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Research Article

Agronomic and Physiological Efficiency of Maize (*Zea mays* L.) Hybrids as Influence by Nitrogen Fertilization in Semi-Arid Areas of Ethiopia

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Abstract

Maize is one of the major food crops in semi-arid areas of Ethiopia. Efficient application of N fertilizer on maize crop enables smallholder farmers have a synergic effect through enhancing yield productivity, reducing cost of production and nitrous oxide emission to the atmosphere exacerbating the challenges of changing climate. This experiment was conducted to determine the effect of nitrogen fertilizer on yield and yield related traits and assess the relationship between yield and nitrogen use efficiency indices. Eight maize hybrids were evaluated at three rates of N fertilizer (0, 32.5 and 65 kg N/ha) using split-plot design with three replications at two locations (Dera and Melkassa) in 2020 main cropping season. The results from analysis of variance (ANOVA) at each location indicated that majority of yield and yield related traits, agronomic and physiological efficiency were significantly influenced either by one or two of the factors (nitrogen and genotype) and/or the interaction effect of the two at both locations. The results of combined ANOVA over locations revealed that the interaction of the three factors (location, nitrogen and genotype) had significant effect on agronomic and physiological efficiency. The hybrids WE7201 and WE8206 had obtained the highest agronomic (27.67 kg kg^{-1}) and physiological efficiency (43.52 kg kg^{-1}) due to the application of 32.5 kg N ha^{-1} respectively. Thus, WE7201 and WE8206 could be recommended for production in the study areas.

Keywords

Agronomic Efficiency, Grain Yield, Nitrogen Fertilization, Physiological Efficiency

1. Introduction

Maize (*Zea mays* L.) is one of the members of the grass family, Gramineae. Its center of origin is accepted to be in Mesoamerica, primarily Mexico and the Caribbean though there is some controversy on the origin of the crop [32]. It is cultivated globally being one of the most important cereal crops worldwide. In 2018, the three cereals (wheat, rice and maize) were cultivated on more than 672 million hectares of which maize accounted 41.6% land, and it had the widest distribution than the two cereal crops [16]. Maize was cultivated in 166 countries which were more than by 49 and 44% than rice and wheat, growing countries respectively [11]. Its high environmental adaptability to diverse climatic conditions and it is grown from sea level to higher than 3000 m.a.s.l. and in areas receiving annual rain fall of 250 to 5000 mm [13]. The crop is being directly consumed as food, used as feed and for the production of fructose/glucose, flour, oils and ethanol. As a

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result of this versatility, adaptability and productivity, maize has become the most abundant crop globally [11].

In 2018/19 *Meher* season, maize is produced by 9,863,145 smallholder farmers on 2,367,797.39 hectares of land and produced 9,492,770.834 tonnes of grain yield with average yield of 3.99 t/ha [12]. The average national maize yield was lower than 5.5 t/ha of the world's average yield [16]. The predominant constraints of maize production in Ethiopia are related to frequent occurrence of drought, low soil fertility, poor agronomic practice, limited use of input, insufficient technologies, lack of credit facilities, poor seed quality, diseases, insects and weeds [10, 29].

Climate change and variability pose a serious threat to food production in sub-Saharan Africa [18]. Climate change contributed significantly to the water scarcity problem [42]. The changes in temperature and precipitation affect crop photosynthesis, crop development rates, as well as water and nutrient availability to crops [38]. It was indicated that an increase in temperature of 2 ℃ or more in the late 20th century was expected to negatively affect major crops (i.e. wheat, rice, and maize) on both temperate and tropical regions [23].

Nitrogen is the main limiting nutrient after carbon, hydrogen and oxygen for photosynthetic process, growth-development of plants and other changes to complete its lifecycle. Excessive use of N fertilizer results in enhanced crop production costs and atmospheric pollution; thus there is an urgent need to up-grade nitrogen use efficiency in agricultural farming system [30]. Therefore, the water scarcity and temperature increase as constraints of maize production in moisture stress areas might not overcome unless the tolerant varieties to moisture stress are also efficient for N use. One of the major goals of crop research program is reducing fertilizer input while maintaining the environment or even increasing crop yield [25, 40]. However, genetic selection for improved nitrogen use efficiency (NUE) is often ignored and the genetic improvement of NUE in maize breeding program is mainly achieved through indirect selection for increased hybrid yield performance [28, 34]. In Ethiopia, 100 kg Urea and 100 kg NPS (65 kg N/ha) fertilizers are recommended for maize production for all the six major maize agro-ecology zones. However, the overall Ethiopia`s average fertilizer use is low and stands at approximately 21 kg/ha [4]. Particularly, the small-scale farmers in moisture stress areas often do not invest in yield enhancing inputs like nitrogen fertilizer, because it contributes to lower crop productivity [9].

