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Genetic analysis and yield assessment of maize hybrids under low and optimal nitrogen environments

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ABSTRACT

Development of maize hybrids that possess tolerant genes to low soil nitrogen is critical for long-term maize production in areas with low soil fertility. In this study, estimates for combining ability effects for grain yield and secondary traits of selected inbred lines, identify potential parents for hybrid development and yield potential of the crosses under sub-optimal and optimal N environments. One hundred hybrids were evaluated under sub-optimal and optimal N environments for two years. The experimental layout was a 10 × 10 alpha lattice design with two replications for two experiments. The results obtained showed that, the genotypes evaluated varied for grain yield and the characters measured under sub-optimal and optimal N conditions. Grain yield reduction due to N stress was 40.9%. General and specific combining ability (GCA) and (SCA) effects for mean squares varied for grain yield demonstrating the importance of additive and non-additive genetic effects for the hybrids evaluated under the study conditions. Even though significant variations were detected for GCA and SCA, GCA which is the additive gene action component mainly controlled the heritage of grain yield under both conditions. Inbred line 15 was identified as the superior parent with positive and significant GCA for grain yield under sub-optimal N. Genotypic correlation studies displayed that grain yield was positively correlated with ears per plant under sub-optimal N and was also positively associated with anthesis-silking interval under high N. The hybrids 52, 75, 81 and 37 were identified to be significantly superior in terms of grain yield, ASI and EPP under the two-contrasting conditions. The results suggest that, there is a need for development of low N tolerant inbred lines and hybrids for production under soils with low N status in the Guinea savanna of Ghana for high grain yield to be realised.

1. Introduction

Nitrogen, an essential macro element which plays a key role in determining yield output of cereal crops most especially in maize production. However due to its volatile nature, nitrogen (N) has become the most limiting macro-nutrient in most agro-ecosystems and is therefore usually applied in relatively large quantities (Chlingaryan et al., 2018; Li et al., 2019). Research has indicated that West African soils are fragile, with a larger proportion being kaolinitic clay (Obalum et al., 2013). Furthermore, tropical climates have high levels of rainfall and solar radiation as well as annual bush fires in most parts of the savannahs. These factors, which lead to nutrient leaching coupled with low levels of soil organic matter has made N the utmost limiting macro nutrient for maize production in sub-Saharan Africa (SSA) (Azeez et al., 2006; Chen et al., 2018).

Annual loss of maize yields due to low N stress varies from 10 to 50% (Wolfe et al., 1988; Southworth et al., 2000). Breeding and promotion of maize hybrids that are tolerant to low soil nitrogen is essential for increased maize production and productivity and for reducing input costs (Reynolds et al., 2015). Research has shown that each tonne of maize grain yield produced needs at least 16 kg N and availability of N to the maize crop during flowering and grain filling periods will significantly enhance grain yield production (Masclaux-Daubresse et al., 2008). It has been hypothesised that the amount of chlorophyll present in the leaf of maize under stress conditions affects the accumulation of photosynthate and dry matter accumulation and grain yield at large. Thus, maize

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varieties or hybrids with enhanced grain yield under N deficient soils can be detected by measuring chlorophyll and N concentrations in the leaf (Edmeades et al., 1997). Other parameters such as days to physiological maturity, stay green ability, plant height, ear height, number of cobs per plant (EPP) and kernel set may also be an indicative trait of how maize varieties perform under sub-optimal N conditions (Betrán et al., 2003; Habash et al., 2006).

Maize hybrids with high nitrogen-use efficiency may decrease the effects of soil N deficiency on maize production (Edmeades et al., 1997). According to Edmeades et al. (1996), best performing hybrids may either be more efficient at N intake or N use, or both. Variations among maize germplasm for N-use efficiency under low nitrogen was identified for parental lines in studies by Almeida et al. (2018) and tropical cultivars by Abe et al. (2013). DoVale et al. (2013) reported that in temperate maize germplasm that genotypes selected for N-use efficiency produced adequate grain yields under optimal N levels, and could be differentiated among other genotypes under low N condition. It has been proposed that effective selection can be realised in environments with limited N by integrating secondary traits that are positively associated with grain yield and with minimal influence by the environment (Gallais and Hirel, 2004). As a result of inadequate heritability of grain yield under low N conditions, Monneveux et al. (2008) suggested the deployment of secondary traits to enhance improvement of grain yield. These traits include EPP, rate of leaf senescence and anthesis-silking interval that demonstrated significant relationship with yield under limited N conditions and have indeed been used to select for higher levels of tolerance to low N stress in maize breeding (Buchaillot et al., 2019).

Even though enhanced N use efficiency has been the major goal for maize breeders, data on the comparative contributions of general and specific combining abilities (GCA) and (SCA) effects for attributes that are related to grain yield under sub-optimal N is crucial. Combining ability refers to the aptitude of two or more parents to produce desirable hybrids when hybridized such that favourable genes/characters from the parents are transmitted to their progeny. Combining ability studies are important to the success of plant breeding programmes when evaluating and comparing the performance of parents in generating of crosses (Fasahat et al., 2016). The GCA denoted the mean performance of an inbred line in hybrid combinations, while SCA indicates the deviations of certain crosses from expectations on the basis of the mean performance of the inbred lines involved (Fasahat et al., 2016). A comprehensive assessment of the relative importance of GCA and SCA under contrasting nitrogen environments could provide reliable information needed for the development of low N tolerant maize hybrids. This will aid breeding programmes on the strategies to adopt as well as serve the interests of the resource-poor farmers in the savannahs of SSA. Hence, it is crucial to conduct genetic studies on the recently developed inbred lines by the CSIR-Savanna Agricultural Research Institute in order to select ideal parents for hybrid development. The present experiment was conducted to estimate combining ability effects for grain yield and other related traits of selected inbred lines, identify potential parents for hybrid development and determine the yield potential of the maize hybrids, under sub-optimal and optimal N environments.

2. Materials and methods

2.1. Germplasm and field evaluations

A total of twenty-four parents with tolerant genes for low N were obtained from the Maize Improvement Programme, CSIR-Savanna Agricultural Research Institute (Table 1). These inbred lines were used to generate 96 single cross hybrids using the NC2 mating design. There were six sets and each set was made up of four inbred lines. Four hybrid checks were added to 96 hybrids developed and assessed under optimal and low N conditions during 2018 and 2019 cropping season in a 10 × 10 lattice. The trials were replicated two times under each study condition.

Table 1. Descriptions of the inbred lines used in the generating the hybrids.

