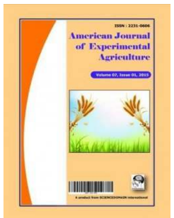

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Varieties and Nitrogen Rates on Grain Yield and Nitrogen Use Efficiency of Highland Maize in Toke Kutaye, Western Ethiopia

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Authors' contributions

This work was carried out in collaboration between all authors. Author TA designed the study, wrote the protocol, managed the field study and wrote the first draft of the manuscript. Authors DW and TD reviewed the experimental design, managed the literature searches and all drafts of the manuscript. Authors TA, DW and TD managed the analyses of the study. Author TA identified the plants and performed the statistical analysis. All authors read and approved the final manuscript.

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ABSTRACT

Soil fertility depletion is a widespread degradation problem in achieving global food security, but different attempts are available for maize production systems to alleviate the problems. Nitrogen use efficiency is required to meet increasing demands to produce sufficient food for the increasing population with sustainable production systems. Mean grain yield of maize positively affected by increased application of nitrogen fertilizer. Hybrid maize varieties were produced higher grain yield as compared open pollinated variety of maize. Higher agronomic efficiency of 35 to 46 as compared to Horra (OPV); and 5-16 as compared to Wenchi (hybrid) were harvested from Jibat

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followed by Wenchi and Webii varieties of maize planted with half recommended nitrogen rate. Higher nitrogen uptake efficiency and nitrogen use efficiency were obtained from Jibat followed by Webii and Wenchi varieties of maize planted with half recommended nitrogen fertilizer applied. Significantly higher nitrogen fertilizer (recovery) use efficiency 79.94% was obtained from maize varieties planted with half nitrogen fertilizer application as compared to recommended. Higher combined mean nitrogen use efficiency was obtained as compared to Horra variety relative to Wenchi. Hybrid highland maize varieties were more nitrogen use efficiency compared to open pollinated varieties. Uses of hybrid highland maize varieties (Jibat and Wenchi) were desirable options and recommended for sustainable maize production in highland areas of Toke Kutaye Western Ethiopia.

Keywords: Varieties; Nitrogen use efficiency; shoots N accumulation; grain N accumulation.

1. INTRODUCTION

Soil is an important factor in crop production and its degradation is one of the limiting factors for sustainable agriculture [1]. With the ever-increasing population, soil fertility management by long fallow periods is practically impossible [2]. The application of mineral fertilizer as sole soil fertility management method under intensive continuous cropping is also no longer feasible due to scarcity, high cost [3] where available and the numerous side effects on the soil. Quiñones et al. [4] stated traditional farming systems in Africa are responsible for the loss of a considerable hectares of forest that are cleared annually to give a room or substitute for the cropland that has become unproductive because of nutrient depletion and the nature of the soil. Forest clearing and continuous cultivation depleted up to 63% of soil organic carbon (SOC) under smallholder farmers in southern Ethiopia Dawite et al. [5], whereas the depletion was extended up to 79% under mechanized cultivation in western Ethiopia within three decades [6]. Sanchez et al. [7,8] reported soil fertility depletion in smallholder farming is the fundamental biophysical root cause of stagnant per capital food production in Africa. The shortage of fertilizer additions has resulted in enormous nutrient depletion and a reduction in yields, due to shortages in nutrients for plant growth. The rate of nutrient depletion has increased over the last 20 years and most of the losses of nitrogen from the soil have occurred since 1985 [9]. Currently, gross nitrogen losses from cultivated African soils exceed 4.4 Tg yr-1 while the annual consumption of mineral fertilizer is 0.8 TG (excluding South Africa) Sanchez et al. [9]. The sub optimal application of fertilizers to agricultural soils and the removal of nutrients in farm produce and erosion losses and the reduction in soil organic matter due to the farming systems, result in mining of nutrients from the soil [10], which has led to land degradation and a reduction in crop yields. The reduction in crop yields affects food security on the continent and contributes to high levels of poverty Galloway et al. [11]. Optimization of nitrogen use to sustain life, and to minimize the negative impacts of nitrogen on the environment and human health is for most important. N use efficiency (NUE), which is considered an important factor in the management of N applications in crop productivity, is expressed as the ratio between the grain yield and the total N accumulation Rehman et al. [12]. Beatty et al. [13] suggested the NUE in cereals should be improved through the optimal management for the N applications as well as through use potential varieties to increase the crop yield. N applications are the most significant factors that can limit NUE and maize productivity. The assessment of the suitable N applications is a vital concern for the increase of N uptake efficiency [14]. The objective was to determine the effects of different varieties and nitrogen rates on NUE and yield of highland maize in Toke Kutaye, western Ethiopia.

2. MATERIALS AND METHODS

The study were conducted in humid highland agroecosystems of western Oromia National Regional State, western Ethiopia. It was executed on four farmers' field around Toke Kutaye in 2013 and 2014 cropping season. It lies between 8'9'80''N to 8'9'90 N latitude and 37'71' E to 37°72'E longitude at an altitude ranged from 2251 to 2273 meter above sea level, receiving mean annual rainfall of 1045 mm with unimodal distribution [15]. It has a warm sub-humid climate with the mean minimum, mean maximum and average air temperatures of 8.9, 27.4 and 18.1$°_C$, respectively [15]. The soil type is brown clay loam Alfisol [16]. The experiment was laid out in factorial with randomized complete block design in three replications. The plot size was 5.1 m x 4.5 m. Four highland maize varieties (Wenchi, Jibat and AMH-760Q from hybrid and Horra from open pollinated variety) for sub-humid high altitude area will be used as main factor. Two level of nitrogen (half of the recommended (55 Kg N ha^{-1}) and recommended (110 Kg N ha^{-1}) and were used as sub factor. Two maize varieties (Wenchi and Horra) without fertilizer were used as control treatments. The total treatment combinations were ten. The weighed nitrogen rate was applied in split half at planting and remaining half at knee height. One hundred kilogram per hectare of Triple superphosphate (TSP) was applied for all treatments uniformly during planting. All other agronomic management practices were applied as per recommendation for the variety. The necessary data were collected at right time and crop growth stage.