Evaluation and identification of inbred lines and QPM hybrids tolerant to low N were reported [2, 8]. Limited research were conducted on fertilizers rates determination for maize production in central rift valley but it was not on maize genotypes developed to tolerant to low N and moisture stresses [36, 22]. Melkassa Agriculture Research Center identified three way cross hybrids for moisture stress areas after evaluation for many years and over locations under managed drought stress and rain-fed conditions. However, these promising maize hybrids were not evaluated to N use efficiency, reducing the cost of production, enhance productivity of maize while maintaining environmental quality. Thus, the determination of NUE of these hybrids helps breeders in making decision and recommendation of better varieties which are efficient to N uptake and utilization that satisfies the interest of resource poor farmers to produce higher yield of maize with low input and cost in dry lowlands of the country. Therefore, the objectives of this study was to determine the genetic variability of maize hybrids for yield, yield related traits and agronomic and physiological efficiency under varying levels of N in semi-arid areas of Ethiopia.

2. Materials and Methods

2.1. Description of Experimental Sites

The field experiment was conducted during 2020 main cropping season at two locations (Dera and Melkassa) in the Central Rift Valley of Ethiopia representing semi-arid maize growing environments (drought prone areas) in Ethiopia is presented in (Table 1).

Table 1. *Description of experimental sites.*

Locations	Geographical position		Soil types	Altitude (m.a.s.l)	Rain fall (mm)	Temperature (℃)	
	Latitude	longitude				Min	Max
Dera	8^0 04` N	39^0 00` E	Andosols	1660	616.86	6.6	26.19
Melkassa	8^0 26` N	39^0 22` E	Andosols	1550	763	14	28

Source: Melkassa Agricultural Research Center

2.2. Experimental Materials

Eight maize hybrids including two standard checks were used at a test crop at two locations (Dera and Melkassa. The six QPM (Quality Protein Maize), a three way cross hybrids were developed for moisture stress areas and selected as better performing hybrids in yield, drought tolerance, rust and TLB diseases from national variety trials. The two check varieties viz. MH 138Q and MH 140 are medium maturing QPM and non-QPM hybrid, respectively, and both varieties were released by Melkassa Agricultural Research Centre. The quality protein maize, MH 138Q is a three way cross hybrid released in 2012, whereas as MH 140 (non-QPM) is also a three way cross hybrid released in 2013. All these hybrids are categorized under a medium physiological maturity group. The list and description of eight maize hybrids are presented in (Table 2).

Table 2. Description of Experimental Materials.

S.N	Genotypes	Pedigree	Year of released	Original source
G1	WE5202	WMA2101/WMC8801//CML539	-	MONSATO -South Africa
G2	WE6205	WMA3104/WMA2001//CML539	-	MONSATO -South Africa
G3	WE7201	WMC5813/WMC8801//CML539	-	MONSATO -South Africa
G4	WE7210	CML539/WMB0001//WMA2002	-	MONSATO -South Africa
G5	WE8203	WMB3002/WMB4810//WMA2502	-	MONSATO -South Africa
G6	WE8206	WMB3002/WMB4810//WMA2230	-	MONSATO -South Africa
G7	MH138Q	CML144/CML159//POLL15#SR538	2012	CIMMYT
G8	MH140	CML444/CML547//ZL0814	2013	CIMMYT

Seed source: Melkassa Agricultural Research Center (MARC).

2.3. Treatments and Experimental Design

The treatments consisted of factorial combinations of eight maize hybrids and three N levels (0, 32.5 and 65 kg N/ha) laid out in a split plot design with three replications. Nitrogen rate was assigned as main plot and the genotypes were assigned as sub plot. The plot size for planting was 4 m × 4.5 m (18 m2) accommodating 6 rows of 0.75 m and 0.25 m inter-and intra-row spacing, respectively. The data was collected from the net plot size of 9 m2 of four middle/central rows of each plot leaving the outside rows and a distance of 50 cm at the ends of each middle row to serve as borders. The distance between the plots and blocks were kept at 1 m and 1.5 m apart, respectively.

2.4. Experimental Procedures

The experimental plots were prepared by tractor plowing and harrowing. In accordance with the specifications of the design, a field layout was prepared and each treatment was assigned randomly to experimental plots within each block independently. The treatments of N soil nutrient were arranged based on the fertilizers recommendation for maize viz. 100 kg/ha Urea (46% N) and 100 kg/ha NPS/Nitrogen, Phosphorus and Sulfur (19% N, 38% P_2O_5 and 7% S). Therefore, The recommended rate of NPS was placed together with the seeds (two seeds per holes) during planting on June 26/2020 and July 14/2020 main cropping season at Melkassa and Dera sites respectively, while N was applied in a split application when plants was at jointing with approximately a 60-cm plant height or knee height and at flowering/anthesis as top dressing. The fertilizer after application was covered with the soil immediately to avoid its loss to the air through volatilization. Two seeds was planted per holes at a spacing of 25 cm intra raw and thinned to 1 plant per stand. Hand weeding was undertaken using a local hand hoe after three weeks of planting.