Entry	Inbred	Pedigree
1	SARI 1	SARI-BB-2-1-3-1-2-3-2-6-1
2	SARI 2	SARI-AA-7-1-3-1-2-1-3-1-1
3	SARI 5	SARI-AC-8-1-2-2-2-2-2-2-1
4	SARI 6	SARI-AS-2-1-1-2-2-1-1-1-1
5	SARI 7	SARI-BA-5-1-1-2-2-2-2-1-1
6	SARI 8	SARI-BB-3-3-2-2-1-2-1-4-1
7	SARI 9	SARI-BC-2-2-2-2-1-2-1-2-1
8	SARI 10	SARI-AA-5-6-1-3-3-3-1-4-1
9	SARI 12	SARI-SS-7-2-3-1-2-1-3-1-1
10	SARI 13	SARI-AD-2-2-2-2-1-2-1-1-1
11	SARI 14	SARI-AD-6-1-1-1-2-1-2-1-1
12	SARI 15	SARI-BC-7-2-3-3-3-2-2-2-1
13	SARI 16	SARI-BD-8-5-1-1-1-2-2-3-1
14	SARI 18	SARI-AL-5-6-1-3-3-3-1-4-1
15	SARI 19	SARI-BB-6-3-3-2-1-1-2-1-1
16	SARI 20	SARI-AB-2-2-2-2-3-1-3-1-1
17	SARI 21	SARI-AA-1-1-2-2-1-1-1-2-1
18	SARI 23	SARI-GH-3-2-3-2-2-2-2-1-1
19	SARI 24	SARI-AH-5-6-1-3-3-3-4-4-1
20	SARI 25	SARI-HH-6-1-1-2-2-2-2-1-1
21	SARI 27	SARI-CC-6-1-1-2-2-1-2-1-1
22	SARI 28	SARI-AG-1-1-2-1-1-2-3-1-1
23	SARI 29	SARI-AF-2-2-1-2-1-2-1-2-1
24	SARI 30	SARI-SA-3-2-3-1-3-2-3-2-1

Evaluations were conducted for 100 hybrids under low- and optimal N environments Nyankpala during 2018 and 2019 cropping seasons to examine performance of grain yield and agronomic traits. The total rainfall recorded during the cropping seasons were 829.60 mm and 638.60 mm for 2018 and 2019, respectively (Table 2). The soil analyses revealed that the soil at the trial sites consisted of 0.76% organic carbon, 0.059% nitrogen, 6.88 mg/kg of phosphorus and 58 mg/kg of potassium. Fertilizer was applied at the rate 60 kg N ha^{-1}, 60 kg P_2O_5 ha^{-1} and 60 kg K_2O ha^{-1} two weeks after planting (WAP) for the optimal N application with NPK 15-15-15. Top-dressing with the application rate 60 kg N ha^{-1} was conducted using urea at 5 WAP. However, for the low N experiment, NPK fertilizer was applied at 30 kg N ha^{-1}, 30 kg P_2O_5 ha^{-1} and 30 kg K_2O ha^{-1} and there was no fertilizer application again till harvest. Weeds in both experiments were controlled by hand weeding and application of herbicide.

2.2. Measurement of parameters

From both experiments, the following traits were recorded: days to 50% silking (DS), days to 50% anthesis (DA), anthesis-silking interval (ASI), plant height (PH), ears per plant (EPP), plant aspect (PA), ear aspect (EA), and stay green ability (SGA). Other traits measured were root lodging (RL), stalk lodging (SL), husk cover (HC) and grain yield. The data collected above were described by Amegbor et al. (2021).

Under optimal N condition, grain yield was determined as follows in Eq. (1):

$$\text{Grain yield}\left(\text{GY, kg ha}^{-1}\right) = \text{field weight}\left(\text{kg plot}^{-1}\right) \times \left(\frac{100-\ \text{moisture}}{85}\right) \times \left(\frac{10{,}000}{3 \times 0.75}\right) \times 80\ \text{shelling}\ \% \qquad \text{Equation 1}$$

Similarly, grain yield for the low N experiments was hand shelled and grain yield was computed using the formula as shown in Eq. (2):

Table 2. Total rainfall and mean wind speed, temperature and relative humidity recorded during 2018 and 2019 cropping seasons.

Month/Year	Rainfall (mm)	Wind speed Mean (km/h)	Temperature Mean (°C)		Relative humidity Mean (%)
			Minimum	Maximum	
2018					
July	162.20	1.97	23.98	31.51	80.84
August	290.50	1.75	24.04	31.03	82.48
September	268.60	1.06	24.25	31.24	84.77
October	108.30	1.01	24.34	32.44	81.77
November	0.00	1.12	23.63	35.33	65.80
December	0.00	1.60	18.87	35.34	37.19
2019					
July	134.40	1.68	25.16	30.85	79.93
August	60.30	2.02	24.02	29.78	79.23
September	284.20	1.02	24.32	30.98	81.77
October	151.10	0.73	24.45	31.87	79.13
November	8.60	0.92	24.53	35.60	70.07
December	0.00	1.11	20.15	36.35	51.90

Source: CSIR-SARI meteorological station.

$$\text{Grain yield}\ (\text{GY},\ \text{kg ha}^{-1}) = \text{grain weight}\ (\text{kg plot}^{-1}) \times \left(\frac{100 - \text{moisture}}{85}\right) \times \left(\frac{10,000}{3 \times 0.75}\right) \qquad \text{Equation 2}$$

2.3. Statistical analysis

For the data taken, analysis of variance (ANOVA) was performed for the hybrids evaluated under each condition. The ANOVA was conducted individually for the low and optimal N conditions for the traits measured using general linear model procedure in SAS (SAS 2011, version 9.3). The best performing hybrids were selected using a multiple trait index "base index (BI)" across the two environments.

Eq. (3) is the model used for the analyses as shown below:

$$Y_{ijkg} = \mu + E_i + R_{j(i)} + B_{k(ij)} + G_g + (EG)_{ig} + \varepsilon_{ijkg} \qquad \text{Equation 3}$$

Where Y_{ijkg} is the recorded trait for the g^{th} hybrid located in the k^{th} block of the j^{th} replication, in i^{th} location; μ represents the pooled mean; E_i denotes the environment effect, $i = 1,2,3$; $R_{j(i)}$ represent the effect of replication within the environment. On the other hand, $j = 1,2,3$; $B_{k(ij)}$ is the effect of blocking in a replication within a particular environment i, $k = 1$ and 2 for the hybrids, G_g represents the hybrids, $g = 1,2,3, \ldots$ 100 hybrids where $(EG)_{ig}$ is the relationship between hybrid and environment, and ϵ_{ijkg} represents the error according to Amegbor et al. (2021).

The PROC GLM model for North Carolina 2 mating design according to (Singh and Chaudhary, 1985) was followed to estimate the GCA and SCA (Equation 4). The formula used is:

$$Y_{ijkl} = \mu + m_i + f_i + (m\,x\,f)_{ij} + G_g + (EG)_{ig} + e_{ijk} \qquad \text{Equation 4}$$

where, "Y_{ijk} is the k^{th} observation on i x j^{th} progeny; μ is the general mean; m_i is the effect of the i^{th} set; b_{ij} is the effect of the j^{th} replication in the i^{th} set, f_{il} is the effect of the i^{th} male; f_i is the effect the j^{th} female in i^{th}; m x f_{ij} is the interaction effect, and e_{ijk} is the error associated with each observation" as adopted by Amegbor et al. (2021).

The statistical software (GEA-R version 4.1) developed by Pacheco et al. (2017) was used to estimate genotypic and phenotypic correlations.

3. Results and discussion

3.1. The analysis of variance for grain yield and agronomic traits under low and optimal N conditions

The analysis of variance revealed significant ($p < 0.05$) differences among the hybrids tested for most of the traits measured under the two conditions. Under low N conditions, year significantly influenced all the traits except ASI. The hybrids differed significantly for GY, PH, EH, HC, PA, EA and SGA (Table 3). Apart from GY, EH, EA and SGA, the response of the hybrids for the rest of the traits did not significantly differ with years. However, in the study conducted under optimal N fertilization, the year effect had significant influence on all the traits, except EA. The hybrids on the other hand varied statistically for GY and most of the measured traits, excluding RL, SL, HC and EPP. The interaction between hybrid and year showed significant differences for GY, PH, EH, HC, DA, DS and ASI (Table 3). The presence of significant differences among the hybrids for GY and the traits measured under low and optimal N conditions implied that hybrids evaluated were genetically diverse and responded differently under the study conditions. The existence of significant interaction observed for hybrid and year under low and optimal N fertilization environments specified that the hybrids performed differently across the years in which the set of trials were tested. The significant dissimilarity observed for the hybrid across years further suggested that nitrogen fluxes were not the same for the two years and thus could influence the inconsistencies observed for the traits measured. These results are in conformity with the study by (Mafouasson et al., 2017) who reported on the differences in the performance of maize hybrids under low N and optimal N conditions. The significant hybrid × year interaction for GY and most of the characters studied under suboptimal N suggested that the hybrids responded differently to the limited N available in the soil and how it was utilised. This further suggested that, N fluxes was different for the two year which could have influenced the responses of the hybrids corroborating the studies by Zhao et al.