Soil sampling and analysis: The soil samples was done before treatment from 10 sites randomly and composited one for analysis. The collected soil analysis were prepared following standard procedures and analyzed at Holleta and Debre Zeit Agricultural Research Center Soil and Plant Analysis Laboratory. Determination of soil particle size distribution was carried out using the hydrometer method [17]. The soil pH was measured with digital pH meter potentiometrically in the supernatant suspension of 1:2.5 soils to distilled water ratio. Organic carbon was determined following wet digestion methods as described by [18] whereas kjeldahl procedure was used for the determination of total nitrogen (N) as described by [19]. The available phosphorus (P) was measured by Olsen method as described by Olsen et al. [20] and available potassium (K) was measured by flame photometry. The steam distillation method was used for determination of NO_3-N and NH_4-N as described by [21].

Crop parameters: grain yield and thousand seed weight were collected at harvesting of maize. The grain yield were harvested from the net plot (3 m x 5.1m =15 m2). The harvested grain yield was adjusted to 12.5% moisture level [22]. The adjusted grain was converted to grain yield as kilogram per hectare.

Plant tissue sampling and analysis: The tissue of maize was collected at 50% tasseling of maize from three replications and composited to after chopping. The grain of maize was collected after harvesting of the crop. The collected tissue and grain was prepared following standard procedures and analyzed at Holleta and Debre Zeit Agricultural Research Center Soil and Plant Analysis Laboratory. The maize tissues and grain were subjected to wet digestion [23]. The N content of the plant tissue was determined by Kjeldahl procedure, whereas the P content was determined by colorimeterically according to [24].

Total N uptake was calculated as = nutrient concentration x dry biomass weight (kg ha^{-1}) of maize. Nitrogen agronomic efficiency (NAE), which is defined as the efficiency of converting applied N to grain yield (Wu et al, 2011), was calculated as the amount of harvestable product, i.e. kg of cereal per kg of applied nutrient (N) (Cleemput et al. [25]).

$$NAE \ (kg \ grain \ / kg \ N) = \frac{(Y_N - Y_0)}{F_N} \qquad (1)$$

where Y_N and Y_0 are the grain yield with and without N applied, respectively; and FN is the amount of N fertilizer applied.

The N uptake efficiency (UEN) is the total amount of N absorbed (including that present in the roots, often disregarded) per kg of applied N:

$$UEN \ (kg \ N \ / \ kg \ N) = \frac{U_N - U_0}{F_N} \qquad (2)$$

Plant nitrogen use efficiency/ physiological efficiency was calculated as total dry matter or grain yield produced per unit of N absorbed. N utilization efficiency was calculated as described by [26].

$$PEN \ (kg \ grain \ / kg \ N) = \frac{U_N - U_0}{y_N - Y_0} \qquad (3)$$

Apparent fertilizer N use (recovery) efficiency (ANRE) is the amount of fertilizer N taken up by the plant per kg of N applied as fertilizer, which was calculated as it is described by Cleemput et al. [25,27].

% fertilizer nutrient recovery (ANRE) =

$$\frac{(TNF)-(TNU)}{R} X100 \qquad (4)$$

The data analyses for agronomic data were carried out using statistical packages and procedures of SAS computer software [28]. Mean separation was done using least significance difference (LSD) procedure at 5% probability level [29].

3. RESULTS AND DISCUSSION

3.1 Some Soil Chemical and Physical Properties of Study Area

The analysis result of soil chemical and physical properties are indicted in Table 1. The three farm soil was clay loam and clay for one farm in textural classes. The soils of different farm field have medium in organic matter content and CEC, and better in moisture holding capacity. The soil had a pH range of 4.87 to 5.94 which found in very strongly acidic to moderately acidic [30].

The level of total N and P were ranged from 0.13 to 0.24% and 5 to 80 ppm. The total N concentrations for all six farms were found in low to medium range [30,31]. In Alfisol the total N was in medium range the amount of N required to amend the soil and have a high potential for maize production. The extractable phosphorus concentration of was found in low, medium to high range [30,31]. The high P level was above critical levels and would need low amount of phosphorous application so as to maintain levels for the current crop.

The organic carbon and organic matter concentrations were ranged from 1.56 to 2.96% and 2.68 to 5.09% found in medium and medium to high range [30,31]. The CEC concentrations were ranged from 21.06 to 31.54 $cmol^{+}kg^{-1}$ and found in medium to high range [30,31]. The exchangeable potassium concentration of the four farm soil was ranged from 0.28 to 0.85 M eq 100 g of $soil^{-1}$ and found in medium to high value range [30,31]. No deficiency of K was expected in this soil. The levels of CEC were above the critical level.

The soil $N0_3^-N$ concentration was ranged between 20.76 to 56.41% for the four farms, found in medium to high range [32]. The soil NH_4^+N concentration was 2.78 to 17.80 among four farms. Horneck et al. [33] reported ammonium-nitrogen concentrations of 2-10 ppm are typical. The NO_3-N and NH_4-N concentration of the soils were found in optimum range.

