World Journal of Agricultural Sciences 16 (5): 339-355, 2020
ISSN 1817-3047

DOI: 10.5829/idosi.wjas.2020.339.355

Yield Components and Nitrogen Use Efficiency of Maize Varieties as Affected by Nitrogen Rate in Mid Altitude Areas of Western Ethiopia

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Abstract: Agronomic management is one of the important inputs for getting high potential yield and net returns in hybrid maize production. The experiments were conducted on farmers' field to examine the effect of four maize varieties and three nitrogen fertilizer rates interactions in mid-altitude of western Ethiopia in 2013 and 2014 cropping seasons. The N fertilizer application significantly increased grain yield of the all maize varieties. Furthermore, the interaction of the maize varieties with the N fertilizer rates were significantly affected the yield and yield components of the maize varieties. Application of half and full recommended N fertilizer increased the grain yield by 31 and 41 % as compared to the control treatment. The maize varieties with the higher grain yield also produced higher aboveground biomass. The N up take of the maize varieties ranged from 225 to 357 kg ha^{-1} and the higher agronomic efficiencies of the maize varieties were obtained by applying half of the recommended N fertilizer that ranged from 18 to 33% or 9.21 to 33.28 kg grain kg N $applied^{-1}$. Also, the significantly higher N up take efficiency and nitrogen use efficiency of the maize varieties were achieved with the application of half -recommended N fertilizer. Application of half of the recommended N fertilizer provided 19.94 kg N uptake kg N $applied^{-1}$ and 62.54 kg grain kg N $uptake^{-1}$ nitrogen up take efficiency and nitrogen use efficiency as compared to the full-recommended N fertilizer application. Maize varieties BH-661>BH-543>BH-660>BH-540>BH-140 were desirable varieties in terms of grain yield, agronomic efficiency and nitrogen up take efficiency for further promotion work and use by smallholder farmers in mid altitude area of western Ethiopia.

Key words: Nitrogen · N Accumulation · Nitrogen Use Efficiency · Varieties · Maize

INTRODUCTION

Nitrogen (N) is an essential nutrient and constituent of 3-4 % of maize dry matter [1] and important constituent of many biomolecules [2]. However, low plant available N in tropical soils often a limiting factor for agricultural production and productivity [3-6]. Although increased crop productivity has been associated with a 20-fold increase in the global use of N fertilizer use during the past five decades [7-9], many socio-political factors have constrained the use of N fertilizer in most Sub-Saharan African countries in general and in Ethiopia in particular. Staple crops such as, maize is highly responsive to N fertilizer application and the crop requires to apply N fertilizer in large quantity [10, 11]. Maize production is consuming almost one-fifth of all nitrogen produced in the world [12]. Therefore, nitrogen is considered a strong tool for high crop yield [2, 13]. Excessive applications of N fertilizers may harm the environment, causing soil acidification and water and air pollution [14, 15]. About 30 to 70% of the applied N may be lost as ammonia within 7 to 10 days after application and may lead to an elevated level of NO_3 in the soil and susceptible to NO_3 loss through leaching or volatilization or surface soil [16, 17].

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Plants can take only up 30 to 40% of the applied N and over 60% of the N in the soil generally is lost by leaching, surface runoff, denitrification, volatilization and microbial consumption [12]. Of the total input in the form of nitrogen and phosphorus fertilizers, only 15-20% is actually embedded in the food that reaches the consumers' plates, implying very large nutrient losses to the environment [18]. Moreover, crops do not use all the nitrogen applied [19].

This indicates indeed needed to increase maize yields with lower environmental impact with application optimum nitrogen fertilizer and use of maize varieties. Kant *et al*. [20] estimated that a 1% increase in nitrogen use efficiency (NUE) of crops could save US$ 1.1 billion annually. The development of NUE cultivars is required to minimize losses of applied N as well as to decrease environmental pollution, reduce inputs and consequently, save production costs [12]. Ma and Dwyer [21] showed that a high ratio of the amount of ^{15}N recovered in a grain or stover to the amount of fertilizer ^{15}N applied to the soil) was primarily associated with greater N-uptake and improved dry matter production during the grain filling period. Worldwide, NUE for cereal production is approximately 33 % [17]. Identification of maize varieties with greater N use efficiency would make a great contribution to smallholder farmers for sustainable maize production in the region. NUE in cropping system depends on the applied N and plant N uptake. Best management practices for improving fertilizer use efficiency include applying nutrients according to plant needs, placed correctly to maximize uptake, at an amount to optimize growth and using the most appropriate source [22]. Exploring NUE maize varieties helps to understand the rate of N applied in relation with crop N requirement. Therefore, management practices that improve NUE without reducing productivity or the potential for future productivity increases are likely to be most valuable options for production maize varieties. Furthermore, understanding the efficient NUE maize varieties help to reduce the N fertilizer cost and loss to the environment. Thus, the objective was to determine N use efficiency and yield of maize varieties for sustainable maize production in mid altitude areas of western Ethiopia.

MATERIALS AND METHODS

Description of the Study Site: The experiment was conducted on six farmers' field around Bako Tibe in 2013 and 2014 cropping seasons. The area lies between 8'59'31"N to 9'01'16 N latitude and 37°13'29 E to 37°21'E longitude and at an altitude ranged from 1727 to 1778 meter above sea level, receiving mean annual rainfall of 1265 mm with unimodal distribution [23]. It has a warm humid climate with the mean minimum, mean maximum and average air temperatures of 13.4, 28.49 and 20.95°C, respectively [23]. The soil type is brown clay loam Ultisols [24, 25].

Treatments and Experimental Design: The treatment used was five maize varieties from sub-humid mid altitude area were used as factor A. Two level of nitrogen half of the recommended (55 Kg N ha^{-1}) and recommended (110 Kg N ha^{-1}) was used as factor B. One maize variety (BH-543) without fertilizer was used as control treatments. The experiment was laid out in randomized complete block design in factorial arrangement with three replications. The maize varieties were (BH-540, BH-543, BH-661, BH-660 and BH-140). The total treatment combinations were 10 plus a satellite treatment. The plot size was 5.1m x 4.5m. An improved seed of each variety was planted in rows spaced at 75 cm between rows and 30 cm between plants. The weighed nitrogen rate was applied half at planting and remaining half at knee height. One hundred kilogram per hectare of diammonium phosphate (DAP) was applied for all treatments uniformly during planting. All other agronomic management practices were applied as per recommendation for the varieties. The necessary data were collected at right time and crop growth stage.