Table 3. Analysis of variance for grain yield and agronomic characters traits of 100 maize hybrids evaluated low and optimal nitrogen applications.

Source	DF	GY	DS	DA	ASI	PH	EH	RL	SL	HC	PA	EA	EPP	SGA
LowN														
Rep(Year)	2	356239.30ns	23.61**	18.64**	0.49ns	657.57*	23.97ns	5141.26**	27.61ns	0.15ns	0.08ns	1.36*	0.03ns	0.13ns
Block (Rep*Year)	36	692666.40ns	2.97ns	2.06ns	1.05ns	129.31ns	64.26ns	317.68ns	112.47ns	0.15ns	0.38ns	0.71*	0.01ns	0.37ns
Year	1	82156367.90**	1369.00**	552.25**	0.04ns	57288.42**	10383.61**	97546.91**	2078.45**	113.96**	0.00ns	16.81**	0.09*	23.04**
Genotype	99	1844316.60**	3.47ns	1.91ns	0.93ns	249.01*	122.59*	317.33ns	120.3ns	0.19*	2.06**	0.63*	0.02ns	6.26**
Year*Genotype	99	1313304.70**	2.86	2.03ns	1.01ns	215.45ns	131.1**	315.9ns	93.37ns	0.15ns	0.36ns	0.78**	0.01ns	0.78*
Error	162	680032	2.78	1.61	1.04	177.98	91.83	316.91	99.98	0.11	0.3	0.42	0.01	0.55
Optimal N														
Rep(Year)	2	5878854.50**	24.03**	17.65**	0.04ns	760.69*	44.76ns	26.55ns	12.38ns	0.03ns	0.01ns	0.18ns	0.02ns	-
Block (Rep*Year)	36	467338.90ns	3.52**	2.88**	0.47ns	98.79ns	77.57ns	202.53ns	210.10ns	0.12ns	0.09ns	0.16ns	0.01ns	-
Year	1	21730887.50**	1365.30**	2152.96**	23.52**	120027.6**	19334.90**	29558.21**	1118.23*	44.22**	2.33**	0.26ns	0.48**	-
Hybrid	99	2045347.30**	2.77*	2.16*	0.45*	275.54**	127.27**	150.95ns	208.40ns	0.15ns	0.15**	0.22*	0.01ns	-
Year*Genotype	99	1497840.60**	2.78*	2.18*	0.39	322.26**	182.82**	150.10ns	306.19**	0.16*	0.11ns	0.16ns	0.01ns	-
Error	162	695849.2	1.92	1.61	0.34	146.5	80.01	178.09	170.19	0.12	0.09	0.16	0.02	-

DF- degree of freedom; GY(t ha^{-1})- grain yield; DA- Days to anthesis; DS- days to silking; ASI - anthesis silking interval; PH - plant height; EH - ear height; RL-root lodging; SL – stalk lodging; EPP- ear per plant; HC - husk cover; ER - ear rot; EA - ear aspect; SGA – stay green ability. *P $<$ 0.05, **P $<$ 0.01, ns – not significant.

(2017) as well as Agarwal et al. (2018) who also found variation among the years in which N experiments were conducted.

3.2. Performance of the hybrids at low and optimal N fertilizer application rates for grain yield and measured traits

For the study under sub-optimal N condition, GY of the hybrids ranged from 2600.6 kg ha^{-1} for hybrid 12 to 5760.7 kg ha^{-1} for hybrid 81. Plant height also varied among the hybrids ranging from 170.2 for hybrid 64 to 205.1 cm for hybrid 51, while ear height ranged from 80.2 to 107.9 cm for entries 12 and 93, respectively (Table 4). Hybrids 87, 75, 88, 41 and 52 had scores less than 5 for PA whilst hybrids 98, 52, 49, 81 and 90 had scores less than 5 for EA under low N condition. Only hybrids 75, 96 and 98 produced more than one EPP under the low N. Based on the BI, hybrids 92, 52, 98, 81, 40 and 37 were selected as the best performing hybrids under sub-optimal N environments. Under optimal N application, GY ranged from 3923.4 to 7667.4 kg ha^{-1} for hybrids 7 and 26, respectively (Table 5). PH ranged from 183.8 to 214.0 cm for hybrids 84 and 85, respectively, while EH varied from 92.1 cm for hybrid 13 to 116.0 cm for hybrid 51 (Table 6). Hybrids 26, 18, 34 and 10 were rated for PA below a score of 5, while hybrids 100, 90, 89 and 20 were rated below a score of 5 for EA. Hybrids that produced more than one EPP were 14, 16, 52, 34, 9 and 85. The BI identified hybrids 52 as the best hybrid across low and optimal N application. This hybrid produced 26.77% more grain under optimal N than low N. However, the best performing hybrid (81) in terms of GY under low N outperformed the best check (hybrid 98) by 37.5%. The yield reduction of 26.77% recorded under sub-optimal N. The best hybrid sub-optimal N performed 38.5% better than best check in this study falls within the range reported in earlier studies (Bolaños and Edmeades 1996; DeBruin et al., 2017; Shimelis et al., 2019) that average yield under low and optimal N should be at least 20% of the anticipated mean grain yield in the same site under optimal N fertilisation. This will permit recognition and selection of hybrids with comparable grain yield under optimal and sub-optimal N application environments. This implied that the hybrids used in this study have varying nitrogen use efficiency levels which would enable high yielding hybrids with inheritable factors for tolerance to low N to be identified. The decrease in grain yield of the hybrids under sub-optimal N was associated with delayed DS, ASI, undesirable EA and SGA (DeBruin et al., 2017; Mebratu et al., 2019).

3.3. Combining ability estimates under low and optimal N applications

The ANOVA for the two conditions revealed significant effect of years for all the characters examined apart from except ASI under low N and EA under optimal N fertilizer application (Table 7). Effect of sets for the characters examined sub-optimal N was not significant, except for PH, HC, PA, SGA, while DS, DA, PA and EA were the only traits for which the sets differed significantly under optimum N application. The interaction effect between year and sets varied for HC, EA and SGA under low N, and GY, DS, PH and SL under optimal N condition. Under low N, apart from GY, PH, HC, PA and SGA that were significant for male set, other traits were not significant. The GCA for male sets under optimal N was significant for GY, PH, DA, DS and PA while the rest of the traits measured were not statistically different. The GCA for female sets under low N condition varied significantly for GY but ASI, EH, RL, SL, HC and EPP were not significantly different. Under optimal N application, only GY recorded varied GCA for female sets. The SCA effects for male × female interaction sets under low N varied significantly for GY, HC, PA and SGA, while only GY and PA were the traits significant under the optimal N application. Under low N application, male GCA effects for GY and SGA were significantly higher than SCA. However, for the female sets, the SCA was higher for GY than GCA. The results for the study under the optimal N condition showed that the GCA effects for both parents were higher than the SCA effects for GY.