3.2 Mean Grain Yield and Thousand Seed Weight of Maize

The mean analysis of results for grain yield and thousand seed weight of maize were presented in Tables 2 and 3. Mean grain yield of maize was significantly among varieties, across farms and cropping seasons. Significantly higher mean grain yield ranging from of 4836 to 7420 kg ha^{-1} were harvested among farms (Table 2), indicating variation of soil fertility status and management practices applied by the farmers in the area. Higher mean grain yields were harvested in 2013 cropping season as compared 2014 cropping season (Tables 2 and 3), indicating variation of environmental factors such as rainfall and solar radiation across seasons. Therefore, considering environmental factors are very crucial for maize production in highlands of Toke Kutaye. Higher mean grain yield varying from 7153 to 8405 kg ha^{-1} were harvested from varieties of maize from farm1 (Table 2). Makhziah et al. [34] found greater genotypic variations were observed on grain yield of maize. Significantly higher grain yield variations were observed among genotypes and ranged 1.4 - 9 tons ha^{-1} [35]. All three hybrid varieties gave better mean grain as compared open pollinated variety (Horra), asserting the saying of F1 hybrids gave significantly higher mean grain yield as compared to open pollinated variety. Similar result was reported by Makhziah et al. [34] on maize genotypes, hybrid varieties tended to yield more than OPV. Except Horra, other three varieties (Webii, Wenchi and Jibat) gave mean grain yield advantage of 3.30, 12.86 and 20.38 % as compared to Wenchi; while 14.79, 44.06, 57.40 and 67.88 % as compared to Horra were produced in ascending order by Horra, Webii, Wenchi and Jibat (Table 2). Jibat followed by Wenchi were gave better mean grain yield among highland maize varieties used. Considering Jibat followed by Wenchi in wider dissemination for farmers in Tokke Kutayyee and similar agroecology were desirable options for sustainable maize production and fulfilling the millennium development goal of food security in the region.

Nitrogen rate were significantly affected mean grain yield maize varieties (Table 2). Significantly higher mean grain yield maize were produced from full recommended (110 kg N ha^{-1}) nitrogen rate as compared to half recommended in 2013 cropping season and vise verse in 2014 cropping season. Similarly Rutkowska et al. [36] found maize yield variability was high from year-to-year. [37] reported grain yield was increased with higher rate of N. N deprivation caused reduction of grain yield Makhziah et al. [34]. Maize grain yield increment was obtained under nitrogen fertilization Rutkowska et al. [36]. Abe et al. [38] found grain yield and yield component both experimental and commercial tropical hybrids response were varied with N supply.

Table 1. Some physicochemical properties soil of farmer's field before planting maize in Toke Kutaye districts, western Ethiopia

Farms	pH	N (%)	P (ppm)	OC	OM	CEC	K	Na	Exchangeable acidity	$N0_3$-N	NH_4-N	Texture
				%		(meq 100 g soil-1)				(ppm)		
Farm-1	4.87	0.18	6	2.03	3.49	24.14	0.56	2.16		20.76	17.8	clay
Farm-2	5.9	0.23	80	2.73	4.7	31.54	0.85	1.92	0.13	50.58	5.96	Clay loam
Farm-3	5.39	0.13	5	1.56	2.68	21.06	0.28	1.68	0.13	26.39	8.8	Clay loam
Farm-4	5.7	0.24	31	2.96	5.09	31.46	0.85	3.12	0.14	56.41	2.78	Clay loam

Farm 1= Deksisa Debela, farm 2= Negera Shito, farm 3= Gutama Kuma, farm4 = Sisay Belete

Significantly higher grain yield (3.567 t ha-1) was obtained from application of N at the rate of 115 kg ha-1 coated with agrotain at the rate of 3 L ton-1 and the fertilizer applied in two splits as compared to lower levels of N and minimum grain yield (3.177 t ha^{-1}) was obtained from control Khan et al. [39]. At half recommended nitrogen rate mean grain yield advantages of 3.42, 9.57, 13.68, and 3.94 as compared Wenchi variety were obtained from farm1, farm2, farm4 and combined mean. While as compared Horra variety, 25.06, 38.47, 54.18, 83.75 and 44.95 % mean grain yield advantage were produced from farm1, farm 2, farm3, farm 4 and combined over farms (Table 2). Rutkowska et al. [36] found application potassium K plus nitrogen fertilization in the range between 150–250 kg N ha^{-1}, secured maize yield at the level of 9 t/ha, and the yield increment was 84% compared to the control treatment. However, irrespective of potassium fertilization, the largest increase of maize yield was recorded with 100 kg N ha^{-1} Rutkowska et al.[36]. Makhziah et al. [34] found reduction of N levels from 180 to 90, 30 and 0 kg N ha^{-1} caused varied reductions of grain yield ranged from 0.3 to 68.8%. Rutkowska et al. [36] found maize yields significantly rose up to the rate of 150 kg N ha^{-1} and then slightly dropped. Reports from different findings confirmed that yield reduction does not exceed 35–40% [40]. And 43% Banziger et al. [41] for selection of low N stress tolerant genotypes of maize. Thus, identification of nitrogen efficient maize varieties was crucial for better production maize under resource poor farmers. At full recommended nitrogen fertilizer except farm3, all other farms gave mean grain yield advantages of 5.13, 18.13, 11.88 and 5.4% over Wenchi variety from farm1 farm2, farm4 and combined over farms. Mean grain yield advantages of 27.13, 49.30, 50.42, 80.86 and 47.11% over open pollinated variety (Horra) were produced from farm1, farm2, farm3, farm 4 and combined over farms with application of full recommended nitrogen fertilizer. Improving nitrogen use efficiency with nitrogen fertilization should be reduced to levels that still guarantee satisfactory yields Médici et al. [42]. Similarly Cancellier et al. [43] reported the same effect concerning grain yield in evaluations of commercial hybrids and maize populations. Abe et al. [38] verified genetic differences between maize hybrids for grain yield, its components, and physiological traits under optimal N levels. Application full recommended fertilizer was crucial to maize production in Tokke Kutayyee and similar agroecology.