Soil Sampling and Analysis: A composite soil sample was collected before the treatment application and the collected soil analysis was prepared following the standard procedures that were adopted by the Holetta and Debre Zeit Agricultural Research Center Soil and Plant Analysis Laboratory. Determination of soil particle size distribution was carried out using the hydrometer method [26]. The soil pH was measured with digital pH meter potentiometrically in the supernatant suspension of 1:2.5 soils to water ratio. Organic carbon was determined following wet digestion methods as described by Walkley and Black [27], whereas kjeldahl procedure was used for the determination of total nitrogen as described by Bremner and Mulvaney [28]. Cation exchange capacity of the soil (CEC) was determined by saturating soil with neutral 1M NH_4OAc (ammonium acetate) and the adsorbed $NH4^+$ ions were displaced by using 1M KCl and then determined by the Kjeldahl distillation method for estimation of CEC of the soil [29, 30]. The available P was measured by Bray II method [31] and available potassium (K) was measured by flame photometry. The steam distillation method was used for determination of NO_3 and NH_4 as described by Keeney *et al*. [32].

Agronomic Data Collection, Plant Tissue Sampling and Analysis: The thousand seed weight and dry biomass and harvest index after maturity and harvesting of maize were obtained. The grain yield was harvested from the net plot (3 m x 5.1m =15m^2). The harvested grain yield was adjusted to 12.5 % moisture level [33, 34]. The adjusted seed yield at 12.5 % moisture level per plot was converted to grain yield as kilogram per hectare.

The tissue of maize was collected at 50 % tasseling of maize from three replications and composited after chopping. The grain of maize was collected after harvesting of the crop. The collected tissue and grain were prepared following standard procedures and analyzed at Holetta and Debre Zeit Agricultural Research Center Soil and Plant Analysis Laboratory. The maize tissues and grain were subjected to wet digestion using concentrated sulphuric acid and hydrogen per-oxide with selenium as catalyst [35] and the N content of the plant tissue was determined by Kjeldahl methods

Total N uptake was calculated by multiplying N concentration x dry biomass weight (kg ha^{-1}) of maize, whereas agronomic efficiency was calculated by multiplying the grain yield and applied N [36].

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

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

The N uptake efficiency (UEN) was obtained by dividing the total amount of N absorbed per kg of applied N as follow:

$$UEN(kgN\ /\ kgN = \frac{U_N - U_0}{F_N} \quad (2)$$

Plant nitrogen use efficiency/ physiological efficiency was calculated by dividing the total dry matter produced to a unit of N absorbed as indicated below:

$$PEN(kg\,grain\ /\ kgN = \frac{Y_N - Y_0}{U_N - U_0} \quad (3)$$

Apparent fertilizer N use (recovery) efficiency (ANRE) was obtained by dividing the amount of fertilizer N taken up by the plant to the kg of N applied as fertilizer as it was described by Azizian and Sepaskhah [37], Craswell and Godwin [38].

$$\%\ \text{fertilizer nutrient recovery (ANRE)} = \frac{(TNF) - (TNU)}{R} X\ 100 \quad (4)$$

The analysis of agronomic data was carried using the SAS software [39] and the mean separation was done using least significance difference (LSD) procedure at 5 % probability level [40].

RESULTS AND DISCUSSION

Some Soil Physical and Chemical and Properties of Study Area: The soil chemical and physical properties of the different farmers' fields are presented in Table 1. All the six-farmers' soils were clay in textural classes. The soil pH in H_2O ranged from 4.63 to 5.45. This showed that all the farmers' fields were very strongly acidic to moderately acidic range [41, 42]. Such variation can be attributed to differences in soil fertility management practices adopted by different farmers. Thus, sound soil management practices are required to use this soil for sustainable crop production. Furthermore, the total N ranged from 0.17 to 0.23 %, whereas the available P ranged from 4.18 to 7.52 ppm (Table 1). The total N concentrations varied from very low, medium to high range [41-43] for the six farms. In Ultisols 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 available phosphorus concentration was low to medium range [41, 42] for the six farms. The low and medium available soil P content of the different farms was a good indicator of the soil P supply for maize production in different farm fields. This showed different farm fields need different rates of phosphorous fertilizer management practices to get the potential yield of maize. The organic carbon and organic matter concentrations were ranged 2.07 to 2.77 and 3.56 to 4.76 % which were low to medium ranges [41,42]. The CEC concentration ranged from 19.7 to 38.5 cmol$^+$ kg^{-1} which was in the range of medium to high range [43]. Horneck *et al.* [44] soils with high clay and/or organic matter content have high CEC. The NO_3-N concentration in the soils of all farms ranged between 30.17 to 66.38 ppm (Table 1) which was in the range of high to very high [45]. The NH_4-N concentration of the soil was ranged from trace to 11.75 ppm (Table 1) found in optimum range [44]. The NO_3-N and NH_4-N concentration of the soils were in the optimum range for maize production. Therefore, low input of N fertilizer can be recommended for improved maize production in mid altitude agroecology of Bako Tibe districts.

Table 1: Some physicochemical properties soil of farmer's field before planting maize in Bako-Tibe districts, western Ethiopia

				OC	OM	CEC	K	Na		$N0_3$-N	NH_4+N	
Farms	pH	N (%)	P (ppm)	--------%--------		-----(meq 100 g soil-1)-----			Exch. Acidity	---------(ppm)---------		Texture
F-1	4.86	0.22	5.02	2.69	4.63	21.26	0.71	1.68	0.09	43.98	trace	Clay
F-2	4.63	0.22	5.43	2.53	4.35	19.7	0.13	2.4	0.17	53.05	8.84	Clay
F-3	5.45	0.23	7.52	2.77	4.76	21.32	0.85	2.4	0.17	41.13	8.81	Clay
F-4	5.4	0.17	6.27	2.07	3.56	38.12	0.85	1.68	0.08	30.17	6.03	Clay
F-5	4.71	0.2	4.18	2.46	4.23	22.74	0.99	2.16	0.24	66.38	9.05	Clay
F-6	5.44	0.18	5.67	2.22	3.82	36.5	0.56	1.44	0.12	41.13	11.75	Clay

F1-6, Farm1-6.

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

	Grain yield (kg ha^{-1})						Thousand seed weight (g)					
	2013			2014			2013			2014		
Varieties	F- 1	F- 2	F-3	F-4	F-5	F-6	F- 1	F- 2	F-3	F-4	F-5	F-6
BH-540	4114bc	2089ab	4751	4518abc	2655b	5282ab	382ab	419a	426	442a	399	450ab
BH-543	4988b	2566ab	4644	3731c	2999ab	4372bc	431a	383ab	434	388ab	403	409bc
BH- 661	6546a	3050a	4691	5643a	4193a	6052a	413a	372ab	418	410ab	377	384c
BH-660	3216c	2509ab	4425	4972ab	3447ab	5867a	321b	388ab	436	366b	428	461a
BH-140	4113bc	1754b	4878	4411bc	3171ab	4223c	366ab	336b	372	397ab	430	392c
BH-543	3796c	1870b	3659	3350c	3941a	1556d	341ab	307c	406	421ab	356	365d
LSD (%)	841.3	1130	NS	327.9	1261	933	66.41	79.68	NS	59.66	NS	48.65
N (kg ha^{-1})												
50 % RR	4705a	2208	4397ab	4535a	3159	4806b	389a	361ab	419	409	386	424
100 %RR	4485ab	2579	4958a	4774a	3427	5513a	376ab	399a 399a	415	392	429	414
Control	3796c	1870	3659c	3350b	3941	1556c	341c	307c	406	421	356	365
LSD (%)	532	NS	792	728	NS	590	42	79.68	Ns	NS	NS	NS
CV (%)	15.54	6.07	6.27	5.81	5.84	8.71	14.31	17.3	9.12	22.2	12.27	9.56