Table 4. Mean values for grain yield and agronomic traits for 39 (top 15, middle 10, worst 10) selected and checks evaluated under low soil nitrogen condition during 2018 and 2019 cropping seasons.

Hybrid	GY	DS	DA	ASI	PH	EH	RL	SL	HC	PA	EA	EPP	SGA	BI
52	5473.5	57.6	57.5	-0.2	190.4	88.8	8.4	12.7	1.9	3.4	3.7	1.0	2.2	16.75
75	5141.6	60.0	60.3	0.1	196.7	96.6	10.5	6.1	2.0	3.2	4.1	1.1	3.0	15.93
81	5760.7	57.9	58.3	0.9	201.4	106.0	21.8	4.6	1.8	3.8	4.0	1.0	2.3	15.17
37	5689.9	58.5	59.1	0.4	187.1	96.8	12.4	14.8	1.9	4.7	4.2	1.0	2.4	13.77
96	5029.5	60.7	59.5	1.1	185.7	89.4	0.3	11.1	2.1	3.5	4.3	1.1	2.4	13.00
49	5021.9	58.4	58.2	1.0	199.8	103.4	14.5	1.2	2.6	3.5	4.0	1.0	3.6	12.97
88	4188.2	58.2	58.0	0.0	193.4	92.2	24.8	9.7	1.9	3.3	4.4	1.0	3.5	11.85
51	4773.4	58.2	58.6	0.6	205.1	106.9	23.1	1.8	2.5	4.3	4.0	1.0	2.5	11.83
21	4248.9	57.5	57.9	0.0	197.4	104.6	20.6	14.1	2.6	3.5	4.5	1.0	5.9	11.68
56	4817.9	59.4	59.8	0.7	182.9	95.0	13.5	10.5	1.9	3.4	4.5	1.0	2.5	11.30
41	5002.0	59.2	59.2	1.6	193.1	96.6	26.5	6.2	2.2	3.3	4.1	1.0	4.4	11.27
45	4995.7	59.3	59.3	0.2	200.0	103.5	25.7	5.4	2.3	5.1	4.2	0.9	5.4	11.10
5	5536.3	60.0	60.9	0.8	192.7	90.3	16.0	8.0	2.1	4.5	4.5	0.9	2.5	11.06
90	4668.5	58.2	57.8	0.6	197.3	87.7	16.9	8.8	2.3	4.3	4.0	0.9	4.6	10.78
93	4791.9	60.3	59.9	0.9	201.3	107.9	18.9	9.0	2.1	3.5	4.8	1.0	3.3	10.75
69	3815.5	59.9	58.7	0.8	193.4	101.7	8.1	2.6	2.4	4.8	4.3	0.9	4.3	6.48
68	4315.6	58.5	57.6	1.4	188.5	94.2	8.7	7.4	2.4	4.9	4.6	1.0	3.8	6.47
64	3998.2	58.9	59.3	0.3	170.2	86.7	30.2	7.5	2.5	4.6	5.3	1.0	3.5	6.45
78	3479.4	58.7	59.1	0.9	196.0	96.7	13.8	17.2	2.3	4.3	4.4	1.0	3.3	6.44
10	4090.6	58.8	58.9	1.0	190.3	90.7	10.2	9.6	2.4	4.2	4.8	0.9	5.3	6.33
9	4535.1	60.0	59.3	1.5	188.7	96.1	16.2	8.9	2.3	5.1	4.5	0.9	3.4	6.08
95	3476.2	59.6	59.3	0.1	201.4	98.5	17.1	4.9	2.2	4.5	4.9	0.9	3.5	6.05
80	3619.0	58.5	59.0	0.5	202.3	106.7	15.7	13.2	2.1	3.6	4.8	0.9	3.6	5.99
67	4074.8	58.8	58.1	1.0	191.7	98.2	6.1	9.5	2.7	5.0	5.0	1.0	4.1	5.97
44	3854.0	58.6	58.6	0.4	188.7	97.5	22.2	9.4	2.2	5.4	4.6	0.9	5.8	5.96
87	3491.1	55.5	57.8	3.2	186.8	85.8	0.1	11.5	2.4	3.2	4.7	0.9	5.0	1.68
17	3059.1	60.7	60.4	1.1	181.2	89.9	17.9	8.8	3.0	4.8	5.0	0.9	2.4	1.67
60	3259.7	61.1	60.2	1.1	184.9	98.2	21.6	8.9	2.4	5.1	5.4	0.9	4.6	1.58
54	3318.0	59.6	58.7	0.8	179.3	89.9	33.6	10.7	2.3	4.9	5.4	0.9	2.4	1.51
29	2987.0	59.2	59.6	0.5	171.3	80.8	16.3	0.4	2.6	4.9	5.3	0.9	3.8	1.39
33	3312.4	58.1	57.7	0.6	177.3	83.7	15.8	14.5	2.4	6.0	5.2	0.9	6.4	1.06
53	3645.7	59.4	59.7	2.0	182.1	90.4	17.6	2.9	2.8	6.5	4.8	0.9	3.3	0.75
12	2600.6	59.9	59.3	1.4	179.0	80.2	11.0	13.3	2.7	5.3	5.0	1.0	5.6	0.57
43	2741.8	61.3	59.9	1.2	178.0	88.1	24.0	6.5	2.7	6.0	5.0	1.0	5.5	0.35
40	3450.2	60.0	59.9	0.6	182.8	93.9	35.5	4.4	2.3	6.1	5.5	0.8	2.3	0.01
97	2915.1	59.7	59.3	1.3	195.1	93.7	24.3	5.9	2.3	4.3	4.8	0.9	2.0	2.14
98	3601.7	59.1	58.5	1.1	190.2	97.0	8.2	5.0	2.2	4.1	3.4	1.1	2.3	10.84
99	3226.5	59.8	59.5	1.2	194.2	91.7	30.3	5.8	2.5	4.5	4.7	0.8	6.5	2.23
100	2792.1	59.0	59.5	0.3	193.1	96.0	17.5	14.7	2.3	5.1	4.1	1.0	5.0	5.97

GY (t ha^{-1})- grain yield; DS- Days to silking; DA-days to anthesis; ASI - anthesis silking interval; PH - plant height; EH - ear height; RL-root lodging; SL – stalk lodging; EPP- ear per plant; HC - husk cover; ER - ear rot; EA - ear aspect; SGA – stay green ability; BI – Base index.

The varied GCA and SCA mean squares recorded for GY and some of the traits examined under conditions of low and optimal N application inferred that additive and non-additive alleles are responsible inheritance of the characters. Differences among male and female parents mean squares for GCA implied that the hybrids used in the study were variable under low and optimal N application (Kamutando et al., 2018). Furthermore, the dominance of GCA over SCA effect for GY and SGA under sub-optimal and optimal N environments confirmed the significance of additive genetic effect to non-additive genetic effect in the inheritance of GY from the parents to their filial generation under stress and non-stress conditions (Amegbor et al., 2021). This suggested that a secondary trait such as SGA could be selected together with GY for yield improvement under low optimal N application. This result is consistent with the findings of (Mafouasson et al., 2017; Wang et al., 2018; Zhang et al., 2018). The substantial and varied of GCA for GY and secondary characters associated with GY sub-optimal N condition will guide plant breeders in the selection of superior lines to be used as female or male in generation of hybrids for genetic gain to be realised. The nonappearance of varied GCA for male and female sets under low and optima fertilizer applications for ASI, EPP, PH, EH, RL and SL indicates that such traits may not be key for yield improvement sub-optimal N environments, which does not agree with the findings reported by (Mafouasson et al., 2017; Zhang et al., 2018; Ogunniyan et al., 2019; Shimelis et al., 2019). The disparities in the two studies could be attributed to the sources of genetic materials used in this study as well as the conditions at which the other studies were conducted. However, the significant differences detected for GCA and SCA effects for most of the inbred lines in this study indicated that

Table 5. Mean values for grain yield and secondary traits for best 15, middle 10 and worse hybrids selected under low and optimal nitrogen conditions.