Thousand seed weight of maize was significantly different among varieties in 2013 cropping seasons on two farms and non-significant in 2014 cropping season (Table 2). Mean thousand seed weight was ranged from 370 to 403g across farms. Greater genotypic variations were observed on thousand grain weight of maize Makhziah et al. [34]. Non-significantly higher thousand seed weight 390 g was recorded from full recommended rate of nitrogen as compared to half recommended, which was 375 g. Makhziah et al. [34] found N deprivation caused reduction of thousand grain weight of maize. Similarly Khan et al. [39] found highly significant differences among different levels of Agrotain coated urea regarding 100 grain weight and minimum 100 grain weight was obtained from no urea applied. Open pollinated variety (Horra) gave higher thousand seed weight among variety; and without and with application of nitrogen fertilizer across farms and seasons too.

The interaction varieties with nitrogen rate were significantly affected mean grain yield of maize across different farmers' fields (Table 3). This revealed maize varieties had different potentials to nitrogen fertilizer application. Similarly [44] found genotype x N interaction is essential due to variation in the adaption of the plant to low N rather than to variation in the adaption to high-N. Significantly higher variations of mean grain yields were obtained between different farmers' fields. This indicated variation soil management practices across farmer's field with different inputs and conservation measures. Significantly higher mean grain yield of 4913, 5229, 5572 and 7548 kg ha^{-1} in ascending order were harvested from farm farm3, farm4, farm 2 and farm 1 respectively (Table 3). Farm 1 and farm 2 had better potential for sustainable maize production. Performances of varieties were varied across farmers' field with different rates of applied nitrogen. These reflected soil fertility status difference across farmers' field due to inputs of applied nutrient before and management systems applied. Both lower and higher nitrogen fertilizer rates significantly affected mean grain yield of maize. Some varieties were performed better at lower of nitrogen rates as compared to higher nitrogen rate on some farmers' field and vise verse on other farmers' field. Significantly higher mean grain yield advantages of 15.37, 46. 14, 57.20 and 61.15% were obtained from Horra, Webii, Wenchi and Jibat varieties with half recommended fertilizer application as compared Horra variety. At full recommended nitrogen fertilizer application, mean grain yield advantages of 14.19, 42, 57.61 and 74.63% were obtained from Horra, Webii, Wenchi and Jibat as compared open pollinated variety (Horra) planted without nitrogen fertilizer. As compared Wenchi maize variety significantly higher mean grain yield advantages of 4.79, 12.72 and 15.55% with half nitrogen and 1.82, 13.02 and 25.22% with recommended nitrogen application were obtained from Webii, Wenchi and Jibat maize varieties, respectively (Table 2). Makhziah et al. [34] found high genotypic variations of grain yield were observed at N fertilization but was low at no N fertilization because all genotypes were stressed strongly. Better management practices with inputs could increase grain yield of maize varieties. The use high quality inputs, agronomic management practices can raise yield per unit area Khavazi et al. [45]. Horra maize variety with half and full recommended nitrogen fertilizer application did not gave mean grain yield advantage over Wenchi maize variety planted without nitrogen fertilizer application. This justifies that open pollinated maize variety was produced lower mean grain yield as compared to hybrid maize varieties. Considering soil test based application and/or specific site based fertilizer recommendation were required for sustainable quality protein maize production in the region.

3.3 Nitrogen Uptake and Agronomic Efficiency of Maize

The mean results for nitrogen up take and agronomic efficiency of highland maize varieties are indicated in Table 4. The mean nitrogen up take and agronomic efficiency of highland maize varieties were varied across season (Table 4). Higher mean nitrogen uptake efficiency of 424 kg ha^{-1} was obtained in 2013 as compared to 2014, which is 365 kg ha$^{-1.}$ The mean agronomic efficiency of 6.35 and 23.36; and 0.66 and 29.08 were obtained as compared to Wenchi and Horra in 2013 and 2014 cropping seasons. Mean nitrogen up take of 333, 361, 369 and 514 kg ha^{-1} were harvested from farm 2, farm 4, farm 3 and farm 1, respectively (Table 4), indicating better fertility status of farm 1 followed by farm 3. The mean nitrogen up take of varieties was varied with application nitrogen rates. [35] found N uptake was varied significantly among genotypes of maize. Higher mean nitrogen uptake was measured from varieties receiving recommended rates (110 kg N ha-1) N fertilizer. Makhziah et al. [34] N uptake was reduced with reducing N level and high genotypic variation was observed at higher N and gradually decreased with reduced level of N. Similar results had been reported that low variation in whole plant N-uptake under low N-input suggests that there was a limiting factor in nitrogen availability in the soil and in the plant capacity to absorb nitrogen [44,46]. Rutkowska et al. [36] found the average nitrogen uptake by maize accounted for 77% of total nitrogen taken up by crop with K plus, and in K minus the total nitrogen up take dropped to 66% with increasing rate of nitrogen levels from 0 to 250 kg ha^{-1}. Mean nitrogen up take advantages of 1.26, 3.42, 5.91 and 7.96% were obtained from varieties (Jibat, Webii, Wenchi and Horra) receiving recommended dose of fertilizer as compared to half recommended fertilizer applied. Higher mean nitrogen up take of 39, 44, 62 and 75%; and 50, 52, 67 and 77% were produced from Horra, Wenchi, Webii and Jibat maize varieties planted with half and full recommended nitrogen fertilizer application as compared to Wenchi maize variety planted without nitrogen fertilizer. In addition mean nitrogen up take advantages of 56, 61, 82 and 97%; and 69, 71, 88 and 100% were harvested from Horra, Wenchi, Webii and Jibat maize varieties planted with half and full recommended nitrogen fertilizer as compared to Horra maize variety planted without nitrogen fertilizer.