F-1-6= Farm 1-6, 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 3: Combination effects of varieties and nitrogen rate on mean grain yield and thousand seed weight of maize on farmer's field around Bako Tibe, western Ethiopia

	Grain yield (kg ha^{-1})						Thousand seed weight (g)					
	2013			2014			2013			2014		
Maize varieties with N rates	F- 1	F- 2	F-3	F-4	F-5	F-6	F- 1	F- 2	F-3	F-4	F-5	F-6
BH-540(50 %RR)	3633cde	1894ab	5057	2613ab	3904bcd	4880bcd	400abc	389ab	438ab	384ab	468a	454ab
BH-540(100 %RR)	4595bcd	2283ab	4446	2696ab	5132abc	5684ab	364abc	449a	414ab	414ab	417ab	447ab
BH-543(50 %RR)	4516cd	2455ab	4141	2990ab	4043bcd	4383cd	437a	391ab	460a	387ab	393ab	408bcd
BH-543(100 %RR)	5459abc	2678ab	5147	3009ab	3419cd	4361cd	425ab	374ab	408ab	420ab	384ab	411bcd
BH-661(50 %RR)	6719a	2628ab	4323	4457a	5472ab	5556abc	406abc	335bc	407ab	382ab	444ab	396bcd
BH-661(100 %RR)	6373ab	3472a	5060	3928ab	5814a	6548a	421ab	408ab	429ab	373ab	377b	372cd
BH- 660(50 %RR)	3872cde	2567ab	4107	3432ab	5042abcd	5155bcd	322c	341ab	404ab	352b	365b	484a
BH-660(100 %RR)	2561e	2451ab	4742	3462ab	4902abcd	6579a	319c	436ab	467a	503a	366b	437abc
BH-140(50 %RR)	4788bcd	1494b	4359	2302b	4216abcd	4053d	379abc	346ab	388ab	426ab	378b	381cd
BH-140(100 %RR)	3437de	2013ab	5398	4039ab	4605abcd	4393cd	353abc	326c	356b	435ab	417ab	403bcd
BH-543	3796cde	1870b	3659	3941ab	3350d	1556e	341bc	307c	406ab	356ab	421ab	365d
LSD (5%)	1844	242	NS	1970	1723	1270	88.79	109	81.67	147.33	83.99	65.55
CV (%)	15.41	6.05	7.01	6.33	5.9	11.45	13.76	17.21	11.52	21.48	12.25	9.288

F-1-6= Farm 1-6, 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.

Mean Grain Yield and Thousand Seed Weight of Maize: The grain yield and thousand seed weight of maize was presented in Table 2 and 3. The grain yield of maize was significantly different among varieties, across farms and combined over farms (Table 2). The grain yield significantly different among the farms in the following order: farm 6 > farm 3> farm1> farm5> farm 4 > farm 2. This indicates variations among farmers' field in soil fertility status and agronomic management practices adopted by the individual farmers. Similarly, Raun *et al.* [46] reported indigenous soil N across the landscape can vary several-fold, resulting in different N recommendations for different farm fields. This indeed justifies site-based fertilizer and variety recommendation to farmers for sustainable maize production in the agroecology. Significant differences in maize grain yield among the applied N rates were varied across site-years [47]. Sileshi *et al.* [48] found that the yield response to N fertilizer is inconsistent, likely because low N is not the only stress in the system. Different varieties gave different yield across farms. Accordingly, the maize varieties BH-661> BH-660> BH-540 > BH-543 > BH-140 in order produced better grain yield. All varieties with the N fertilizer application produced significantly higher grain yield than the maize varieties planted without N fertilizer application. Combined mean grain yield advantage of 24.07, 28.19, 28.79, 3.47 and 66.03 % of maize were achieved from BH-140, BH-543, BH-540, BH-660 and BH-661 maize varieties as compared variety planted without N (Table 2). Maize variety BH-661 followed by BH-660 was produced significantly higher combined mean grain yield advantage as compared to other varieties of maize and recommended for farmers to produce better grain yield of maize in area. Farmers can use maize varieties BH-661>BH-660> BH-540> BH-543>BH-140, importance in descending order for alternative options.

Application N fertilizer was significantly influenced grain yield of maize varieties (Table 2). Significantly higher mean grain yield was harvested from maize varieties planted with application of full recommended (110 kg N ha^{-1}) as compared to application of half N rate. Application of nitrogen fertilizer rate has produced higher mean grain yield of maize varieties as compared to maize varieties planted without nitrogen in all farms except farm 4. This indicates maize planted in farm 4 was not responding N fertilizer application which might be due to very poor fertility status of the soil and termite infestation problems observed in the farm. Higher mean grain yield advantage of 18.07, 20.17, 23.95, 35.37 and 208.87 % were obtained from farm2, farm3, farm1, farm5 and farm6, respectively with half recommended nitrogen as compared to maize variety planted without nitrogen (Table 2).

Maize varieties planted with full recommended (110 kg N ha^{-1}) gave significantly higher mean grain yield advantages of 18.15, 35.50, 37.91, 42.51 and 254.31 % from farm1, farm 3, farm 2, farm5 and farm6 as compared to maize variety planted without nitrogen fertilizer (Table 2). Combined mean grain yield advantages of 31 and 41.60 % across farms were produced from maize planted with half and full recommended nitrogen applied as compared to maize varieties planted without nitrogen. Furthermore, application of full recommended nitrogen across farms gave grain yield advantage of 8.09 % as compared maize planted with half recommended nitrogen applied. Similarly, Mupangwa et al. [49] found that application of 90 kg N ha^{-1} had produced higher mean grain yield of maize as compared with 0 and 30 kg N ha^{-1} in all three cropping seasons in conservation agriculture-based cropping systems of Southern Africa. Application of N fertilizer significantly increased maize yields by between 0.25 and 1.6 t ha^{-1} compared to control and more positive for the low fertilizer application rates (55% at < 30 kg N ha^{-1}) compared (17 %) fertilizer rates to medium (30 to 100 kg N ha^{-1}) and (29 %) high (> 100 kg N ha^{-1}) [50]. Application of increasing rate of N fertilizer could increase the mean grain yield and higher grain yield of (8.8 t ha^{-1}) obtained with 240 kg N ha^{-1} as compared to rates between 120-200 kg N ha^{-1} [51].