Hybrid	GY		ASI		PH		EH		PA		EA		EPP		SGA	YR	BI
	LN	OPT	LN	OPT	LN	OPT	LN	OPT	LN	OPT	LN	OPT	LN	OPT			
52	5473.5	7474.8	-0.2	1.0	190.4	207.9	88.8	108.0	3.4	2.7	3.7	2.6	1.0	1.1	2.2	-26.8	10.89
75	5141.6	6576.6	0.1	0.5	196.7	213.1	96.6	112.1	3.2	2.7	4.1	2.3	1.1	1.0	3.0	-21.8	8.88
37	5689.9	7363.8	0.4	0.5	187.1	188.1	96.8	109.7	4.7	2.7	4.2	2.5	1.0	1.0	2.4	-22.7	8.11
98	3601.7	6091.0	1.1	0.1	190.2	210.3	97.0	111.9	4.1	2.5	3.4	2.3	1.1	1.1	2.3	-40.9	6.69
26	4838.8	7667.4	1.5	0.9	179.4	200.6	91.2	102.7	3.9	2.2	4.9	2.3	1.1	1.0	5.9	-36.9	6.63
81	5760.7	6177.1	0.9	1.0	201.4	202.5	106.0	115.0	3.8	2.5	4.0	2.7	1.0	1.0	2.3	-6.7	6.26
73	4320.7	6947.7	1.2	0.6	191.0	205.0	93.1	101.9	4.5	2.8	3.7	2.3	1.0	1.1	2.7	-37.8	6.13
90	4668.5	6961.0	0.6	0.5	197.3	201.1	87.7	97.5	4.3	2.8	4.0	2.1	0.9	1.0	4.6	-32.9	5.96
18	4994.4	6798.8	1.1	0.6	179.1	187.6	95.0	103.2	4.4	2.3	4.7	2.3	1.0	1.0	4.0	-26.5	5.53
51	4773.4	6270.0	0.6	0.4	205.1	211.4	106.9	116.9	4.3	2.6	4.0	2.7	1.0	1.0	2.5	-23.9	5.48
89	4263.2	7363.2	0.3	0.8	201.1	209.5	95.6	98.1	4.5	2.7	4.3	2.2	0.9	1.0	3.2	-42.1	5.46
41	5002.0	7154.9	1.6	1.0	193.1	205.7	96.6	105.2	3.3	2.7	4.1	2.6	1.0	1.0	4.4	-30.1	5.06
49	5021.9	6614.2	1.0	1.0	199.8	200.4	103.4	103.1	3.5	2.8	4.0	3.0	1.0	1.0	3.6	-24.1	5.03
16	4594.9	6361.4	0.6	0.2	196.7	212.0	90.2	104.9	3.3	2.7	4.7	2.7	0.9	1.1	3.5	-27.8	4.97
45	4995.7	6906.6	0.2	0.4	200.0	208.9	103.5	101.3	5.1	2.9	4.2	2.6	0.9	1.0	5.4	-27.7	4.96
79	3982.5	5137.5	0.6	0.8	203.9	192.2	99.5	101.9	3.5	2.9	4.6	3.0	1.0	0.9	6.2	-22.5	-0.62
68	4315.6	5928.7	1.4	0.9	188.5	188.7	94.2	98.9	4.9	3.2	4.6	2.4	1.0	1.0	3.8	-27.2	-0.87
38	3941.7	5351.6	1.1	0.5	188.0	189.2	102.2	98.1	4.8	2.6	4.6	3.0	0.9	1.0	5.6	-26.3	-1.02
84	4888.9	4754.4	0.7	0.5	191.2	183.8	99.7	94.6	5.0	2.7	4.3	3.0	0.9	0.9	2.8	2.8	-1.02
59	3945.9	5229.1	1.1	0.3	199.3	198.0	98.3	105.6	4.8	3.1	4.8	2.9	1.0	1.0	5.5	-24.5	-1.06
23	4058.8	4669.7	0.2	0.2	188.8	178.3	88.2	93.3	4.8	2.9	4.5	3.0	1.0	0.9	4.0	-13.1	-1.18
65	3932.4	5321.5	0.4	0.2	184.8	192.2	96.4	104.3	5.0	3.1	5.0	3.1	1.0	1.0	5.2	-26.1	-1.20
58	4318.6	5235.0	1.0	0.2	179.0	180.4	88.5	99.8	6.0	2.8	4.9	3.2	1.1	1.0	2.6	-17.5	-1.30
10	4090.6	5119.0	1.0	0.8	190.3	199.2	90.7	101.7	4.2	2.5	4.8	2.7	0.9	1.0	5.3	-20.1	-1.33
64	3998.2	5875.7	0.3	1.1	170.2	177.5	86.7	89.6	4.6	3.1	5.3	2.8	1.0	1.0	3.5	-32.0	-1.39
66	3337.1	5391.0	0.0	0.5	183.5	186.5	96.4	95.6	5.4	3.0	5.0	2.9	0.9	0.9	3.0	-38.1	-4.31
33	3312.4	5804.4	0.6	0.5	177.3	186.0	83.7	101.7	6.0	3.1	5.2	2.8	0.9	1.0	6.4	-42.9	-4.57
36	3521.0	5292.4	1.1	1.0	193.0	194.7	99.1	97.9	5.5	2.7	4.9	2.7	0.9	1.0	2.4	-33.5	-4.84
13	3640.5	5112.2	1.4	0.6	188.0	198.7	88.2	92.1	5.1	2.8	4.9	3.1	1.0	0.9	5.5	-28.8	-5.15
47	3085.3	4722.7	1.0	0.8	197.3	197.6	100.5	110.0	4.8	2.7	4.8	2.7	0.9	0.9	4.4	-34.7	-5.48
60	3259.7	4617.8	1.1	0.2	184.9	195.6	98.2	100.5	5.1	2.8	5.4	2.8	0.9	0.9	4.6	-29.4	-5.85
99	3226.5	5012.5	1.2	1.8	194.2	210.2	91.7	113.8	4.5	2.8	4.7	2.9	0.8	1.0	6.5	-35.6	-6.32
43	2741.8	5613.3	1.2	1.2	178.0	185.7	88.1	99.5	6.0	3.1	5.0	2.7	1.0	0.9	5.5	-51.2	-6.37
40	3450.2	4778.3	0.6	0.4	182.8	191.9	93.9	95.9	6.1	3.3	5.5	2.9	0.8	0.9	2.3	-27.8	-8.15
7	3604.9	3923.4	1.8	0.8	199.1	199.8	97.8	99.6	5.3	3.2	5.0	3.3	1.0	0.9	3.2	-8.1	-9.48

GY(t ha^{-1})- grain yield; DS-days to silking; DA-days to anthesis; ASI - anthesis silking interval; PH - plant height; EH - ear height; RL-root lodging; SL – stalk lodging; EPP-ear per plant; HC - husk cover; ER - ear rot; EA - ear aspect; BI – Base index; YR – yield reduction; OPT-optimal N, LN-low N; SGA – stay green ability.

the use of recurrent selection schemes would be effective for the improvement of the traits.

