly, Alvarez reported insignificant differences in nitrogen recovery efficiency between different tillage systems. On the other hand, cropping systems had a significant impact on ANRE, with higher ANRE for Hawassa Zuria and Meskan in the haricot bean maize rotation and maize mono cropping, respectively. Carsky found that maize following soybean had lower ANRE than maize mono cropping.

At both sites, ANRE showed a statistically significant variation due to nitrogen fertilization, with a decreasing trend as N levels increased. Despite the inherent soil fertility differences between the experimental sites, the integrated N treatment resulted in the highest ANRE of 57% for Hawassa Zuria and 93% for Meskan, indicating that integrated N treatment caused in less N loss (Table 3). This result confirms the fact that organic inputs application reduces the leaching of applied inorganic N fertilizer and promotes better use of applied mineral nutrients [30].

The effect of a single application of compost and mineral N fertilizer on ANRE differed between the two sites; this could be due to the differences in soil textural classes. Similarly, Huggins and Pan found that soil textural classes could be a good attributor for N losses in the form of volatilization, leaching, fixation and immobilization. At Meskan, the sole compost treated plot had a lower ANRE than the mineral N treated plot, but at Hawassa Zuria, the sole mineral N treated plot had a lower ANRE than the compost treated plot. According to Moll and Huggins and Pan, poor N RE is caused by N fluxes to competing channels such as gaseous N losses, leaching and biological N immobilization.

Treatments	**Hawassa Zuria**			**Meskan**		
	AE	**PE**	**ANRE**	**AE**	**PE**	**ANRE**
Tillage methods						
MT	9.12	20.85	48.57	22.3	29.3	78.5
CT	11.61	23.66	49.41	21.1	29.1	77
LSD (0.05)	ns	ns	ns	ns	ns	ns
Cropping systems						

RCS	11.42	18.49^b	62.9^a	23.8	36.1^a	66.7^b
MCS	9.31	26.02^a	35.1^b	19.7	22.3^b	88.8^a
LSD (0.05)	ns	4.8	7.9	ns	6.01	10.6
Nitrogen fertilization						
20 t ha^{-1} Compost	10.59	22.23	47.5^{ab}	11.98^c	23.14^b	65.4^b
46 kgNha^{-1}+10 t ha^{-1} Compost	10.64	21.55	55.3^a	34.09^a	36.77^a	93.2^a
92 kgNha^1	9.86	22.99	44.3^b	19.07^b	27.62^b	74.7^b
LSD (0.05)	ns	ns	11.67	6.38	7.36	12.9
CV (%)	30.6	31.3	27.16	33.9	29.2	19.2
Note: Means followed by the same letter did not differ significantly across the tillage methods, cropping systems and N-fertilization at P ≤ 0.05 according to LSD test. AE: Agronomic Efficiency; PE: Physiological Efficiency; ANRE: Apparent N-Recovery Efficiency; CV: Coefficient of Variation						

Table 3: Means for main effects of tillage, cropping system and nitrogen fertilization on AE, PE and ANRE of maize grown at the two sites.

In both sites, there was no significant variation in Physiological Efficiency (PE) across tillage methods. On the other hand, cropping systems had a significant effect on PE, with maize monocropping and haricot bean-maize rotation systems providing higher PE at Hawassa Zuria and Meskan sites, respectively [31]. At Meskan, N fertilization had a significant effect on PE; the integrated N treatment gave the highest value of 36.77 kg grain per kilogram N uptake.

The three-way interactions of tillage methods, cropping systems and N fertilization

At Hawassa-Zuria, the three-way interaction of TM, CS and NF significantly (p ≤ 0.05) affected GNC, GNU and SNC (Figures 1 and 2). At Meskan, however, the three way interaction had brought significant (p ≤ 0.05) variation on the SNC, TNU and NUtE parameters.

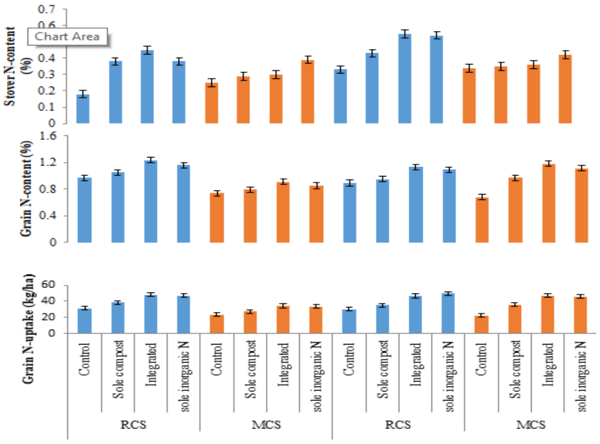

Figure 1: Interaction effects of tillage methods, cropping systems and nitrogen fertilization on grain and stover nitrogen concentration and grain N-uptake of maize growth at Hawassa Zuria soil.