2.5. Plant Tissue Sampling and Analysis

At crop maturity, a sub-sample from each net plot was harvested at ground level and dried at 70℃ until constant weight was reached for dry weight determination and partitioned into straw and grain. The dried samples were milled, and the grain and straw N content of the plant samples were determined using the micro-Kjeldahl method as stated by American Association of Cereal Chemists [3]. The laboratory analysis was done at Melkassa Agricultural Research Center, Soil Laboratory.

2.6. Data Collection

Nitrogen use efficiency (NUE) evaluated in terms of agronomic efficiency and physiological efficiency. Agronomic efficiency was determined as kg grain produced per kg of nitrogen applied, whereas physiological efficiency was determined as kg grain produced per kg of nutrient uptake. It was calculated using the equation established as agronomic efficiency and physiological efficiency by [15] as below.

$$\text{Agronomic efficiency (AE)} = \frac{\text{Gf}-\text{Gu}}{Na} = \text{kg grain/kg N} - \text{fertilizer}$$

Where Gf is the grain yield in the fertilized plot (kg), Gu is the grain yield in the unfertilized plot (kg), and Na is the quantity of nutrient applied (kg).

$$\text{Physiological efficiency (PE)} = \frac{\text{Yf}-\text{Yu}}{\text{Nf}-\text{Nu}} = \text{kg kg}^{-1}$$

Where Yf is the total biological yield (grain plus straw) of the fertilized plot (kg), Yu is the total biological yield in the unfertilized plot (kg), Nf is the nutrient accumulation in the fertilized plot (kg), and Nu is the nutrient accumulation in the unfertilized plot (kg).

2.7. Data Analysis

Data collected from each location was subjected to analysis of variance (ANOVA) for individual location and combined ANOVA over location was also done using the procedure of SAS version 9.2 (SAS Institute, 2008). F-ratio homogeneity test was conducted to error variances as outlined in [21]. Following the presence of significant difference among hybrids for parameters, the mean values of maize hybrids was compared using least significant test (LSD) at 5% probability level.

3. Results and Discussions

3.1. Soil Physico-chemical Properties of the Experimental Sites

The results of physical and chemical analyses of the soil sample for each location have been presented in (Table 3). The textural class of the soils was sandy loam and sandy-clay loam at Dera and Melkassa sites respectively. The soil pH was neutral for Melkassa site and moderately alkaline for Dera as per the rating suggested by [39]. According to [17], suitable pH range for most crops is between 6.5 and 7.5 in which N availability is optimum. Thus the results of soil test indicated the suitability of the soil reaction in the experimental sites for optimum crop growth and yield.

Table 3. *Physicochemical properties of soil at Dera and Melkassa sites before planting maize in 2020 main cropping season.*

	Location				
Soil property	**Dera**			**Melkassa**	**Reference**
Physical properties	Value	Rating	Value	Rating	
Sand (%)	58		52		
Silt (%)	26		18		
Clay (%)	16		30		
Textural class		Sandy loam		Sandy-clay loam	Tekalign [39]
Chemical properties					
pH	7.41	Moderately alkaline	7.3	Neutral	Tekalign [39]
Total N (%)	0.09	Low	0.12	low	Tekalign [39]
Av. P (ppm)	5.02	Medium	6.12	Medium	Olsen et al. [31]
OC (%)	0.91	Low	1.23	Low	Tekalign [39]
OM (%)	1.56	Low	2.10	Low	Berhanu [6]
CEC (cmol(+) kg	0.3	Low	1.0	Low	FAO [17]

N (%) = percentage of total Nitrogen, P=Phosphorus, OC (%)= Percent Organic Carbon, OM (%)=Percent Organic Matter and CEC (cmol(+) kg = Cation Exchange Capacity.

The soil organic matter content (OM) (1.56 and 2.10%), total nitrogen (TN) (0.09 and 0.12%), organic carbon (OC)

(0.91 and 1.23%) and cation exchange capacity (CEC) (0.3 and 1.0 cmol kg^{-1} soil) were low at Dera and Melkassa sites respectively, as suggested by (Berhanu, [6]; Tekalign, [39] and FAO, [17]. According to the rating suggested by [31], the soil for the two sites had medium available P content (Dera, 5.02 ppm and Melkassa, 6.12 ppm) but slightly saline soil at Dera site. As suggested by [14], the N nutrient of the soils at both sites were low; hence, amending the soils of the sites with fertilizer was important for enhancing crop yield as well as soil health.