Interaction maize varieties with nitrogen rate were significantly (P<.0.05) affected mean grain yield of maize among farms and combined across farms to (Table 3). This is implying that the responses of different maize varieties to rates of N fertilizer were different. Le Gouis *et al*. [52] confirmed that there is a genetic variability for grain yield at a low N level and that the genotype x N level interaction is significant. Average mean grain yield 2346, 3352, 4523, 4536, 4585 and 4832 kg ha^{-1} of maize were obtained from farm2, farm4, farm1, farm5 farm3 and farm 6, respectively (Table 3). This indicates variation of soil fertility status and management practices applied among each farm. Vanlauwe *et al.* [53] reported a long-term interplay of geological and landscape conditions and plot-specific management have generated such often called within farm soil fertility gradients variations. Similarly, Mack [54] reported a wide range of management practices and production history at each site which subsequently affects treatment response of on-farm research; and each farmer managed his farm on his own way, such as applying either preplant or top dress N rates. Tittonell *et al*. [55] reported heterogeneity in soil fertility in these smallholder systems is caused by both inherent soil-landscape and human-induced variability across farms differing in resources and practices. Farm and/or soil test-based fertilizer recommendations were required for sustainable maize production in the area. Masvaya *et al*. [56] reported that farming sector gives some insights into imbedded agronomic management levels which have a bearing on residual soil fertility which in turn determines maize growth response to N fertilization. Maize varieties planted with half (55 kg N ha^{-1}) recommended nitrogen application were gave mean grain yield advantages of 16.71, 20.93, 23.97, 33.01 and 60.42 % from BH-140, BH-540,

Table 4: Effects of varieties and nitrogen rate on mean number of dry biomass and harvest index of maize on farmer's field around Bako-Tibe, western Ethiopia

	Dry biomass (kg ha^{-1})						Harvest index (%)					
	2013			2014			2013			2014		
Varieties	F- 1	F- 2	F-3	F-4	F-5	F-6	F- 1	F- 2	F-3	F-4	F-5	F-6
BH-540	15993c	10400c	20988	18041	21599b	19102c	27.48b	20.53a	20.87b	25,28cd	17.11c	27.75a
BH-543	23467a	14752a	23480	17483	13481b	23193bc	21.49b	17.38ab	20.02b	21.46c	22.64ab	20.01c
BH- 661	21991ab	15225a	24075	18254	21599a	33339a	26.75b	20.22a	19.51b	31.33a	20.85ab	18.57c
BH-660	13885c	13095ab	20255	17322	14427b	29305ab	26.34b	19.24a	21.98b	29.58ab	24.14a	20.58bc
BH-140	16267bc	11911bc	21918	16586	15672b	17660c	26.12b	15.42b	23.24b	26.64bc	20.08c	24.15ab
BH-543	10232c	8811c	10677	14853	9101c	12505d	40.82a	23.41a	37.18a	25.23cd	26.56a	13.38d
LSD (%)	5748	2318	NS	NS	4343	6376.8	9.09	3.2231	4.25	3.88	3.68	4.1353
CV (%)	25.87	14.62	16.47	20.22	12.29	21.44	29.23	14.32	16.59	18.990	11.92	15.35
N (kg ha^{-1})												
50 % RR	17560a	12402ab	21323	17280	15350	23330	21.96c	17.73	20.22b	25.64	20.27b	21.42a
100 %RR	17011ab	13750a	22964	17795	16946	25709	29.31b	19.38	22.02b	28.08	21.67b	23.00a
Control	10232c	8811c	10677	14853	9101	12505	40.82a	23.41	37.18a	25.23	36.56a	13.38b
LSD (%)	3635	1466	NS	NS	NS	NS	5.746	NS	2.68	NS	2.33	2.62
CV (%)	25.87	14.62	16.47	22.17	12.29	21.44	29.23	14.32	16.59	14.5	11.92	15.35

F-1-6= Farm 1-6, 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.

BH-543, BH-660 and BH-661 as compared maize planted without nitrogen application. BH-543, BH-660 and BH-661 varieties were better nitrogen efficient varieties among maize varieties used. Significantly higher mean grain yield advantages of 31.43, 32.45, 35.89, 36.65 and 71.64 % were produced from maize varieties (BH-140, BH-543, BH-660, BH-540 and BH-661) planted with full (110 kg N ha^{-1}) recommended nitrogen fertilizer as compared to maize variety planted with nitrogen. Likewise, Tremblay *et al.* [57] reported that maize yields increased by 1.6 (over the unfertilized control) in medium-textured soils and 2.7 in fi ne-textured soils at high N rates. The grain yield of maize was increased as the rate of nitrogen fertilizer increased [58]. Maize varieties BH-661 followed BH-660 were ranked first and second among the maize varieties used. Higher mean grain yield and nitrogen use efficiency were obtained from BH-661 followed BH-660 varieties of maize. This indicates maize varieties with higher grain yield potential had higher nitrogen use efficiency.

Maize varieties revealed significant ($P<0.05$) difference on thousand seed weight among farms and combined across farms (Table 2). Significantly higher thousand seed weights were obtained from BH-540, BH-5443, BH-660, BH-661 and BH-140 in descending order, respectively across farms (Table 2). This indicates different varieties were varied in seed size and carbohydrate accumulation in the seed coats. Application of nitrogen was non-significantly influenced mean thousand seed weight of maize varieties across farms (Table 2). Thousand seed weight of maize was significantly influenced by interaction of maize varieties with nitrogen rates applied (Table 3). Mean thousand seed weight ranged between 373 to 416 g among farms. Combined mean across farms, thousand seed weight ranged between 366 to 422 g. The lowest thousand seed weight was obtained from maize varieties planted without nitrogen application. Different maize varieties gave varied mean thousand seed weight with nitrogen rate application. BH-661 and BH-660 were gave higher mean thousand seed weight with full recommended nitrogen application as compared to other maize varieties which vise verse with nitrogen application.

Mean Dry Biomass and Harvest Index of Maize: The summarized analysis mean results of dry biomass and harvest index of maize varieties are presented in Table 4 and 5. Significant ($P<0.05$) differences were observed among maize varieties on mean dry biomass across farms and between varieties (Table 4). Significantly higher mean dry biomass of 9912, 11684, 14015, 16110 and 18647 kg ha^{-1} were collected from farm2, farm6, farm5, farm1 and farm 6 planted maize varieties. All maize varieties were produced higher combined mean dry biomass as compared to maize varieties planted without nitrogen fertilizer. Mean dry biomass was ranged from 1361 to 21230 kg ha-1 received from BH-540 and BH-661 (Table 4). Similarly, Asghar et al. [59] reported that the mean biomass yield of maize was significantly affected NPK application and higher (16.83 t ha^{-1}) mean biomass yield with application of 250-110-85 kg NPK ha^{-1} and the minimum (10.80 t ha^{-1}) produced from control.