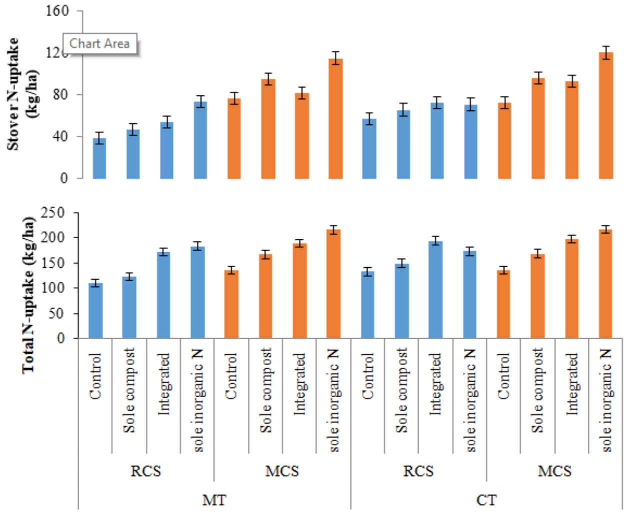

Figure 2: Interaction effects of tillage methods, cropping systems and nitrogen fertilization on stover nitrogen uptake and total N uptake of maize growth at Meskan soil.

Pearson`s correlation coefficients

Pearson correlation coefficient of grain yield under different soil management practices were positively and significantly correlated with GNC, GNU, TNU, GPC, AE, PE and ANRE (r=0.71, 0.89, 0.93, 0.71, 0.81, 0.63 and 0.73) in Hawassa Zuria and (r=0.73, 0.95, 0.84, 0.74, 0.93, 0.86 and 0.78) in Meskan, respectively. This observation is consistent with the findings of Milena, which indicated that grain yield was positively and highly correlated with grain protein content (r=0.82) and nitrogen uptake.

In our investigation, the association between GY to ANRE was stronger than that of GY to PE at Hawassa Zuria. This tells us applying N-containing fertilizers is more recommended for Hawassa

Citation: Nigussie A, Haile W, Agegnehu G, Kiflu A (2023) Nitrogen Uptake and Use Efficiency of Maize as Affected by Tillage, Cropping System and Nitrogen Fertilization on Cambisols and Phaeozems. Adv Crop Sci Tech 11:561.

Zuria in order to enhance maize productivity rather than adopting practices that contribute to efficient N utilization, which might probably be due to smaller initial soil total N content. This result is concomitant with the findings of Bingham, which indicated a stronger association between maize grain yields to ANRE over that of GY to PE. However, at Meskan, the correlation between GY to PE was stronger than GY to ANRE, suggesting physiological efficiency is more vital than apparent N recover efficiency (Table 4). Thus, adopting improved soil and crop management practices are essential to augment grain yield in contrast to applying additional N inputs, probably due to the presence of higher initial soil total N at Meskan site than that of Hawassa Zuriya. In both sites, grain yield positively significantly correlated with the components of N use efficiency, indicating NUE can be increased by improving the grain yield per unit of N application.

	GY	SY	GNC	SNC	GNU	SNU	TNU	GPC	NHI	NUtE	AE	PE	ANRE
GY	1	0.62**	0.71***	0.83**	0.89***	0.84**	0.93***	0.71**	-0.21	-0.86***	0.81***	0.63**	0.73**
SY	0.44	1	0.17	0.61*	0.38	0.79**	0.68**	0.17	-0.64**	-0.63**	0.38	0.31	0.41
GNC	0.73**	0.29	1	0.55	0.96***	0.49	0.73**	1.00***	0.34	-0.72**	0.71**	0.37	0.75**
SNC	0.23	0.03	-0.2	1	0.72**	0.96***	0.94***	0.55*	-0.56**	-0.95***	0.71**	0.37	0.77**
GNU	0.85***	0.4	0.90**	0.03	1	0.68**	0.88**	0.95***	0.13	-0.83***	0.79**	0.48	0.79**
SNU	0.36	0.33	-0.11	0.95***	0.16	1	0.95**	0.49	-0.60*	-0.91***	0.64**	0.33	0.71**
TNU	0.84***	0.48	0.48	0.68**	0.73**	0.79**	1	0.73*	-0.34	-0.96***	0.76**	0.43	0.80**
GPC	0.74**	0.29	1.00***	-0.21	0.91***	-0.1	0.49	1	0.34	-0.72**	0.71**	0.37	0.75**
NHI	0.27	-0.12	0.71**	-0.76***	0.50*	-0.76**	-0.22	0.71*	1	0.4	-0.08	-0.04	-0.14
NUtE	-0.36	-0.47	0	-0.87***	-0.2	-0.97**	-0.80**	0.01	0.70**	1	-0.77***	-0.44	-0.83***
AE	0.93***	0.34	0.76**	0.05	0.92**	0.15	0.67**	0.76**	0.43	-0.17	1	0.80***	0.91***
PE	0.86**	0.33	0.72**	-0.12	0.80**	-0.03	0.47	0.73*	0.52*	0	0.86***	1	0.53*
ANRE	0.78**	0.33	0.53*	0.49	0.72**	0.57*	0.84***	0.53*	-0.03	-0.60*	0.81***	0.62*	1