Open pollinated variety (Horra) had lower nitrogen uptakes as compared hybrid varieties of maize. Makhziah et al. [34] found Higher N-uptake obtained from hybrids as compared to OPVs. Jibat maize variety had had showed better potential in nitrogen up take as compared other varieties. All varieties planted with half and full recommended fertilizer applications were gave higher nitrogen up take efficiency as compared Horra and Wenchi varieties planted without fertilizer application indicting application nitrogen improved nitrogen uptake efficiency of maize varieties.

The agronomic efficiency of maize varieties was varied across farms with similar varieties (Table 4). Mean agronomic efficiency of negative to 9 as compared to Wenchi; and 22, 23, 24 and 34 as compared to Horra were obtained from farm 1, farm 2, farm 3 and farm 4, respectively. Higher mean agronomic efficiency were measured from Jibat followed by Wench and Webii varieties planted with half recommended rates of N fertilizer as compared applied with full recommended N fertilizer (Table 4). Higher mean agronomic efficiency of 23 and 86%; 64 and 95%; 100 and 400%; 140 and 119% were obtained from Jibat, Wenchi, Horra and Webii variety planted with half recommended nitrogen fertilizer application as compared to full recommended calculated Wenchi and Horra varieties planted without nitrogen fertilizer. Over all mean agronomic efficiency was ranged from negative to 16 as compared to Wenchi; and 5 to 46 as compared Horra (Table 4). Wu et al. [47] found significant differences among genotypes for nitrogen agronomic efficiency. Nitrogen utilization efficiency was varied significantly among genotypes [35]. Application of 100 kg N ha^{-1} was gave agronomic efficiency of 26 in K plus and 23 kg grain kg N^{-1} applied in K minus, respectively and decreased with increasing nitrogen rates Rutkowska et al. [36]. The lowest agronomic efficiency was obtained from open pollinated variety (Horra) as compared to other varieties. Higher agronomic efficiency was obtained for all hybrid maize varieties planted with half recommended nitrogen fertilizer application. Higher agronomic efficiency variation was observed at half and full recommended nitrogen fertilizer application. High genotypic variation for agronomic efficiency was observed at high-N Makhziah et al. [34]. Improved germplasm can equally enhance agronomic efficiency of fertilizer nutrients by ensuring a higher demand for applied nutrients Vanlauwe et al. [48]. Jibat and Wenchi varieties were desirable varieties with Nitrogen up take and agronomic efficiency. The generated information would be used for further breeding and promotion work in scale up on farmers' field. Vanlauwe et al. [48] outlined results from regional scale analysis have been valuable in informing policy on urgent need to support farmers to access improved seed and fertilizers to resolve soil fertility challenges underlying low crop productivity (e.g. increase fertilizer use to support crop production intensification, which led to the target of increasing fertilizer use in SSA to 50 kg nutrients per ha^{-1}). Therefore, further promotion work would be done for further dissemination of these varieties with full packages on farmers' field.

3.4 Nitrogen Uptake Efficiency, Plant Nitrogen Use Efficiency and Fertilizer N (Recovery) Use Efficiency of Maize

The mean nitrogen up take efficiency, plant nitrogen use efficiency and fertilizer N use efficiency of maize are presented in Tables 5, 6 and 7. The mean nitrogen uptake efficiency was different across cropping seasons. Higher mean nitrogen uptake efficiency of 2.46 and 3.06 kg ha^{-1} was obtained in 2013 cropping season as compared to 1.78 and 1.98 in 2014 cropping season calculated as compared to Wenchi and Horra (Table 5). The nitrogen uptake efficiency of maize varieties was varied across varieties and farmers' fields. Mean nitrogen uptake efficiency of 1.77, 1.79, 2.30 and 2.61 kg ha^{-1}; and 1.57, 2.39, 2.89 and 3.24 kg ha^{-1} compared Wenchi and Horra were obtained from farm 3, farm 4, farm 1 and farm 2, respectively (Table 5). Farm 2 followed by farm 1 had better fertility status and potential for sustainable maize production. Jibat followed by Webii, Wenchi and Horra varieties had higher nitrogen uptake efficiency at half (55 kg N ha^{-1}) recommended nitrogen fertilizer applied as compared to full recommended N fertilizer application. Similarly reduction N levels caused increasing NUE were reported by Makhziah et al. [34,46]. Generally, NUE parameters are high under low-N levels and it decreases with increasing N level. [49] argued decreased NUE at high N to higher volatilization losses because the plant was unable to assimilate all of N taken up. Significantly higher nitrogen uptake efficiency was obtained from Jibat, Webii, Wenchi and Horra, in descending order, respectively (Table 5). [35] nitrogen uptake efficiency was varied significantly among genotypes of maize. Maximum N Utilization Efficiency (NUtE) (32.65 kg kg^{-1}) was obtained from application of 200 kg N ha-1 and Minimum N Utilization Efficiency (NUtE) (30.07 kg kg^{-1}) was obtained from application of 400 kg N ha^{-1} Niknam et al. [50]. All hybrid maize varieties had higher nitrogen uptake efficiency as compared open pollinated variety (Horra) in the highland areas. Therefore high yielding varieties of maize had high nitrogen up take efficiency.