Significantly higher mean dry biomass advantages of 23.43, 26.64, 42.29, 48.84 and 92.48 % as compared maize variety planted without nitrogen were obtained from BH-540, BH-140, BH-660, BH-543 and BH-660 (Table 4). This justifies there were variations among maize varieties in dry matter accumulation and morphological growth. Application of nitrogen was non-significantly affected

Table 5: Combination effects of varieties and nitrogen rate on mean number of dry biomass and harvest index of maize on farmer's field around Bako Tibe, western Ethiopia

	Dry biomass (kg ha^{-1})						Harvest index (%)					
	2013			2014			2013			2014		
Maize varieties with N rates	F- 1	F- 2	F-3	F-4	F-5	F-6	F- 1	F- 2	F-3	F-4	F-5	F-6
BH-540(50 %RR)	15488cd	11471d	20396ab	15488bc	18227ab	18323ef	23.86abc	20.47ab	20.72ab	19.83b	22.57de	28.43ab
BH-540(100 %RR)	16499bcd	11561cd	22420a	15637bc	17998ab	19881def	31.09ab	20.59ab	21.01ab	17.31b	29.18ab	33.54a
BH-543(50 %RR)	22338abc	14242abc	22420a	13343c	16967ab	22061cde	20.28bc	17.57bcd	18.88b	22.35ab	22.57e	18.45cd
BH-543(100 %RR)	24597a	15261ab	24540a	13619c	17998ab	24324bcde	22.69abc	17.65abcd	21.15ab	22.93ab	22.57cde	20.47bcd
BH-661(50 %RR)	20564abc	14222abc	23608a	20610ab	18227ab	31024ab	25.86abc	18.74abc	18.33b	20.54ab	30.74ab	18.41dc
BH-661(100 %RR)	23418ab	16229a	24542a	20610ab	18457a	36654a	27.63abc	21.70a	20.68ab	21.17ab	31.92a	18.24dc
BH- 660(50 %RR)	15312cd	12839bc	19089ab	13997c	17038ab	28272abcd	17.86c	19.07abc	21.64ab	23.96a	29.51ab	21.43bcd
BH-660(100 %RR)	12458d	13351abc	21422a	14857bc	17607ab	30337abc	34.81a	19.40abc	22.33ab	24.33a	29.64ab	23.08abd
BH-140(50 %RR)	15948bcd	11471cd	21100a	13314c	16967ab	16969ef	21.93bc	13.27d	21.55ab	17.55b	26.20bcd	28.70ab
BH-140(100 %RR)	16586bcd	12351bcd	22736a	18031abc	17056ab	17335ccde	30.31ab	17.57abcd	24.90a	22.61ab	27.09abc	25.38abc
BH-543	16848bcd	12161bcd	19089b	17534abc	14782b	12523f	22.66bc	15.46cd	24.61a	23.01ab	23.30cde	17.25d
LSD (5%)	7729	3157	6003	6268.7	3530	8650.5	12.14	4.4077	5.70	6.1211	5.43	5.8337
CV (%)	24.95	14.265	16.40	22.62	11.99	21.68	28.11	14.16	15.60	16.99	12.02	15.74

F-1-6= Farm 1-6, 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.

mean dry biomass of maize varieties (Table 4). Higher mean dry biomass was harvested from application of recommended (110 kg ha^{-1}) nitrogen fertilizer as compared to maize planted with half recommended N and without nitrogen fertilizer application (Table 4). Application of 100% of recommended dose of NPK fertilizer was produced higher biological yield (17.79 t ha^{-1}) of maize while lowest was observed where no NPK fertilizers was not applied [60].

Interaction of varieties by nitrogen rates were significantly ($P<0.05$) affected mean dry biomass of maize across farms and among varieties (Table 5). Mean dry biomass of maize varieties were ranged from 10012 to 22413 kg ha^{-1} obtained from farm 2 and farm 6 (Table 5). All maize varieties were produced significantly higher mean dry biomass yield with application of half and recommended nitrogen fertilizer as compared to maize variety planted without nitrogen fertilizer (Table 5). At half recommended and full recommended nitrogen application mean dry biomass advantages ranged from 17.13 to 92.21 % and 25.58 to 92.75 % as compared maize variety planted without nitrogen application. Mupangwa *et al*. [49] found that application of 90 kg N ha^{-1} had produced higher mean grain yield of maize as compared with 0 and 30 kg N ha^{-1} in all three cropping seasons in conservation agriculture- based cropping systems of Southern Africa. Application of increasing rate of N fertilizer could increase the mean grain yield and higher grain yield of (8.8 t ha^{-1}) obtained with 240 kg N ha^{-1} as compared to rates between 120-200 kg N ha^{-1} [51]. Anbessa and Juskiw [61] stated high biomass is the result of the plant's internal efficiency to utilize the N taken-up to produce dry matter and there is a direct relationship between biomass and N utilization efficiency. Dry Biomass is certainly an important component of grain yield and NUE in all grain crops [62]. Lemaire *et al*. [63] reported high above-ground biomass is often associated with a well-developed root system and more N uptake. Gava *et al.* [64] found increase in dose of nitrogen fertilizer caused increase in dry matter and dry matter production rate in corn. Nitrogen fertilizer promoted increase 79.5 % in shoot dry matter production of corn plants as compared to without fertilizer treatment [65]. This revealed application of nitrogen was very crucial for improved maize varieties production in the agroecology.

Main effects varieties were significantly affected mean harvest index of maize varieties at farm 2, farm4, farm5 and farm 6 (Table 4). Across farms, mean harvest index of maize varieties was ranged from 21.98 to 41.17 %, which received from farm 6 and farm 5. Higher mean harvest index was harvested from BH-540 followed by BH-660 and BH-140, respectively. Application of nitrogen rates were non-significantly affected mean harvest index maize varieties across each farm except farm1. Interaction of maize varieties by nitrogen rates were significantly affected mean harvest index maize varieties (Table 5). Across farm mean harvest index were ranged from 23 to 42 %, which received from farm 6 and farm 5. Application of nitrogen fertilizer at half and recommended fertilizer rate were gave significantly higher mean harvest index as compared maize varieties planted without fertilizer application.

Mean harvest index advantages of 8.1 % at half nitrogen and 5.5 and 11.2 % at full recommended nitrogen application as compared maize varieties planted without nitrogen application were obtained from BH-540 and BH-660. This indicates application of nitrogen fertilizer was give more yield as compared to planting maize varieties without nitrogen fertilizer application. This justifies BH-540 and BH-660 had better response to applied nitrogen fertilizer. Improved nitrogen

Table 6: Effects of varieties and nitrogen rate on nitrogen up take and agronomic efficiency of maize on farmer's field around Bako-Tibe, western Ethiopia