3.4. Estimates of GCA effects of maize inbred lines under low and optimal nitrogen application

Under low soil nitrogen, only inbred 15 showed highly significant and positive GCA as a female parent. Lines 15 and 30 exhibited substantial and positive GCA effects for male sets of inbred lines for GY (Table 8). No parental lines recorded negative and statistical difference GCA-female effect for ASI, however line 24 revealed significant and negative GCA-male effect for ASI. For PH, female line 15 exhibited positive and significant GCA effects, while male lines 8, 18, 28 and 30 recorded positive and values that were statistically different for GCA. Line 15 (female) showed highly significant GCA for EH, while male lines 23 and 30 also exhibited worthwhile and significant GCA effects for EH. For PA, the GCA-female for inbred lines 5, 7, 13, 14, 15, 24, 27 and 29, and the GCA-male for lines 12, 16 and 28 showed significant and negative effects. The GCA-female effect for EA was negative and significant for lines 7 and 15, whereas none of the inbred lines had significant GCA-male effect for EA. Lines 7, 9, 13 and 20 (female) and lines 8, 10, 12, 15, 16 and 18 (male) showed highly significant differences for GCA effects for EPP. For SGA, female parents 1, 6, 9, 12, 15, 16 and 30.

For optimal N fertilization, only female lines 15 and 28 exhibited significant and positive GCA effect, while male lines 12, 15 and 30 also exhibited highly significant and positive GCA for GY (Table 9). Female lines 6 and 9 had significant and negative GCA effects for ASI. Female line 15 exhibited highly significant and positive GCA effects for PH and EH.

From the study under low and optimal N fertilizations, parental lines that displayed substantial GCA effects for GY and the secondary traits measured under the study conditions implied that these characters are highly influenced by additive gene action. These lines will be valuable for the forming of high yielding hybrids targeting low N conditions (Pswarayi and Vivek 2007; Weber et al., 2012; Kamutando et al., 2018). This also implied that such inbred lines have the capacity to transfer the characteristics to their F_1 progeny when used as parents in crosses (Ogunniyan et al., 2019; Sun et al., 2019). Female line 15 and male lines 15 and 30 which displayed varied GCA effects for GY sub-optimal N application signified that; these parents possess highly heritable genes for GY which could be passed toto their F_1 progenies under marginal soil environments. Similarly, female lines 6 and 9 which showed varied and negative GCA for ASI and other parents that exhibited varied but

Table 6. Mean values for grain yield and agronomic traits for 39 (top 15, middle 10, worst 10) selected and checks evaluated under optimal nitrogen during 2018 and 2019 cropping seasons.

Hybrid	GY	DS	DA	ASI	PH	EH	RL	SL	HC	PA	EA	EPP	BI
26	7667.4	53.5	52.4	0.9	200.6	102.7	0.5	21.5	2.2	2.2	2.3	1.0	14.21
18	6798.8	51.2	51.6	0.6	187.6	103.2	15.2	13.7	2.1	2.3	2.3	1.0	13.05
89	7363.2	51.6	52.1	0.8	209.5	98.1	10.3	15.3	2.2	2.7	2.2	1.0	12.72
73	6947.7	51.6	52.1	0.6	205.0	101.9	3.3	2.3	2.0	2.8	2.3	1.1	12.43
37	7363.8	51.3	51.4	0.5	188.1	109.7	18.0	10.4	1.8	2.7	2.5	1.0	12.23
9	6823.0	52.4	52.4	0.4	194.6	104.1	5.2	0.2	1.9	2.7	2.5	1.1	12.16
52	7474.8	50.6	51.4	1.0	207.9	108.0	8.6	10.5	2.2	2.7	2.6	1.1	11.87
90	6961.0	51.1	51.9	0.5	201.1	97.5	14.1	19.0	2.1	2.8	2.1	1.0	11.72
85	6269.9	52.9	52.6	0.5	214.3	108.4	3.3	3.9	2.0	2.5	2.5	1.1	10.96
6	6324.9	50.8	51.4	0.7	203.9	111.1	0.9	14.1	1.9	2.7	2.4	1.1	10.71
34	5835.2	52.3	52.3	0.4	187.8	96.4	1.9	8.2	2.1	2.5	2.6	1.1	10.43
16	6361.4	51.0	51.3	0.2	212.0	104.9	1.6	11.1	2.0	2.7	2.7	1.1	10.06
75	6576.6	52.3	52.8	0.5	213.1	112.1	18.5	12.1	1.8	2.7	2.3	1.0	10.00
51	6270.0	51.9	52.6	0.4	211.4	116.9	1.5	7.3	1.9	2.6	2.7	1.0	9.47
45	6906.6	52.4	52.3	0.4	208.9	101.3	5.6	10.1	2.0	2.9	2.6	1.0	9.44
10	5119.0	51.0	51.2	0.8	199.2	101.7	1.1	13.8	1.6	2.5	2.7	1.0	5.02
56	5949.3	51.4	52.4	0.7	194.6	98.4	14.4	20.6	2.1	2.9	2.7	0.9	4.84
91	5457.9	53.1	52.8	0.1	206.0	98.8	0.2	28.0	2.4	3.0	2.8	0.9	4.72
50	5171.8	52.0	52.6	0.7	206.4	113.1	11.9	36.0	2.3	2.7	2.8	1.0	4.67
33	5804.4	51.4	51.6	0.5	186.0	101.7	16.0	7.2	2.3	3.1	2.8	1.0	4.58
2	5849.8	51.2	51.6	1.6	192.1	105.1	0.8	21.1	2.0	2.6	2.5	1.0	4.54
21	5607.0	52.3	52.6	0.5	199.0	103.6	18.4	14.5	2.4	2.9	2.9	1.0	4.38
14	5978.3	49.6	50.4	1.4	195.6	101.9	8.8	8.2	2.0	3.0	2.8	1.1	4.36
68	5928.7	51.6	52.2	0.9	188.7	98.9	17.9	11.0	2.3	3.2	2.4	1.0	4.30
35	6082.3	51.6	51.9	1.0	193.5	103.7	12.6	5.8	2.4	2.9	2.9	1.0	4.28
95	4377.5	54.0	54.0	0.3	205.2	104.7	20.3	2.6	2.0	2.8	3.1	1.0	1.78
84	4754.4	50.4	50.6	0.5	183.8	94.6	2.3	18.6	2.3	2.7	3.0	0.9	1.78
46	4811.6	52.7	53.5	0.8	197.3	109.2	10.0	17.8	2.4	2.9	2.9	1.0	1.42
13	5112.2	51.8	52.0	0.6	198.7	92.1	17.5	3.8	2.2	2.8	3.1	0.9	1.13
79	5137.5	51.5	51.0	0.8	192.2	101.9	3.9	11.3	2.3	2.9	3.0	0.9	0.67
40	4778.3	51.6	51.9	0.4	191.9	95.9	15.2	16.6	2.4	3.3	2.9	0.9	-0.11
78	4688.1	51.7	52.1	0.4	196.2	102.3	2.2	23.5	2.3	3.1	3.0	0.9	-0.93
31	4543.5	51.9	51.8	0.4	187.6	101.0	6.3	34.9	2.3	3.0	3.4	1.0	-1.01
3	4343.2	52.5	52.5	0.9	210.9	104.6	3.2	15.3	2.0	2.8	3.1	0.9	-1.21
7	3923.4	51.8	52.9	0.8	199.8	99.6	13.2	17.4	2.3	3.2	3.3	0.9	-5.73
97	6768.2	52.4	52.1	1.2	197.4	106.6	5.5	8.4	2.4	2.5	2.5	1.1	10.83
98	6091.0	51.9	52.3	0.1	210.3	111.9	0.6	8.9	2.0	2.5	2.3	1.1	12.60
99	5012.5	51.4	51.7	1.8	210.2	113.8	13.9	21.5	1.9	2.8	2.9	1.0	-0.01
100	6855.5	51.4	51.9	0.2	201.1	100.5	10.1	13.8	2.0	2.8	2.0	0.9	11.01

GY(t ha^{-1})- grain yield; DS- days to silking; DA-days to anthesis; ASI - anthesis silking interval; PH - plant height; EH - ear height; RL-root lodging; SL – stalk lodging; EPP-ear per plant; HC - husk cover; ER - ear rot; EA - ear aspect; BI – Base index.

negative GCA for PA, SGA and EA could serve as a source of germplasm from which low N tolerance genes which could be transferred to their progenies when used in hybrid combinations as well as for population improvement. These results corroborate the findings by (He et al., 2018; Ogunniyan et al., 2019).