The soils of the study sites had higher sand to clay ratio at (Dera, the sand to clay ratio is 3.63:1. and at Melkassa the sand to clay ratio is 1.73:1), low organic matter and low organic carbon (Table 3). This indicated that the soil fertility of the two sites was low. If the CEC is low, it is necessary to consider the increasing inputs of organic matter through additional inputs of organic materials [7]. According to [5], loss of soil organic matter due to topsoil erosion along with poor physicochemical properties is the prominent causes for the deterioration of soil fertility and productivity. Balanced and careful use of external inputs together with eco-friendly and environmentally sounds soil management practices are essential issues for sustainable agriculture production [24].

3.2. Analysis of Variance for Yield and Yield Component Traits

The results from analysis of variance (ANOVA) for yield and yield related traits of eight maize hybrids at individual location are presented in (Table 4). Ear length, number of kernel per ear, thousand kernel weight, grain yield, biomass yield and harvest index were significantly influenced by N and genotype at both locations. In addition, these traits except number of kernel per ear and biomass yield were significantly influenced by the interaction of N x genotype at both locations. The application of Nitrogen had significant effect on plant height and leaf area index at both locations while a day to maturity was significantly influenced by N and genotype at Dera and Melkassa, respectively. Neither Nitrogen nor genotype had significant effect on days to emergence, days to 50% tasselling, days to 50% silking and number of ear per plant. at both locations.

The results indicated that the eight maize hybrids had significant variations for yield and yield components, and nitrogen fertilizer had significant effect on the performances of hybrids on plant height, leaf area index, yield, and yield components at both locations. Grain yield, ear length, thousand kernel weight and harvest index) were significantly influenced by the interaction of genotype and nitrogen fertilizer rates indicated that the hybrids had differential response to the applied rates of nitrogen fertilizer on the performances of these traits. The effects of nitrogen fertilizer rates on maize hybrids on phenology, growth traits, yield and yield components at different sites and years were reported by many authors, which was in agreement of the current study results. There was a significant difference among five maize genotypes for grain yield, thousand seed weight and harvest index evaluated at Bako Tibe in 2013 and 2014 cropping season [41]. [20] who also reported that significant variation between two maize varieties for grain yield, ear length and thousand kernel weights and the effect of genotype x nitrogen fertilizer interaction on these traits.

The results of combined analysis of variance over locations are presented in (Table 5). Nitrogen had revealed a significant effect on all traits and genotypes also showed significant differences for all traits except plant height and leaf area index. Location had significant effect on all traits except days to physiological maturity, ear length and biomass yield. The interaction between nitrogen and genotype had a significant effect on all traits except days to physiological maturity and plant height. The interactions between location x nitrogen and location x genotype had significant effect on days to maturity and number of kernel per ear. Besides, thousand kernels weight was significantly influenced by the interaction of location x genotype. The interaction of the three factors (location, nitrogen and genotype) had significant effect on only leaf area index and number of kernel per ear.

The result of combined ANOVA suggested that the maize hybrids had significant differences to the utilization (uptake) of nitrogen and produce grain yield in response to the rates of nitrogen fertilizer. The significant effect of nitrogen x genotype interaction on all yield and yield related traits except phenology (days to maturity) and plant height indicated the effort of increasing the maize yield and yield related traits should be towards the identification of the responsive maize hybrids to nitrogen fertilizer and produce high yield. The presence of significant differences for genotypes x nitrogen interaction, and three way interaction (location x genotype x nitrogen) for maize hybrids were reported by many authors. [37], who reported that significant differences among ten maize hybrids for grain yield, thousand kernels weight, leaf area index and harvest index evaluated at four sites (Bako, Hawassa, Melkassa and Adamitulu) in 2013 and 2014 cropping season. The result was in agreement with the finding of [1], who reported that significant variation on maize variety for grain yield, leaf area index, 1000 kernels weight, above ground biomass and harvest index and the interaction of genotype x nitrogen fertilizer effects on these traits evaluated at two sites (Melkassa and Adamitulu) in 2014 main cropping season.

***Table 4.** Mean squares from analysis of variance for 13 yield and yield related traits of eight maize hybrids as influenced by Nitrogen fertilizer rates at Dera and Melkassa during 2020 main cropping season.*