Maize varieties with N rates	Nitrogen up take (kg ha^{-1})							Agronomic efficiency (kg grain kg N $applied^{-1}$)						
	2013			2014				2013			2014			
	Farm 1	Farm 2	Farm 3	Farm4	Farm5	Farm6	Mean	Farm 1	Farm 2	Farm 3	Farm 4	Farm 5	Farm 6	Mean
BH-540(50 %RR)	324	77	285	187	113	306	215	-2.96	0.44	25.42	-24.15	10.07	60.44	11.54
BH-540(100 %RR)	199	178	265	240	233	294	235	7.26	3.75	7.15	-11.32	16.20	37.53	10.10
BH-543(50 %RR)	266	153	392	197	190	330	255	13.09	10.64	8.76	-17.29	1.26	51.40	11.31
BH-543(100 %RR)	599	247	329	290	207	414	348	15.12	7.35	13.53	-8.47	6.31	25.50	9.89
BH-661(50 %RR)	398	197	448	267	216	580	351	53.15	13.78	12.07	9.38	38.58	72.73	33.28
BH-661(100 %RR)	436	188	304	285	274	693	363	23.43	14.56	12.74	-0.12	22.40	45.38	19.73
BH- 660(50 %RR)	366	129	248	128	214	440	254	1.38	12.67	8.15	-9.25	27.77	65.44	17.69
BH-660(100 %RR)	242	130	320	207	201	398	250	-11.23	5.28	9.85	-4.35	15.71	45.66	10.15
BH-140(50 %RR)	317	105	167	149	195	264	200	18.04	-6.84	12.73	-29.8	15.75	45.40	9.21
BH-140(100 %RR)	285	134	270	380	230	360	277	-3.26	1.30	15.81	0.89	11.41	25.79	8.66
BH-543	175	109	174	236	143	230	178							
Mean	328	150	291	233	201	392		11.40	6.29	12.62	-9.45	16.55	47.53	

F-1-6= Farm 1-6, 50 % and 100 % RR= half and full doses (55 and 110 kg N ha^{-1}) recommended for maize.

use efficiency by better varieties can be achieved by selecting for cultivars with high harvest index [66]. Therefore, application of optimum nitrogen fertilizer was very crucial for sustainable maize production. In conclusion planting of maize varieties with optimum nitrogen application was far most important for sustainable maize production.

Nitrogen Uptake and Agronomic Efficiency of Maize: The nitrogen uptake and agronomic efficiency of maize varieties are indicated in Table 6. Nitrogen uptake of maize varieties was varied across farms and among varieties. Mean nitrogen uptake of maize varieties were ranged between 150-392 kg ha^{-1} among farms. This indicates there is variation of farmers' field in nitrogen uptake of maize varieties. Higher nitrogen uptake of all maize varieties was obtained with application of full recommended (110 kg N ha^{-1}) fertilizer as compared to half recommended nitrogen fertilizer application. Application of N rate significantly influenced total nitrogen uptake of maize and total nitrogen uptake was increased linearly up to 200 and 150 kg N ha^{-1} for the clay and loam soil textural groups [67]. The N uptake in the dry biomass increased for all cultivars with the increase in rate of N fertilizer [78]. Heinrich *et al*. [69] reported N uptake was likely at its maximum for an N fertilizer rate of around 120 lb. N $Acre^{-1}$ as compared to 80 lb. N $Acre^{-1}$. Higher mean nitrogen uptake of 12, 21, 43, 43 and 97 % were obtained at half recommended nitrogen application as compared to maize planted without fertilizer application from BH-140, BH-540, BH-660 and BH-543 and BH-661 varieties of maize (Table 6). Maize varieties BH-540, BH-660, BH-140, BH-543 and BH-661 applied with full recommended nitrogen fertilizer rate had mean nitrogen uptake of 32, 40, 55, 96 and 104 kg N ha^{-1} as compared to maize variety planted without nitrogen fertilizer application. Cultivars with enhanced capacity to take up and utilize N would increase NUE. Anbessa and Juskiw [70] reported the integration of improved N management practices and more efficient cultivars will bring about a significant improvement in NUE. Thus, considering higher nitrogen uptake of maize varieties was very crucial to have higher productivity of maize varieties.

Agronomic efficiency of maize varieties was varied across farms and among varieties (Table 6). Higher mean agronomic efficiency of 6, 11, 13, 17 and 48 kg grain kg N $applied^{-1}$ in increasing order were obtained farm 2, farm 1, farm 3, farm 5 and farm 6. Farm 5 and farm 6 fields gave better productivity of maize varieties as compared to other farms. Higher mean agronomic efficiency of maize varieties was produced form all maize varieties with half recommended nitrogen fertilizer application as compared to full recommended nitrogen application. The genetic variation in agronomic NUE, when N is applied in high application, might be due to the N uptake differences of maize varieties [71]. At low N applications, the variation in agronomic NUE could be primarily caused by variation in nitrogen utilization efficiencies [2]. This indicates all maize varieties had higher agronomic efficiency at lower nitrogen application.

Agronomic efficiency of maize varieties was ranged from 9 to 33 and 9 to 20 kg grain kg N $applied^{-1}$ with half and full recommended nitrogen fertilizer application. Better agronomic efficiency was obtained with all varieties under lower rates of nitrogen fertilizer. Similarly, Amanullah and Alkas [72] reported NAE was 28 kg $(kg N)^{-1}$ at an application rate of 60 kg N ha^{-1} but decreased to 23 and 19 kg $(kg N)^{-1}$ at application rates of 120 and 180 kg N ha^{-1}. Higher mean nitrogen agronomic efficiency of (42.85 and 19.40 kg grain kg N $applied^{-1}$)

Table 7: Effects of varieties and nitrogen rate on nitrogen up take efficiency and nitrogen use efficiency of maize on farmer's field around Bako-Tibe, western Ethiopia

Maize varieties with N rates	Nitrogen up take efficiency (kg N uptake kg N applied^{-1}) 2013 Farm 1	Farm 2	Farm 3	2014 Farm4	Farm5	Farm6	Mean	Plant nitrogen use efficiency (kg grain kg N uptake^{-1}) 2013 Farm 1	Farm 2	Farm 3	2014 Farm 4	Farm 5	Farm 6	Mean
BH-540(50 %RR)	2.71	-0.58	2.02	2.98	-0.55	1.38	7.96	-1.09	-0.75	12.59	27.10	-18.47	43.74	10.52
BH-540(100 %RR)	0.22	0.63	0.83	1.97	0.82	0.58	5.05	33.29	5.99	8.65	-311.25	19.80	64.50	-29.84
BH-543(50 %RR)	1.65	0.80	3.96	3.16	0.85	1.82	12.25	7.91	13.30	2.21	24.38	14.74	28.27	15.14
BH-543(100 %RR)	3.85	1.25	1.41	2.43	0.58	1.67	11.20	3.92	5.86	9.60	-17.26	1.08	15.24	3.07
BH-661(50 %RR)	4.05	1.60	4.98	4.44	1.33	6.36	22.76	13.11	8.61	2.42	16.65	29.07	11.43	13.55
BH-661(100 %RR)	2.37	0.72	1.18	2.38	1.19	4.21	12.05	9.87	20.28	10.78	-0.27	18.81	10.78	11.71
BH- 660(50 %RR)	3.47	0.36	1.35	1.91	1.29	3.82	12.20	0.40	34.85	6.05	4.71	23.83	17.14	14.50
BH-660(100 %RR)	0.61	0.19	1.33	1.67	0.53	1.53	5.85	-18.43	27.67	7.42	16.52	26.76	29.90	14.97
BH-140(50 %RR)	2.58	-0.07	-0.13	2.29	0.95	0.62	6.24	6.99	94.00	-100	18.84	16.65	73.44	18.32
BH-140(100 %RR)	1.00	0.23	0.87	3.25	0.79	1.18	7.32	-3.26	5.72	18.11	0.68	14.43	21.82	9.58
Mean	2.25	0.51	1.78	2.65	0.78	2.32		5.27	21.55	-2.22	-21.99	14.67	31.63	

F-1-6= Farm 1-6, 50 % and 100 % RR= half and full doses (55 and 110 kg N ha^{-1}) recommended for maize.