3.5. Estimates for phenotypic and genotypic correlations of variables under low and optimal N applications

The phenotypic correlation among the measurables in the germplasm evaluated showed that GY was positively and significantly interrelated with EH under low N application. Negative and varied correlation was observed between GY and DS, GY and PA and GY and EA (Table 10). Positive and significant phenotypic associations were found between DA and DS, DS and SL and DS and EPP. Plant height was positively and significantly associated with EH, but was negatively interrelated with HC, PA and EA. In this study, genotypic correlation among several traits could not be estimated under the low N condition (Table 11). However, GY exhibited positive and significant genotypic correlation with EPP. Also, GY recorded negative and significant genotypic relationships with DA, PH and SGA. The genotypic relationships of PH with SL, HC and PA were negative and significant, but its association with EPP was positive and significant.

Under the optimal N application, GY exhibited positive and significant phenotypic association. Ears per plant recorded negative and significant correlation with GY. From the study, GY also displayed negative but significant correlations with SL, HC and PA (Table 11). Plant height had positive correlation with EH while EA was negatively correlated with SL and PA. The genotypic association between GY and ASI was positive and significant, whereas GY recorded significant and negative associations with PA and EA. The correlation between ASI and EA was positive and significant, but ASI was negatively correlated with PA.

The substantial and positive association detected for GY and EH under the low N condition implied that EH is an essential parameter and should

Table 7. Analyses of variance and mean squares for general and specific combining abilities for measured traits under low and optimal N conditions.

Source	DF	GY	DS	DA	ASI	PH	EH	RL	SL	HC	PA	EA	EPP	SGA
LowN														
Year	1	82214392.21**	1286.76**	527.77**	0.01ns	52290.70**	9787.07**	92080.77**	2300.47**	105.92**	0.02ns	13.25**	0.07*	23.04**
SET	5	502024.47ns	1.28ns	0.52ns	0.98ns	792.15**	178.09ns	369.28ns	69.11ns	0.32*	4.07**	0.39ns	0.01ns	4.29**
Year*SET	5	1219958.96ns	3.84ns	2.53ns	0.32ns	370.35ns	188.38ns	277.81ns	71.67ns	0.27*	0.18ns	1.23**	0.01ns	1.65*
Rep(Year*SET)	10	287305.56ns	5.24*	2.51ns	0.75na	163.56ns	128.80ns	799.50*	294.48**	0.06ns	0.55*	0.36ns	0.01ns	0.33ns
Block (Year*Rep)	36	670376.53ns	3.50ns	2.20ns	1.07ns	111.19ns	61.62ns	310.82ns	118.12ns	0.14ns	0.36ns	0.74*	0.01ns	0.43ns
Male (SET)	18	1870121.96**	2.30ns	2.06ns	1.14ns	313.00*	108.86ns	308.37ns	77.81ns	0.25**	2.31**	0.42ns	0.02ns	4.51**
Female (SET)	18	1502040.58**	7.18**	2.76*	0.54ns	358.93**	150.60ns	365.42ns	130.97ns	0.15ns	2.55**	1.08**	0.01ns	7.18**
Female*Male (SET)	54	1667916.29**	3.28ns	1.99ns	1.10ns	170.92ns	110.55ns	269.74ns	120.70ns	0.17*	1.54**	0.51ns	0.02ns	5.49**
Year*Male (SET)	18	1419717.90*	2.41ns	1.54ns	0.88ns	240.63ns	120.82ns	299.57ns	66.07ns	0.18ns	0.41ns	1.05*	0.01ns	1.21**
Year*Female (SET)	18	1790250.93**	2.97ns	2.54ns	2.02*	295.80*	142.34ns	366.82ns	99.57ns	0.14ns	0.44ns	0.82*	0.01ns	0.87*
Year*Female*Male (SET)	54	1106219.66*	3.16ns	2.06ns	0.80ns	155.01ns	115.08ns	270.08ns	84.92ns	0.11ns	0.39ns	0.68*	0.01ns	0.63ns
Error	144	707703.3	2.63	1.62	1.05	169.88	89.02	291.65	89.28	0.12	0.28	0.41	0.01	0.52
Optimal N														
Year	1	22912180.66**	1319.89**	2046.59**	21.79**	114495.68**	20088.17**	28604.16**	1030.96*	41.60**	2.22**	0.30ns	0.52**	-
SET	5	491139.36ns	5.16*	3.80*	0.43ns	800.44**	96.00ns	117.64ns	283.56ns	0.11ns	0.06ns	0.37*	0.01ns	-
Year*SET	5	2282408.91**	5.11*	3.38*	0.51ns	855.29**	130.45ns	117.64ns	441.05*	0.14ns	0.14ns	0.34ns	0.01ns	-
Rep(Year*SET)	10	479684.38ns	5.95**	5.08**	0.22ns	123.11ns	89.70ns	279.53ns	147.63ns	0.21*	0.14ns	0.19ns	0.02ns	-
Block (Year*Rep)	36	488784.32ns	3.67**	3.21**	0.49ns	101.24ns	80.67ns	248.38ns	224.75ns	0.13ns	0.09ns	0.16ns	0.01ns	-
Male (SET)	18	4253021.09**	4.30**	3.12**	0.34ns	261.86*	128.82ns	120.11ns	189.62ns	0.25**	0.24**	0.24ns	0.01ns	-
Female (SET)	18	2122929.73**	3.23ns	2.09ns	0.46ns	389.33**	170.16*	186.79ns	236.41ns	0.10ns	0.11ns	0.19ns	0.01ns	-
Female*Male (SET)	54	1318000.67**	2.07ns	1.77ns	0.35ns	173.06ns	96.33ns	172.16ns	201.42ns	0.14ns	0.13*	0.17ns	0.01ns	-
Year*Male (SET)	18	1637049.59**	3.41*	3.17**	0.42ns	255.70*	130.32ns	120.11ns	277.46ns	0.11ns	0.11ns	0.18ns	0.01ns	-
Year*Female (SET)	18	1683388.52**	5.29**	4.25**	0.52ns	729.91**	361.36**	186.79ns	433.58**	0.27**	0.19*	0.20ns	0.01ns	-
Year*Female*Male (SET)	54	1332976.66**	1.84ns	1.39ns	0.36ns	193.30ns	142.79*	172.16ns	258.20*	0.15*	0.08ns	0.14ns	0.01ns	-
Error	144	709402.6	1.69	1.39	0.34	150.23	81.94	174.13	171.92	0.1	0.09	0.16	0.02	-

GY- grain yield; DA-days to anthesis; DS- days to silking; ASI - anthesis silking interval; PH - plant height; EH - ear height; RL-root lodging; SL – stalk lodging; EPP- ear per plant; HC - husk cover; ER - ear rot; EA - ear aspect; SGA-stay green ability; ENV – environment; *P < 0.05, **P < 0.01, ns – not significant.