Location		Dera								Melkassa						
Trait	**Rep (4)**	**Nitrogen (A) (2)**	**Error (a) (4)**	**CV (%)**	**Genotype (B) (7)**	**A x B (14)**	**Error(b) (42)**	**CV (%)**	**Rep(4)**	**Nitrogen (A) (2)**	**Error (a) (4)**	**CV (%)**	**Genotype (B) (7)**	**A x B (14)**	**Error (b)(42)**	**CV (%)**
DE	1.91	1.08ns	2.16	15.4	1.084ns	0.799ns	1.1349	10.2	1.263	1.513ns	0.33	13.7	2.093ns	1.117ns	0.12	11.39
TS	0.53	12.86ns	3.15	7.84	4.183ns	1.923ns	2.0992	5.91	6.291	5.291ns	5.33	6.55	5.744ns	2.815ns	3.51	4.87
SK	0.92	10.24ns	4.96	16.2	7.229ns	2.443ns	2.073	8.13	7.49	6.543ns	0.93	8.55	4.876ns	2.981ns	0.67	2.88
DPM	2.43	175.68**	5.74	9.15	5.442ns	6.014ns	3.6706	8.38	3.7431	1.930ns	2.08	11.4	19.230**	4.819ns	1.84	10.97
PLH	161.3	4135.17*	200.97	14.7	134.98ns	232.55ns	168.38	10.2	200.97	3500.1*	229.97	13.7	193.42ns	202.7ns	191.35	6.83
LAI	0.18	12.774**	0.3	11.6	0.141ns	0.1436ns	0.013	5.88	0.297	19.087**	0.58	14.3	0.176ns	0.256*	0.31	6.2
NEPP	0.05	0.03ns	0.18	13.7	0.035ns	0.053ns	0.047	8.45	0.061	0.021ns	0.072	13	0.041ns	0.056ns	0.045	8.44
EL	2.02	47.75**	1.42	11.9	24.886**	4.849**	1.303	6.7	1.423	33.611**	1.67	11.4	45.121**	9.088**	0.16	6.87
NKPE	797.1	37156.4**	1490.7	8.91	4667.2*	2552.7ns	1078.4	7.8	1090.7	32856.5**	5621.47	9.25	5172**	2610.4ns	3280.4	7.4
TKW	321.2	37638.9**	300.5	10.3	8658**	3478.6*	160.9	8.68	300.5	36515.8**	1229.72	8.13	8744**	3658.6*	1085.7	6.46
GY	0.1	28.93**	0.14	9.45	3.0933**	1.152**	0.017	8.95	0.139	22.931**	2.22	10.7	4.5714**	0.994**	1.4	7.52
BY	5.92	121.62**	1.43	11.9	28.976*	13.72ns	0.732	9.46	1.431	137.597**	47.06	9.25	10.601**	4.994ns	10.83	7.13
HI	0.04	0.012**	5.43	12.1	0.020*	0.002**	3.272	10.2	0.003	0.093**	0.07	11.1	0.002**	0.013*	0.004	9.74

ns, * and **, nonsignificant, significant at P<0.05 and P<0.01, respectively. DE = Days to emergence, TS= Days to 50% tasselling, SK= Days to 50% silking, DPM = days to physiological maturity, PLH= Plant height, LAI= leave area index, NEPP= Number of ear per plant, EL =Ear length, NKPE=Number of kernels per ear, TKW=Thousand kernels weight, GY=Grain yield, BY=Biological yield, HI= Harvest index and CV (%)= percentage of coefficient of variance. Number in parenthesis in each source of variation is degree of freedom.

***Table 5.** Mean squares from combined analysis of variance for nine yield and yield related traits of eight maize hybrids as influenced by Nitrogen fertilizer rates at two sites (Dera and Melkassa) during 2020 main cropping season.*

Trait	**R(L) (4)**	**Location (L) (1)**	**Nitrogen (N) (2)**	**L x N (2)**	**Error(a) (8)**	**CV (%)**	**Genotypes (G) (7)**	**L x G (7)**	**N x G (14)**	**L x N x G (14)**	**Error(b) (84)**	**CV (%)**
DPM	14.396	126.562ns	105.215**	72.396**	4.087	4.77	11.428**	13.245**	6.422ns	4.412ns	3.824	3.28
PLH	4.72	108.51*	7621.26**	14.01ns	181.15	8.99	139.55ns	188.86ns	185.8ns	249.45ns	168.96	6.11
LAI	0.0596	0.9983*	31.541**	0.3209ns	0.2367	13.59	0.1845ns	0.1327ns	0.2173*	0.1826*	0.0998	11.13

Trait	R(L) (4)	Location (L) (1)	Nitrogen (N) (2)	L x N (2)	Error(a) (8)	CV (%)	Genotypes (G) (7)	L x G (7)	N x G (14)	L x N x G (14)	Error(b) (84)	CV (%)
EL	0.7158	6.2834ns	80.7253**	0.6366	1.7233	9.65	68.245**	1.7617	13.3615**	0.5765	1.2123	5.21
NKPE	1973	6894384**	17694**	15210**	946	16.76	2874**	2323**	1316*	1299*	740	12.87
TKW	2193	469990**	73023**	649ns	1549	11.86	10068**	3343*	4047**	2164ns	1233	10.93
GY	0.1319	12.8403*	51.6458**	0.2153ns	1.1181	11.97	7.1895**	0.4752ns	1.9871**	0.1597ns	0.3085	7.21
BY	3.444	37.007ns	257.757**	1.465ns	3.674	13.4	34.618**	4.959ns	14.487*	4.227ns	2.456	11.64
HI	0.00026	0.00737*	0.022**	0.00019ns	0.00039	10.2	0.00388**	0.00056ns	0.00256**	0.00073ns	0.0006	8.63

ns, * and **, nonsignificant, significant at P<0.05 and P<0.01, respectively. R(L) = Replication by location, DPM = days to physiological maturity, PLH= Plant height, LAI= leave area index, EL =Ear length, NKPE=Number of kernels per ear, TKW=Thousand kernels weight, GY=Grain yield, BY=Biological yield, HI= Harvest index and CV (%)= percentage of coefficient of variance. Number in parenthesis in each source of variation is degree of freedom.