Table 8: Effects of varieties and nitrogen rate on Fertilizer N use efficiency of maize on farmer's field around Bako Tibe, western Ethiopia

Maize varieties + N Kg ha^{-1}	Fertilizer N (recovery) use efficiency (%) 2013 Farm1	Farm2	Farm3	2014 Farm4	Farm5	Farm6	Mean
BH-540(50 %RR)	271	-58	201	-89	-55	139	68
BH-540(100 %RR)	22	63	83	3	82	58	52
BH-543(50 %RR)	165	81	397	-70	86	182	140
BH-543(100 %RR)	386	126	141	49	58	167	155
BH-661(50 %RR)	406	160	499	57	132	637	315
BH-661(100 %RR)	238	72	118	44	119	421	169
BH- 660(50 %RR)	348	36	134	-196	130	381	139
BH-660(100 %RR)	61	19	132	-27	53	153	65
BH-140(50 %RR)	258	-7	-14	-158	95	62	39
BH-140(100 %RR)	100	23	87	131	79	118	90
Mean		226	52	178	-26	78	232

F-1-6= Farm 1-6, 50 % and 100 % RR= half and full doses (55 and 110 kg N ha^{-1}) recommended for maize

were obtained for highland maize variety (Wenchi) with application 55 kg N ha^{-1} as compared to 110 kg N ha^{-1} in two farmers field [73]. The average agronomic nitrogen efficiency of maize during 2000-2010 was 11.5 kg grain kg N applied^{-1} in China [74]. Agronomic efficiency is defined as extra crop yield produced per unit of fertilizer nutrient applied. Maximizing Agronomic efficiency also minimizes the risk that fertilizer nutrients move beyond the rooting zone into the environment and pollute water sources [75]. Vanlauwe *et al.* [76] suggested the use of improved germplasm is essential to ensure that the supply of nutrients is matched with an equivalent demand for those nutrients. All inputs need to be managed following sound agronomic principles [77]. The highest and lowest mean agronomic efficiency was received from BH-661 and BH-140. This indicates maize varieties with higher agronomic efficiency were produced higher mean grain yield.

Nitrogen Uptake Efficiency, Nitrogen Physiological Efficiency and Fertilizer N Use Efficiency of Maize: The summarized results of nitrogen uptake efficiency, nitrogen use efficiency and fertilizer N use efficiency are indicated in Table 7 and 8. Across farms mean nitrogen uptake efficiency of 0.51, 0.78, 1.78, 2.25, 2.32 and 2.65 kg N uptake kg N applied^{-1} were obtained from maize varieties planted on farm 2, farm 5, farm3, farm 1, farm 6 and farm 4 (Table 7). Farm1, farm6 and farm4 had better nitrogen uptake efficiency of maize varieties and Significantly better maize production among other farms. The three farms had better soil fertility status and productive potentials of maize varieties. BH-140 and BH-660 maize varieties were had higher nitrogen uptake efficiency at half recommended nitrogen application whereas BH-540, BH-543 and BH-661 were had at recommended nitrogen fertilizer application.

The nitrogen uptake efficiency of maize varieties was ranged from 6.24-22.76 and 5.05-12.05 kg N uptake kg N applied^{-1} with half and full recommended nitrogen fertilizer application. The nitrogen utilization efficiency decreased as the rate of nitrogen fertilizer increased and varieties differed significantly in N utilization efficiency [58]. Similarly, Correia Granato *et al.* [78] found nitrogen absorption (uptake) efficiency was showed greater genetic variability under low N availability. Likewise, Eivazi and Habibi [79] found variation in nitrogen physiological efficiency between single cross maize varieties, which is true for three-way crosses which is true also for three-way crosses. The NUE decreased with increasing N rate, from 59% when N was applied at 100 kg N ha^{-1} to 42% when N was applied at 250 kg N ha^{-1} [67]. Likewise, Gagnon and Ziadi [80]; Qiu *et al.* [81] found that decreasing trend in NUE of maize with increasing N fertilizer rates. Fageria and Baligar [82] suggested that the low NUE associated with high N rates is related to the inability of plants to absorb or utilize N at higher rates, or N loss exceeded the rate of plant N uptake. The NUE of maize ranged from 33 to 68 % and was greater in the clay soil texture group than the loam and Sp soil textural groups [67]. The highest mean nitrogen uptake efficiency was obtained from BH-661 followed BH-660 and BH-543 among other varieties of maize. Therefore BH-661> BH-660> BH-543 were the most promising varieties with nitrogen uptake efficiency and sustainable production of maize in the region.

The nitrogen physiological efficiency of maize varieties was varied across farms, nitrogen rates and among maize varieties used (Table 7). Mean nitrogen physiological efficiency of 5.27, 21.55, -2.22, -21.99, 14.67 and 31.63 kg grain kg N uptake^{-1} were obtained from varieties planted on farm1-6 respectively. Farm 1, farm 2, farm 5 and farm 6 were had better nitrogen physiological efficiency as compared to other farms. This indicates producing maize varieties on these four farms had a good potential for sustainable maize production in the region which implies better fertility status of the above four farms. Soil quality heterogeneity has been shown to be a factor in NUE on smallholder production fields, with much lower NUE in ‘outfields’ which are extensively management and sometimes associated with low soil organic matter [83]. The mean nitrogen physiological efficiency of maize varieties ranged from 10.52 to 18.32 for half recommended nitrogen application and -29.84 to 14.97 kg grain kg N uptake^{-1} for full recommended nitrogen fertilizer (Table 7). Except BH-140, all other maize varieties were showed better nitrogen physiological efficiency at half recommended nitrogen fertilizer application.

Higher mean nitrogen physiological efficiency of maize varieties was obtained from half recommended nitrogen application as compared to full recommended nitrogen rate. Enhanced efficiency fertilizer can improve the crop N use efficiency (NUE) as well as minimize negative environmental losses compared to conventional fertilizers [18, 84]. Hart *et al.* [85] reported nitrogen use effectiveness at increasing the NUE of corn has been variable. Presterl *et al.* [86] observed that nitrogen absorption (uptake) efficiency and nitrogen utilization efficiency were contributed to the genetic variation in NUE. Zhu [87]; Raun and Johnson [17] reported large amounts of N fertilizers are required to attain maximum yield and for which NUE is estimated to be far less than 50 %.