The plant nitrogen use efficiency of highland maize varieties were varied among varieties used farm sites and interaction of varieties with nitrogen applied (Table 6). Plant nitrogen use efficiency of maize varieties differed across cropping seasons. Higher mean plant nitrogen use efficiency of 0.20 and 0.17 was harvested in 2013 cropping season from Wenchi and Horra varieties as compared 2014 (Table 6). Mean plant nitrogen use efficiency was ranged from negative to 0.33 and negative to 0.16 as compared to Wenchi and Horra varieties of across farms. Significantly higher plant nitrogen use of was observed for Horra variety with application of half (55 kg N ha^{-1}) of nitrogen fertilizer indicating open pollinated variety was promising for sustainable maize production in the region. [35] found nitrogen utilization efficiency was varied significantly among genotypes of maize. Diversity for NUE and its component traits have been observed in a variety of maize germplasm [44]. Lack et al. [51] reported that nitrogen use efficiency was decreased with increasing fertilizer rates. Usually the highest performance with the first absorption of nutrients (fertilizer) unit is obtained Niknam et al. [50]. Cancellier et al. [43] found variation in N use efficiency of maize genotypes based on greater averages being considered. Higher N utilization efficiency for maize grains was found by (Gonçalves da Silva et al. [52]. Worku et al. [53] examined physiological mechanisms such as post-anthesis N uptake, grain production per unit N accumulated and N harvest index, and differences in root morphology that may contribute to differences in N use efficiency among maize hybrids. Zhang et al. [54] reported the favorable effect of nitrogen fertilizer in the synthesis and storage of cereal chemical compound grains as protein, lipids and carbohydrate concentrations during the course of maize, which may contributed for higher grain N accumulation. Horra variety had negative nitrogen use efficiency with application of half and full recommended nitrogen fertilizer as compared Wenchi variety planted without nitrogen fertilizer. This revealed that open pollinated maize variety (Horra) was high nitrogen use efficiency as compared to hybrid varieties. This indicates open pollinated variety (Horra) has adapted to low nitrogen rates and produce better mean grain yield with marginal N as compared to other varieties. Makhziah et al. [34] found OPVs had moderate NUE and have adapted to low-N. Maize varieties originating from local populations have a better capacity to absorb and utilize N under low N fertilization conditions Ortiz-Monasterio et al. [55]. Plant nitrogen use efficiency was ranged from -0.1 to 1.34 and 0.25 to 0.75; -0.79 to 0.87 and -0.82 to 0.31 as compared to Wenchi and Horra maize varieties with half and full recommended nitrogen fertilizer application. Higher nitrogen use efficiency was obtained from Horra, followed by Wenchi, Jibat and Webii, respectively in descending order (Table 6). Considering nitrogen use efficiency was crucial for sustainable highland maize varieties production based on available inputs of production and wealth of farmers in the agroecology. Giving training and advice to farmers depend on nitrogen use efficiency were necessary options for further promotion and dissemination of different highland maize varieties for sustainable maize production in the agroecology.

The fertilizer N (recovery) use efficiency of maize varieties were significantly varied across cropping season and farms; and interaction varieties with nitrogen application (Table 7). The mean fertilizer use efficiency was 246 and 306%; and 178 and 198% from Wenchi and Horra varieties in 2013 and 2014 cropping seasons. Higher fertilizer N (recovery) use efficiency of maize varieties were obtained in 2013 cropping season. Higher fertilizer N (recovery) use efficiency was directly correlated to yield. Mean fertilizer N use efficiency of ranged from 157 to 324% among farms and 138 to 399% among varieties with nitrogen application were obtained as compared to Wenchi and Horra varieties. This indicates significant variation among farmers field with soil fertility status. Horra variety was produced lower fertilizer N use efficiency (Table 7). Higher mean fertilizer N use efficiency of highland maize varieties was produced with application of half recommended (55 kg n ha^{-1}) nitrogen fertilizer. The result was in agreement with Akintoye et al. [56] who reported that nitrogen utilization efficiency decreased as availability of N increased. Rutkowska et al. [36] found application of 100 kg N ha^{-1} was produced highest apparent nitrogen recovery – 75% in K plus treatment and 57% in K minus one and reduced with increasing nitrogen rates. High fertilization was associated with low apparent recovery of mineral fertilizer nitrogen was reported by [57]. Therefore all highland maize varieties had higher fertilizer N use efficiency with half recommended fertilizer application. Therefore, giving half recommended nitrogen fertilizer could produce optimum grain yield of highland maize varieties in Tokke Kutaye districts.

Table 2. Effects of varieties and nitrogen rate on mean grain yield and thousand seed weight of maize on farmer's field around Toke Kutaye, western Ethiopia

Variables	Grain yield (kg ha^{-1})					Thousand seed weight (g)				
	2013		2014		Mean	2013		2014		Mean
Maize varieties	**Farm 1**	**Farm 2**	**Farm 3**	**Farm4**		**Farm 1**	**Farm 2**	**Farm 3**	**Farm 4**	
Jibat	8405	6577	6198	6562	6935	358	369	379	412	379
Wenchi	7818	6441	5223	6528	6502	367	389	364	391	378
Horra	7153	4770	3536	3507	4742	361	417	444	388	403
Webii	7582	5491	5160	5572	5951	329	388	372	393	370
Wenchi	7422	5112	5596	4914	5761	358	353	412	387	378
Horra	6138	4045	3302	3040	4131	404	366	438	366	394
LSD (%)	481.22	324.74	577.62	236.89	233.25	29.91	42.402	54.739	NS	NS
CV (%)	5.02	4.51	9.64	3.45	18.46	6.83	8.76	11.34	8.36	22.2
N(kg ha^{-1})										
50 %RR	7676	5601	5091	5586	5988	337	385	386	393	375
100 %RR	7803	6039	4967	5498	6077	370	397	393	399	390
Wenchi	7422	5112	5596	4914	5761	358	353	412	387	378
Horra	6138	4045	3302	3040	4131	404	366	438	366	394
LSD (%)	340.27	229.62	408.44	167.51	138.79	21.15	NS	NS	NS	NS
CV (%)	5.02	4.51	9.64	3.45	18.46	6.83	8.76	11.34	8.36	10.7