3.3. Interaction Effect of Nitrogen x Genotype on Biomass, Grain Yield and Harvest Index

3.3.1. Aboveground Biomass

The results of analysis of variance indicated that the two-way interaction of nitrogen and genotype had a significant effect on biomass yield (Table 6). The maximum biomass yield (28011 kg) was obtained from WE7210 at a plot that received 65 N kg/ha while, the lowest (19003 kg) biomass yield was obtained from the variety WE7201 at the control plot. Biomass yield of this hybrid (WE7201) increased by 25.24 and 26.43% than control plot due to the application of 32.5 and 65 N kg/ha, respectively, that had statistically non-significant difference with biomass yield of WE5202 (65 kg N/ha) and WE6205 (32.5 kg N/ha and at the control plot) and WE8203 (at the control plot). The hybrid, WE7210 had higher biomass at three levels of N (0, 32.5 and 65 kg/ha) as compared to other genotypes. The research result showed that the hybrids had genetic variation and had differential response to the rates of N for biomass yield. This result is in line with [26] who reported that the maximum biomass yield was obtained from Bate maize variety where plants were fertilized with 150 kg NPS and 87 kg N/ha at Babile.

3.3.2. Grain Yield

The results of analysis of variance revealed that the interaction of nitrogen and genotype had a significant effect on grain yield (Table 6). The highest grain yield (8390 kg) was obtained from WE8206 at a plot that was treated with 65 N kg/ha while, the lowest (3489 kg) grain yield was obtained from the standard check variety of MH138Q at the control plot. Grain yield of this hybrid (WE8206) increased by 47.31% and 14.63% than control plot due to the application of 32.5 and 65 N kg/ha respectively, that had statistically nonsignificant difference with grain yield of the genotypes WE7210, WE7201 and WE8203 (65 N kg/ha). This hybrid, WE8206 also had higher grain yield at three levels of N (0, 32.5 and 65 kg/ha) as compared to other genotypes. The results of research revealed that the hybrids had genetic variation in grain yield and had differential response to the rates of N for grain yield. The result was in harmony with the finding of [27] who reported that significant differences between maize varieties for grain yield, evaluated at Haramaya in 2018 and 2019 cropping season under rain-fed condition. [19], who also obtained significant difference among three wheat varieties for grain yield, evaluated at Enewari in 2014 and 2015 cropping season.

3.4. Harvest Index

The harvest index of a crop is an interaction of its physiological efficiency and its ability to convert the photosynthetic material into economic yield. Harvest index was significantly influenced by the interaction effect of nitrogen and genotype. As indicated in (Table 6), the maximum harvest index (39.61%)) was obtained from the variety WE8206 where plots was treated with 65 kg N/ha however, two genotypes (WE7210 and WE 7201) had statistically nonsignificant difference with the application of 65 kg N/ha for harvest index. The lowest (25.51%) harvest index was noted from the standard check variety MH138Q at a plot did not receive fertilizer application. The genotype, WE8206 had higher harvest index at the three levels of N (0, 32.5 and 65 kg/ha) and its overall mean of harvest index was significantly higher than other hybrids. The research results indicated that the hybrids had genetic variation and differential response to the rates of N for harvest index. Similarly [33], who reported that higher harvest index was found from variety R-2210. [26], also stated that harvest index was significantly affected by the interaction of genotype and N rate.

Table 6. Interaction effect of Genotype x Nitrogen on biomass yield, grain yield and harvest index of eight maize hybrids at two locations during 2020 cropping season.

N rate (kg/ha)	Genotype	BY (kg/ha)	GY (kg/ha)	HI (%)
0	WE5202	20167fgh	3831h	28.81g
	WE6205	19667hi	3777h	29.32ef
	WE7201	19003i	3833h	27.21gh
	WE7210	22167efg	4367g	29.59ef
	WE8203	19509ghi	3809h	30.56de
	WE8206	22500def	4421g	31.55cde
	MH138Q	22164efg	3489i	25.51h
	MH140	21161fgh	4001h	29.98ef
32.5	WE5202	25167a-d	6500ef	30.67de
	WE6205	19333ghi	7310bc	31.22cde
	WE7201	25419a-d	6330ef	32.66cde
	WE7210	24667a-e	7333bc	30.74de
	WE8203	26333ab	7159bcd	34.91b
	WE8206	24500a-e	7162bcd	31.28cde
	MH138Q	24333a-e	6166fg	32.01cde
	MH140	22502def	6159fg	30.08de
65	WE5202	19833hi	6033ef	28.03g
	WE6205	24830a-e	7533cde	33.44bc
	WE7201	25833a-d	8103ab	36.01ab
	WE7210	28011a	8159ab	37.84ab
	WE8203	27000abc	8092ab	34.80b
	WE8206	27167abc	8390a	39.61a
	MH138Q	25167a-d	7959bcd	31.11cde
	MH140	24332a-e	7364def	32.35cde
LSD (5%)		79.58	62.11	3.02