Note: Significant at *p<0.05, **p<0.01, ***p<0.001; ns: not significant. GY: Grain Yield; SY: Stover Yield; GNC: Grain N Content; SNC: Stover N Content; GNU: Grain Nitrogen Uptake; STU: Stover Nitrogen Uptake; TNU: Total Nitrogen Uptake; GPC: Grain Protein Content; NUtE: Nitrogen Utilization or Internal Efficiency; AE: Agronomic Efficiency; PE: Physiological Efficiency; ARE: Apparent N Recovery Efficiency

Table 4: Pearson`s coefficients of correlation for gain, stover yields, N uptake and N use efficiency of maize grown with two tillage methods, two cropping system and four nitrogen levels at Hawassa Zuria (upper right side) and at Meskan (lower left side).

Conclusion

The results revealed that soil management practices had different effects on GNC, GNU, GPC, NHI, NUtE and N utilization efficiency components. In both soils, the CT and RCS increased the GNC and GNU, in contrast to the MT and MCS, respectively. We observed that N content, uptake and use efficiency were stimulated under CT compared to the MT. In comparison to maize mono cropping, the haricot bean maize rotation system improved grain N uptake and NUE in both soils. Correspondingly, nitrogen fertilization evidently affected the GNC, GNU, GPC and NHI.

However, tillage methods differed in their effects on NHI and NUtE; NHI and NUtE were improved through MT compared to CT. Therefore, a CT along with haricot bean-maize rotation system with the addition of integrated 46 kgNha^{-1}+ 10 t compost ha^{-1} could be recommended for both soil types of the study areas. However, to ensure sustainable nitrogen utilization in the studied soils of the study area, an integrated N-treatment plus MT and legume based rotation system could be recommended, which could improve NHI and NUtE.

References

1. Hirel B, Tetu T, PLea PJ, Dubois F (2011) Improving nitrogen use efficiency in crops for sustainable agriculture. Sustainability 3: 1452-1485.
2. Mi G, Chen F, Zhang F (2007) Physiological and genetic mechanisms for nitrogen use efficiency in maize. J Crop Sci Biotechnol 10: 57-63.
3. Lewis CE, Noctor G, Causton D, Foyer C (2000) Regulation of assimilate partitioning in leaves. Aust J Plant Physiol 27: 507-519.
4. Djaman K, Irmak S, Martin DL, Ferguson RB, Bernards ML (2013) Plant nutrient uptake and soil nutrient dynamics under full and limited irrigation and rainfed maize production. Agron J 105: 527-538.
5. Qiu SJ, He P, Zhao SC, Li WJ, Xie JG, et al. (2015) Impact of nitrogen rate on maize yield and nitrogen use efficiencies in northeast China. Agron J 107: 305-313.
6. Wasaya A, Tahir M, Ali H, Hussaina M, Yasir TA, et al. (2017) Influence of varying tillage systems and nitrogen application on crop allometry, chlorophyll contents, biomass production and net returns of maize (*Zea mays* L.). Soil Till Res 170: 18-26.
7. Dinnes DL, Karlen DL, Jaynes DB, Kaspar TC, Hatfield JL, et al. (2002) Nitrogen management strategies to reduce nitrate leaching in tile drained Midwestern soils. Agron J 94: 153-171.
8. Jin L, Cui H, Li B, Zhang J, Dong S, et al. (2012) Effects of integrated agronomic management practices on yield and nitrogen efficiency of summer maize in North China. Field Crop Res 134: 30-35.
9. Pittelkow CM, Linquist BA, Lundy ME, Liang X, van Groenigen KJ, et al. (2015) When does no-till yield more? A global meta-analysis. Field Crops Res 183: 156-168.
10. Malhi SS, Grant GA, Johnston AM, Gill KS (2001) Nitrogen fertilization management for no-till cereal production in Canadian Great Plain: A review. Soil Till Res 60: 101-122.
11. Couto-Va´zquez AM, Gonza´lez-Prieto SJ (2016) Fate of 15N-fertilizers in the soil plant system of a forage rotation under conservation and plough tillage. Soil Tillage Res 161: 10-18.
12. Kumar R, Singh M, Tomar SK, Meena BS, Rathore DK (2016) Productivity and nutritive parameters of fodder maize under varying plant density and fertility levels for improved animal productivity. Indian J Anim Res 50: 199-202.