Farm 1-Farm 4= four farmers field (Dekisisa Debela, Negera Shito, Gutuma Kuma and Sisay Belete), NS=Non-significant difference at 5 % probability level, 50 % and 100 % RR= half and full doses (55 and110 kg N ha^{-1}) recommended for maize

Table 3. Combination effects of varieties and nitrogen rate on mean of grain yield and thousand seed weight of maize on farmer's field around Toke Kutaye, Western Ethiopia

Treatments	Grain yield (kg ha^{-1})					Thousand seed weight (g)				
	2013		2014		Mean	2013		2014		Mean
	Farm 1	**Farm 2**	**Farm 3**	**Farm4**		**Farm 1**	**Farm 2**	**Farm 3**	**Farm 4**	
Jibat (50%RR)	8471	6026	6433	5697	6657	332	363	360	403	364
Jibat (100%RR)	8338	7129	5962	7427	7214	383	375	398	422	395
Wenchi (50%RR)	7959	6250	5021	6747	6494	320	399	390	396	376
Wenchi (100%RR)	7678	6632	5425	6308	6511	413	379	338	387	379
Horra (50%RR)	7477	4623	3896	3069	4766	360	400	447	383	398
Horra (100% RR)	6829	4917	3176	3944	4717	363	435	441	394	408
Webii (50%RR)	6798	5505	5014	6830	6037	335	378	349	391	363

Treatments	Grain yield (kg ha^{-1})					Thousand seed weight (g)				
	2013		2014		Mean	2013		2014		Mean
	Farm 1	Farm 2	Farm 3	Farm4		Farm 1	Farm 2	Farm 3	Farm 4	
Webii (100%RR)	8366	5478	5305	4314	5866	322	397	395	395	377
Wenchi	7422	5112	5596	4914	5761	358	353	412	387	378
Horra	6138	4045	3302	3040	4131	404	366	438	366	394
LSD (%)	634.64	417.35	740.4	320.4	263.8	62.31	56.558	78.53	NS	33.665
CV (%)	4.90	4.37	9.07	3.57	5.62	10.12	8.57	11.54	10.32	10.81
Cropping season										
2013	6560					372				
2014	5071					395				

Farm 1-Farm 4= four farmers field (Dekisisa Debela, Negera Shito, Gutuma Kuma and Sisay Belete), NS=Non-significant difference at 5 % probability level, 50 % and 100 % RR= half and full doses (55 and 110 kg N ha^{-1}) recommended for maize

Table 4. Effects of varieties and nitrogen rate on Nitrogen up take and agronomic efficiency of maize on farmer's field around Toke Kutaye, western Ethiopia

Treatments	Nitrogen up take (kg ha^{-1})					Agronomic efficiency									
	2013		2014		Mean	2013				2014				Mean	
	Farm 1	Farm 2	Farm 3	Farm 4		Farm 1		Farm 2		Farm 3		Farm 4			
						Wenchi	Horra	Wenchi	Horra	Wenchi	Horra	Wenchi	Horra	Wenchi	Horra
Jibat (50%RR)	647	367	423	462	475	19.07	42.42	16.62	36.02	15.22	56.93	14.25	48.31	16	46
Jibat (100%RR)	642	461	424	395	481	8.33	20.00	18.34	28.04	3.33	24.18	22.85	39.88	13	28
Wenchi (50% RR)	471	400	363	321	389	9.76	33.11	20.69	40.09	-10.45	31.25	33.35	67.40	13	43
Wenchi (100%RR)	525	380	345	399	412	2.33	14.00	13.82	23.52	-1.55	19.30	12.68	29.71	7	22
Horra (50%RR)	464	415	382	245	377	1.00	24.35	-8.89	10.51	-30.91	10.80	-33.5	0.53	-18	12
Horra (100% RR)	534	282	436	377	407	-5.39	6.28	-1.77	7.93	-22.00	-1.15	-8.81	8.22	-9	5
Webii (50%RR)	523	338	423	468	438	-11.35	12.00	7.15	26.55	-10.58	31.13	34.85	68.91	5	35
Webii (100%RR)	628	358	348	476	453	8.58	20.25	3.33	13.03	-2.65	18.21	-5.45	11.58	1	16
Wenchi	376	185	265	256	271										
Horra	333	139	279	211	241										
Cropping season						Wenchi		Horra		Wenchi		Horra			
2013	424					6.35		22.38							
2014	365									0.66		29.075			

Farm 1-Farm 4= four farmers field (Dekisisa Debela, Negera Shito, Gutuma Kuma and Sisay Belete), NS=Non-significant difference at 5 % probability level, 50 % and 100 % RR= half and full doses (55 and 110 kg N ha^{-1}) recommended for maize

Table 5. Effects of varieties and nitrogen rate on nitrogen up take efficiency of maize on farmer's field around Toke Kutaye, western Ethiopia.