Estimates of NUE on maize plots derived from nationally representative and site-specific household survey data in Malawi are typically in the range of 7 to 14 [88-91]. Vanlauwe *et al.* [92]; Whitbread *et al.* [93] reported nitrogen use efficiency on maize plots following researcher management protocols can be in the range of 14 to 50 kg maize per kg nitrogen (N) and even higher in some cases. The average nitrogen use efficiency (NUE) was 89 and 67 % for the plots receiving 80 and 160 lb N/A and ear yield and NUE could be maximized by applying only 80 lb N/A [69]. Nitrogen use efficiency is highest for the first unit of added N and it decreases with the increase in rate of N fertilization [94].

Similarly, Agostini *et al*. [95]; Burns [96] stated the optimization of fertilization and the improvement of NUE of crops to achieve high yields with reduced N fertilization rates and limited environmental side effects related to N leaching. Bertin and Gallais [97] reported that the genetic variability in NUE under conditions of low N is primarily due to differences in nitrogen utilization efficiency. In contrast, LeGouis *et al*. [52]; Dovale *et al.* [98] concluded that the most important component for NUE under low N availability is nitrogen absorption (uptake) efficiency. Enhanced NUE may result from increased efficiency of recovery of soil available N (uptake efficiency) and higher efficiency of utilization of the N taken up for grain formation (utilization efficiency) [99]. The highest nitrogen physiological efficiency was obtained from BH-661 followed by BH-660 and BH-543. Anbessa and Juskiw [61] suggested increase in NUE may allow growers ultimately to maximize yield under moderate N conditions rather than the need for high N conditions. The optimization of NUE rests on management practices that can counter N losses from the soil plant system [17]. Therefore, these three maize varieties had better potential for sustainable maize production and/or uses to develop nitrogen efficient varieties through breeding strategies.

The fertilizer N (recovery) use efficiency was varied across farms and nitrogen rates applied. Fertilizer N use efficiency was ranged from 52 to 232 among farms except farm 4 (Table 8). Farm 4 had negative fertilizer N use efficiency indicating very poor soil fertility status due termite problem during operation and needs higher investment to replenish the soil and use it for maize production. Application of half recommended nitrogen fertilizer gave higher range 39 to 312 fertilizer N use efficiency as compared to maize varieties planted with full recommended nitrogen fertilizer (52 to 169). BH-661, BH-543, BH-660 and BH-540 in descending order gave better fertilizer N recovery use efficiency. Significantly better fertilizer N (recover) use efficiency was obtained with half recommended nitrogen fertilizer application. The highest agronomic fertilizer recover efficiency was obtained when 140 and 280 kg N ha^{-1} applications were applied [71]. Similarly, Tilman *et al*. [94] reported that agronomic fertilizer recover efficiency was highest with the lowest N application. Improving the management practices during plant growth could improve ARF and ultimately improve the productivity when low level or alternate N is applied [71]. Nitrogen recovery by the maize crop was higher in the urea treatment (76% of the applied N) as compared to Tithonia treatment (55.5% of the applied N) [100].

The apparent N fertilizer recovery decreased as the rate of nitrogen fertilizer increased [58]. Anbessa and Juskiw [61] stated increased N recovery and utilization efficiency may allow growers to maximize yield under a moderate rate of N fertilization instead of the traditional high rate of N fertilization. Soil N recovery and utilization efficiency may be increased through improved N management strategies that counter N losses from the soil-plant system plus a superior capacity of the crop cultivar to take up and use available N [92] Anbessa and Juskiw [70] found combination of improved N management practices and more efficient cultivars should bring about a significant increase in NUE under low to moderate N application rates. The percentage N recovery varied among the genotypes tested, demonstrating that maize varieties may differ in total N loss [101]. Nitrogen is the key driver for cereal crop performance across most environments, both in terms of yield and stability of yield [92]. Snapp *et al*. [102] reported raising the efficiency of nitrogen use by maize is therefore crucial for the sustainability and economic feasibility of land intensification in the region. Hoisington *et al.* [103] stated the effective use of plant genetic resources will be required to meet the challenge posed by the world's expanding demand for food, the fight against hunger and the protection of the environment. The mechanisms controlling plant N economy is essential for improving NUE and for reducing excessive input of fertilizers, while maintaining an acceptable yield and sufficient profit margin for the farmers [104].

Considering both economically and environmental challenge by reducing both the cost and application of N fertilizers were possible through improving NUE. Moreover, improvement in yield for most crops over the last 50 years has been estimated to be 40 %, due to improvements in cultural practices and 60% due to genetic gains, thus indicating that testing for improved NUE is still possible [105]. The ratio of plant N content to the N supplied does not exceed 50 % whatever the level of N fertilization [106], which suggests that improvement of NUE in this species is also a possibility [107]. Identification maize varieties with better NUE were agronomically and economically feasible and environmentally safe for sustainable maize production and desirable for further breeding use. Strategies to improve NUE are to use genetic modification or to breed for new varieties that take up more organic or inorganic N from the soil N and utilize the absorbed N more efficiently [8, 107]. Therefore, application of half recommended nitrogen fertilizer had better potentials for sustainable maize production in better soil fertility status.

CONCLUSION

Soil fertility problem was alleviated using improved crop management practices. Maize varieties were produced significantly different biological and grain yield. Application of nitrogen fertilizer significantly improved mean grain yield maize as compared to control. Higher nitrogen uptake of all maize varieties was obtained at full recommended nitrogen fertilizer application as compared to half recommended nitrogen fertilizer application indicating positive relation of nitrogen fertilizer application with nitrogen up take. Agronomic efficiency of maize varieties was ranged from 9.21 to 32.28 and 8.66 to 19.73 kg grain kg N $applied^{-1}$ with half and full recommended nitrogen fertilizer application. BH-661 followed by BH-660 and BH-543 had higher nitrogen uptake efficiency and plant nitrogen use efficiency and recommended for wide production in the region. Significantly improved fertilizer N use efficiency was obtained with half recommended nitrogen fertilizer application indicating half recommended nitrogen fertilizer had better potentials for sustainable maize production in better soil fertility status. Planting of BH-661, BH-660, BH-540 and BH-543 maize varieties with half recommended nitrogen fertilizer rate was agronomically gave higher grain yield and nitrogen use efficiencies for sustainable maize production. Identifying maize varieties with better nitrogen use efficiency was very crucial to reduce cost production for stallholder farmers and environmental pollination. Thus, planting of maize varieties with optimum nitrogen application was far most important for sustainable maize production in the agroecology. In conclusion, the results empathy of NUE maize varieties with good agronomic practices is essential components of sustainable maize production in the area.

ACKNOWLEDGEMENTS

First, we would like to thank the almighty God who lives us and lead us to see seed of my work. The authors thank Regional University Fund for Capacity Building in agriculture, I am very grateful to Ambo Agricultural Research center management for providing me all necessary equipment's and logistics during the research work. All the technical and field assistants of Land and Water Resources Research Process are also acknowledged for unreserved effort during executing the experiment. Ambo Plant Protection Research center, Holetta and Debre Zeit Agricultural Research Center, Soil and Plant Analysis Laboratory are acknowledged for their provision of laboratory service for soil. We want to thank Bako Tibe farmers for providing me land for field research work and their assistance in field managements.

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