13. Kumar G, Singh M, Kumar R, Yadav RK, Datt C, et al. (2015) Yield and quality of fodder turnip as affected by nitrogen application and weed management during winter lean period. Indian J Anim Nutr 32: 57-62.
14. Habbib H, Verzeaux J, Nivelle E, Roger D, Lacoux J, et al. (2016) Conversion to no till improves maize nitrogen use efficiency in a continuous cover cropping system. PLoS One 11 : 0164234.
15. Wang X, Zhou B, Sun X, Yue Y, Ma W, et al. (2015) Soil tillage management affects maize grain yield by regulating spatial distribution coordination of roots, soil moisture and nitrogen status. PLoS One 10: e0129231.
16. Simic M, Dragicevic V, Mladenovic Drinic S, Vukadinovic J, Kresovic B, et al. (2020) The contribution of soil tillage and nitrogen rate to the quality of maize grain. Agronomy 10: 976.
17. Lafond GP, May WE, Stevenson FC, Derksen DA (2006) Effects of tillage systems and rotations on crop production for a thin black chernozem in the canadian prairies. Soil Tillage Res 89: 232-245.
18. Adesoji AG, Abubakar IU, Labe DA (2015) Influence of incorporated legumes and nitrogen fertilization on maize (*Zea mays* L.) nutrient uptake in a Semi-Arid environment. J Agric Vet Sci 8: 01-08.
19. Hussaini MA, Ogunlela VB, Ramalan AA, Falaki AM (2008) Mineral composition of dry season maize (*Zea mays* L.) in response to varying levels of nitrogen, phosphorus and irrigation at Kadawa, Nigeria. World J Agric Sci 4: 775-780.
20. 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.
21. Negassa W, Gebrekidan H, Friesen DK (2005) Integrated use of farmyard manure and NP fertilizers for maize on farmers' fields. J Agric Rural Dev Trop Subtrop 106: 131-141.
22. Rusinamhodzi L, Corbeels M, Zingore S, Nyamangara J, Giller KE (2013) Pushing the envelope? Maize production intensification and the role of cattle manure in recovery of degraded soils in smallholder farming areas of Zimbabwe. Field Crop Res 147: 40-53.
23. Makinde E, Ayoola O (2010) Growth, yield and NPK uptake by maize with complementary organic and inorganic fertilizers. African J Food Agric Nutr Dev 10: 2204-2217.
24. Sabo M, Jug D, Jug I (2007) Effect of reduced tillage on quality traits of soybean (*Glycine max L. Merr)*. Acta Agron Hungar 55: 83-88.
25. Zhang HL, Wang Q, Zhao YL, Yang QH, Li CH (2010) Effects of nitrogen fertilization rate and harvest time on summer maize grain yield and its quality. Ying Yong Sheng Tai Xue Bao 21: 2565-2572.
26. Soon YK, Clayton GW (2002) Eight years of crop rotation and tillage effects on crop production and N fertilizer use. Can J Soil Sci 82: 165-172.
27. Qiao J (2012) Nitrogen fertilizer reduction in rice production for two consecutive years in the Taihu Lake area. Agric Ecosyst Environ 146: 103-112.
28. Wasaya A, Tahir M, Yasir TA, Akram M, Farooq O, et al. (2018) Soil physical properties, nitrogen uptake and grain quality of maize (*Zea mays* L.) as affected by tillage systems and nitrogen application. Ital J Agron 13: 1197.
29. Berihun T, Tadele M, Kebede F (2017) The application of biochar on soil acidity and other physico-chemical properties of soils in southern Ethiopia. J Plant Nutr Soil Sci 180: 381-388.
30. Almaz MG, Halim RA, Yusoff MM, Wahid SA (2017) Effect of incorporation of crop residue and inorganic fertilizer on yield and grain quality of maize. Indian J Agric Res 51: 574-579.
31. Griffin TS (2008) Nitrogen availability. Nitrogen Agric Syst 49: 616-646.