Treatments	Nitrogen up take efficiency (kg ha^{-1})									
	2013				2014				Mean	
	Farm 1		Farm 2		Farm 3		Farm4			
	Wenchi	Horra	Wenchi	Horra	Wenchi	Horra	Wenchi	Horra	Wenchi	Horra
Jibat (50%RR)	4.93	5.71	3.31	4.15	2.87	2.61	3.76	4.56	12.05	13.61
Jibat (100%RR)	2.42	2.81	2.51	2.93	1.44	1.31	1.27	1.67	6.69	7.47
Wenchi (50%RR)	1.73	2.51	3.90	4.74	1.79	1.52	1.18	1.99	7.72	9.27
Wenchi (100%RR)	1.35	1.74	1.77	2.19	0.73	0.60	1.30	1.70	4.18	4.96
Horra (50%RR)	1.59	2.37	4.18	5.02	2.14	1.87	-0.19	0.62	7.86	9.42
Horra (100% RR)	1.44	1.83	0.88	1.30	1.55	1.42	1.10	1.50	4.15	4.93
Webii (50%RR)	2.67	3.45	2.77	3.61	2.88	2.62	3.86	4.67	9.29	10.85
Webii (100%RR)	2.29	2.68	1.57	1.99	0.76	0.63	2.00	2.40	5.12	5.90
Cropping season	Wenchi		Horra		Wenchi		Horra			
2013	2.46		3.06							
2014					1.78		1.98			

Farm 1-Farm 4= four farmers field (Dekisisa Debela, Negera Shito, Gutuma Kuma and Sisay Belete), 50 % and 100 % RR= half and full doses (55 and 110 kg N ha^{-1}) recommended for maize

Table 6. Effects of varieties and nitrogen rate on plant nitrogen use efficiency of maize on farmer's field around Toke Kutaye, western Ethiopia

Treatments	Plant nitrogen use efficiency									
	2013				2014				Mean	
	Farm 1		Farm 2		Farm 3		Farm4			
	Wenchi	Horra	Wenchi	Horra	Wenchi	Horra	Wenchi	Horra	Wenchi	Horra
Jibat (50%RR)	0.259	0.135	0.199	0.115	0.189	0.046	0.094	0.264	0.67	0.36
Jibat (100%RR)	0.290	0.140	0.137	0.104	0.434	0.054	0.042	0.055	0.87	0.31
Wenchi (50%RR)	0.177	0.076	0.189	0.118	-0.171	0.049	0.030	0.036	0.20	0.25
Wenchi (100%RR)	0.581	0.125	0.128	0.093	-0.468	0.031	0.057	0.103	0.26	0.27
Horra (50%RR)	1.591	0.097	-0.470	0.477	-0.069	0.174	1.167	0.006	1.34	0.75
Horra (100% RR)	-0.266	0.291	-0.495	0.164	-0.071	-1.24	0.183	-0.125	-0.79	-0.82
Webii (50%RR)	-0.235	0.287	0.388	0.136	-0.272	0.084	0.068	0.111	-0.10	0.53
Webii (100%RR)	0.267	0.132	0.472	0.153	-0.287	0.034	0.207	-0.367	0.50	0.23
Cropping season	Wenchi		Horra		Wenchi		Horra			
2013	0.20		0.17							
2014					0.07		-0.04			

Farm 1-Farm 4= four farmers field (Dekisisa Debela, Negera Shito, Gutuma Kuma and Sisay Belete), 50 % and 100 % RR= half and full doses (55 and 110 kg N ha^{-1}) recommended for maize

Table 7. Effects of varieties and nitrogen rate on fertilizer N (recovery) use efficiency of maize on farmer's field around Toke Kutaye, western Ethiopia

Maize varieties + N (Kg ha^{-1})	Fertilizer N (recovery) use efficiency (%)								
	Farm 1		Farm 2		Farm 3		Farm 4		Mean
	Wenchi	Horra	Wenchi	Horra	Wenchi	Horra	Wenchi	Horra	
Jibat (50%RR)	493	571	331	415	287	261	376	456	399
Jibat (100%RR)	242	281	251	293	144	131	127	167	204
Wenchi (50%RR)	173	251	390	474	179	152	118	199	242
Wenchi (100%RR)	135	174	177	219	73	60	130	170	142
Horra (50%RR)	159	237	418	502	214	187	-19	62	220
Horra (100% RR)	144	183	88	130	155	142	110	150	138
Webii (50%RR)	267	345	277	361	288	262	386	467	332
Webii (100%RR)	229	268	157	199	76	63	200	240	179
Mean	230	289	261	324	177	157	178	239	
Cropping season	Wenchi		Horra		Wenchi		Horra		
2013	246		306						
2014					178		198		

Farm 1-Farm 6= four farmers field (Dekisisa Debela, Negera Shito, Gutuma Kuma and Sisay Belete), 50 % and 100 % RR= half and full doses (55 and 110 kg N ha^{-1}) recommended for maize

4. CONCLUSION

Soil fertility depletion is a widespread degradation problem and alleviated with different improved maize production systems in the highland areas of western Ethiopia. Maize varieties were produced significantly different mean grain yield indicating variation of genetic potential maize varieties. Open pollinated maize variety was produced lower mean grain yield as compared to hybrid maize varieties. Application of nitrogen fertilizer was significantly affected mean grain yield of highland maize varieties. Mean grain yield of maize varieties were varied among farms indicating soil fertility status and management practices applied variation among farms. Soil test based application and/or specific site based fertilizer recommendation was required for sustainable maize production in the region. The mean nitrogen up take and agronomic efficiency of highland maize varieties were varied among varieties and with application nitrogen fertilizer rates. Jibat and Wenchi varieties were desirable varieties with nitrogen up take and agronomic efficiency. The nitrogen up take efficiency, nitrogen use efficiency and fertilizer N use efficiency of maize varieties were varied among farms and maize varieties used and nitrogen fertilizer rate applied. All highland maize varieties had higher fertilizer N use efficiency with half recommended fertilizer application indicating better fertility status highland maize producing soils. Hybrid maize varieties had higher nitrogen uptake efficiency as compared open pollinated variety (Horra) in the highland areas. Higher nitrogen use efficiency was obtained from Jibat, followed by Wenchi, Webii and Horra. Jibat followed by Wenchi was recommended for wider dissemination to smallholder farmers in Tokke Kutaye and similar agroecology and fulfilling the millennium development goal of food security in the region.

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COMPETING INTERESTS

Authors have declared that no competing interests exist.

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