Mean values with similar letter(s) in column had nonsignificant difference at P<0.05. BY=Biomass yield (kg ha^{-1}), GY = Grain yield (kg ha^{-1}), HI =Harvest index (%) and LSD (5%) = least significant difference at 5% probability level

3.5. Interaction Effect of Location x Nitrogen x Genotype on Agronomic Efficiency

The hybrid WE7201 had significantly highest agronomic efficiency of 27.67 kg grain kg^{-1} nitrogen at plot received 32.5 kg N/ha at Melkassa, while WE 8203 had lowest agronomic efficiency (13.43 kg grain kg^{-1} nitrogen) at plot that received 65 kg N/ha at Dera. The hybrids except WE 8203 and WE 8203 had higher agronomic efficiency by about 4.74 kg grain kg^{-1} nitrogen at Melkassa due to the application of 32.5 kg N/ha than the application of 65 kg N/ha. There was variation among hybrids for the reduction of agronomic efficiency at plots that received 65 kg N/ha in which WE7201 hybrid had highest reduction of 13.67 kg grain kg^{-1} nitrogen followed by WE7210 hybrid with the reduction of 7.6 kg grain kg^{-1} nitrogen than AE at plots that received 32.5 kg N/ha. Whereas hybrids WE8203 and WE8203 showed lower agronomic efficiency reduction of 0.71 and 1.24 kg grain kg^{-1} nitrogen, respectively, at plots that received 65 kg N/ha than plots received 32.5 kg N/ha (Table 7). This showed that the agronomic efficiency of hybrids was significantly influenced by location and rates of nitrogen. The results suggested that the higher chance of identifying hybrids with higher agronomic efficiency in response of low rate of nitrogen at both locations and/or specific location than others as stable and/or fit to specific location. Maize crop had a genotypic variation in nitrate absorption and partitioning of N among plant parts. This result is in line with the reports of [35] that significant differences for maize varieties for agronomic efficiency, evaluated at two sites (Addis Alem and Tepi) in 2016 cropping season.

Table 7. Interaction effect of Location x Genotype x Nitrogen on agronomic efficiency (kg grain kg^{-1} applied nutrients) of N of eight maize hybrids at two locations during 2020 main cropping season.

Genotype	Location	N rate (kg N/ha)	
		32.5	65
WE5202	Dera	22.22b-g	19.30d-k
WE6205		21.02c-h	17.23i-n
WE7201		20.08c-j	14.41mn
WE7210		23.31b-e	19.08e-l
WE8203		14.67lmn	13.43n
WE8206		20.02c-j	17.69h-n
MH138Q		19.56c-i	16.01j-n
MH140		19.33d-k	16.39j-n
WE5202	Melkassa	24.59b	19.00e-l
WE6205		24bc	17.33i-n
WE7201		27.67a	14mn
WE7210		22.60b-f	15k-n

Genotype	Location	N rate (kg N/ha)	
		32.5	65
WE8203		19.04e-l	18.33f-m
WE8206		23.33b-e	18g-n
MH138Q		23.05b-e	17.57h-n
MH140		20.06c-j	16j-n
LSD (5%)		6.42	

Mean values with similar letter(s) in columns and rows had nonsignificant difference at P<0.05, and LSD (5%) = least significant difference at 5% probability level.

3.6. Interaction Effect of Location x Nitrogen x Genotype on Physiological Efficiency

Table 8. *Interaction effect of Location x Genotype x Nitrogen on physiological efficiency (kg grain kg^{-1} nutrients uptake) of eight maize hybrids at two locations during 2020 main cropping season.*

Genotype	Location	N rate (kg N/ha)	
		32.5	65
WE5202	Dera	21.56d-i	18e-i
WE6205		23.91c-g	14.29ghi
WE7201		27.51b-f	13.82ghi
WE7210		25.02b-h	12.34hi
WE8203		22.06c-i	15ghi
WE8206		27.03b-g	18e-i
MH138Q		22.66c-i	18.31e-i
MH140		23.30c-h	15.75f-i
WE5202	Melkassa	31.67b-e	21d-i
WE6205		31.67b-e	12.46hi
WE7201		34.74bcd	13.33ghi
WE7210		39.47ab	27.64b-g
WE8203		36.23bc	28.32b-f
WE8206		43.52a	35.04bc
MH138Q		30.03b-e	12i
MH140		28.67b-f	22.61c-i
LSD(5)		11.64	

Mean values with similar letter(s) in columns and rows had nonsignificant difference at P<0.05, and LSD (5%) = least significant difference at 5% probability level.

The hybrid WE8206 had significantly highest physiological efficiency of 43.52 kg grain kg^{-1} nitrogen at plot received 32.5 kg N/ha, while the standard check variety MH138Q had lowest physiological efficiency (12.56 kg kg-^{1}kg grain kg^{-1} nitrogen) at plot that received 65 kg N/ha at Melkassa site. Most of maize genotypes had significantly higher physiological efficiency with the application of 32.5 kg N/ha than the application of 65 kg N/ha at Melkassa site as compared to Dera. There was variation among hybrids for the reduction of physiological efficiency at plots that received 65 kg N/ha in which the standard check variety WE6205 hybrid had highest reduction of 19.21 kg grain kg^{-1} nitrogen followed by MH138Q hybrid with the reduction of 18.03 kg grain kg^{-1} nitrogen than PE at plots that received 32.5 kg N/ha. Whereas hybrid WE5202 showed lower physiological efficiency reduction of 3.56 kg grain kg^{-1} nitrogen, at plots that received 65 kg N/ha than plots received 32.5 kg N/ha (Table 8). The results of the research showed that the physiological efficiency of hybrids was significantly influenced by location and rates of nitrogen. The results suggested that the higher chance of identifying hybrids with higher physiological efficiency in response of low rates of nitrogen at locations and/or specific location than others as stable and/or fit to specific location. Similarly, [43] reported that significant differences for maize variety on physiological efficiency, evaluated at three sites (Bako, Central rift valley and Jimma) in 2015 and 2016 cropping season.

4. Conclusions

Moisture stress in the central rift valley part of Ethiopia is one of the major factor that affect maize crop production in semi-arid areas of the country. The climate change and variability pose a serious threat to food production in this area contributed significantly to the water scarcity and with nutrient stress such as nitrogen. Thus the development of varieties to moisture stress areas is one of the strategies to withstand the maize production problems brought by water scarcity and temperature increase.

The results of analysis of variance for individual locations indicated that nitrogen and genotypes had a significant effect on leaf area index, ear length, number of kernel per ear, thousand kernel weight, grain yield, biomass yield and harvest index at both locations. In addition, days to physiological maturity and plant height at Dera site and plant height at Melkassa was significantly influenced by nitrogen levels. Genotype had also significantly influence days to physiological maturity at Melkassa site. Nitrogen and genotypes interacted to influence ear length, thousand kernel weight, grain yield and harvest index at both locations, but leaf area index was significantly influenced by the interaction of nitrogen and genotypes at Melkassa site. The results of combined analysis of variance across locations indicated that the interaction of the interaction of between nitrogen and genotype had significant effect on all traits except days to physiological maturity and plant height. The interactions between location x nitrogen and location x genotype had significant effect on days to maturity and number of kernel per ear. Besides, thousand kernels weight was significantly influenced by the interaction of location x genotype. The interaction of the three factors (location, nitrogen and genotype) had significant effect on only leaf area index and number of kernel per ear.

The genotypes also had significant differences for agronomic and physiological efficiency. These traits were significantly influenced by one or more than one of the possible two factors interactions (nitrogen x genotype, location x nitrogen, and location x genotype). The interaction of the three factors (location, nitrogen and genotype) had significant effect on leaf area index, number of kernel per ear, agronomic and physiological efficiency. This showed that the importance of identifying genotypes with high yield and nitrogen use efficiency to increase the productivity of the crop in the study areas.

The physiological maturity, most of the plant growth traits, yield components, agronomic and physiological efficiency were the function of genotype and nitrogen and/or the interaction of the two factors. Thus, the effort of enhancing nitrogen use efficiency of the maize genotypes in the study areas needs to be towards the identification of maize hybrids efficient to the utilization of available nitrogen nutrient at different locations. Hence, WE7201 and WE8206 hybrids could be recommended for production in the study areas.

However, further studies will be needed, because the two locations have received sufficient rainfall during the experimental year, and the response of the hybrids at both locations with low soil fertility conditions may not be sufficient to represent the semi-arid areas of Ethiopia.

Abbreviations

AACC	American Association of Cereal Chemists
ANOVA	Analysis of Variance
FAO	Food and Agriculture Organization of the United Nations
MH	Melkassa Hybrid
NUE	Nitrogen Use Efficiency
TLB	Turcicum Leaf Blight
WHO	World Health Organization

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Author Contributions

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Yaya Tesfa: Data curation, Formal Analysis, Resources, Software, Writing – original draft, Writing – review & editing

Conflicts of Interest

The authors declare no conflicts of interest.

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