Table 8. General combining ability effects of 24 lines for grain yield and other traits evaluated at low soil nitrogen condition during 2018 and 2019.

Line	GY		ASI		PH		EH		PA		EA		EPP		SGA	
	Female	Male	Female	Male	Female	Male	Female	Male	Female	Male	Female	Male	Female	Male	Female	Male
1	437.4	-131.8	0.25	-0.06	1.1	-2.2	2.5	-1.1	0.13	0.15	-0.11	-0.08	0.02	-0.05**	-0.61**	1.40**
2	-429.6	-672.3*	0.01	0.43*	-5.3	1.0	-3.3	-2.2	0.21	0.17	0.16	0.15	0.04	-0.06**	1.12*	0.30
5	4.9	144.9	0.03	-0.03	-0.5	-5.7*	-2.3	-2.7	-0.31*	0.00	0.09	-0.05	0.04	-0.03	0.43*	-0.70*
6	204.1	211.5	-0.04	-0.02	-4.0	-0.2	-0.6	-0.3	0.20	0.14	0.00	-0.06	0.01	-0.02	-0.50*	-0.10
7	-24.1	62.8	0.00	0.15	6.2	-1.7	3.6	1.8	-0.39*	0.15	-0.40*	-0.26	0.05*	-0.03	-0.20	0.00
8	162.2	-219.1	0.20	0.05	3.3	7.2*	-3.0	3.2	-0.08	0.04	0.19	0.20	0.03	0.08**	1.50**	0.10
9	-342.3	-55.1	-0.20	-0.30	-5.4	-5.2	-0.1	-4.6	0.43**	-0.17	0.09	-0.01	0.05*	0.04	-0.80**	0.00
10	-128.8	-183.5	-0.05	-0.09	-4.0	4.1	-3.1	-0.3	0.35*	0.06	0.08	0.03	0.03	-0.01	0.00	0.20
12	377.4	499.0	0.02	0.47*	-0.2	-2.8	1.5	2.0	0.18	-0.63**	0.14	-0.26	0.04	0.09**	-0.70**	0.00
13	-327.3	-309.9	0.25	-0.19	-0.2	3.6	0.2	0.8	-0.31*	-0.07	-0.05	0.22	0.09**	0.06**	0.90**	0.50
14	78.9	-5.7	0.04	-0.24	4.5	-4.8*	1.4	-2.6	-0.34*	0.80**	-0.04	-0.11	0.02	-0.01	-0.30	-0.70*
15	728.4*	635.9*	-0.17	-0.11	9.0*	3.4	5.7*	-2.0	-0.89**	-0.14	-0.71**	-0.18	-0.02	0.04*	-0.60**	0.30
16	-365.5	-113.5	0.08	-0.01	-4.1	-7.3*	-2.2	0.9	0.28	-0.63**	0.23	0.02	-0.07*	0.06**	-0.70**	-0.20
18	-131.7	-230.5	0.23	0.38	2.0	7.5*	-0.3	0.1	0.20	0.25	0.22	0.15	0.01	0.08**	0.40*	0.60*
19	-231.2	-291.8	-0.04	0.00	-6.9	-3.6	-3.3	1.1	0.29	0.42**	0.44*	0.15	-0.07*	0.00	0.90**	-0.80**
20	-159.1	212.9	0.01	0.59*	-3.1	-2.7	-1.1	0.6	0.60**	-0.02	0.29	-0.19	0.06*	-0.02	0.20	-0.40
21	79.5	-233.9	-0.16	-0.01	-0.7	-1.9	1.8	-3.3	0.05	0.40*	-0.07	0.29	0.04	-0.02	-0.20	0.10
23	210.8	-49.6	0.34	-0.07	-1.9	5.4	-3.8	4.7*	-0.25	0.31*	-0.27	0.03	0.04	-0.05**	0.10	0.60*
24	-131.1	70.6	-0.12	-0.42*	5.6	-1.0	3.1	-2.1	-0.57**	-0.80**	0.00	0.03	0.02	-0.05**	0.10	-0.30
25	353.5	115.9	0.09	-0.03	-5.1	3.4	3.3	0.2	0.42*	0.16	-0.36	-0.20	-0.04	0.03	0.00	-0.10
27	-255.6	-413.1	0.25	-0.03	-0.1	-7.3*	-1.4	-0.9	-0.31*	0.14	0.06	0.19	-0.08**	0.00	0.30	0.10
28	-210.9	351.0	-0.02	-0.21	4.3	7.5*	-3.2	1.0	0.45**	-0.28*	-0.01	-0.02	-0.06*	0.11	0.10	0.50*
29	111.7	-53.7	-0.19	0.35	1.0	-3.6	1.5	-0.3	-0.37*	-0.19	0.17	-0.02	-0.01	0.01	-0.30	-0.30
30	-12.5	659.1*	-0.41	-0.21	4.8	6.9*	3.3	6.3*	0.14	-0.13	-0.26	-0.16	-0.02	-0.05**	-1.05**	-0.90**
SE	289.7	258.0	0.31	0.20	3.7	3.4	2.6	2.4	0.14	0.14	0.20	0.22	0.03	0.02	0.20	0.24

GY- Grain yield; ASI - anthesis silking interval; PH - plant height; EH - ear height; EPP- ear per plant; HC - husk cover; ER - ear rot; EA - ear aspect; SGA – stay green ability; SE – standard error; *P < 0.05, **P < 0.01.

Table 9. General combining ability effects of 24 lines for grain yield and other traits evaluated under optimal soil nitrogen condition during 2018 and 2019.

Line	GY		ASI		PH		EH		PA		EA		EPP	
	Female	Male	Female	Male	Female	Male	Female	Male	Female	Male	Female	Male	Female	Male
1	-294.4	179.0	-0.04	-0.13	0.7	-6.2	2.1	-3.7	-0.05	-0.01	-0.04	-0.16	-0.02	0.03
2	427.3	-633.9*	-0.03	-0.13	-0.8	8.5*	-0.5	2.5	0.02	0.02	-0.20*	0.19*	0.04	-0.01
5	-1.4	-149.5	-0.17	0.06	-0.2	-7.4*	-1.3	-2.7	0.02	0.04	0.04	0.17	0.00	-0.03
6	1.5	336.4	-0.39*	0.02	-2.8	-0.4	0.3	-1.8	0.03	-0.14	-0.04	-0.03	-0.03	0.00
7	-197.9	96.4	-0.19	0.35	-2.9	-2.4	-0.3	3.3	0.02	-0.07	0.02	-0.20*	-0.03	0.04
8	255.0	-757.2*	0.07	-0.03	10.9	-0.8	2.0	-0.6	-0.13	0.08	-0.22*	0.18*	-0.02	-0.05*
9	-58.6	324.5	-0.33*	-0.21	-5.2	3.7	-2.2	-0.8	0.00	0.07	0.21*	-0.11	-0.01	0.04
10	-54.8	59.4	0.02	-0.23	-2.5	5.7	-3.6	1.7	-0.02	0.10	0.04	-0.01	0.00	-0.01
12	-198.0	918.8**	-0.24	-0.14	-1.8	-0.8	-0.8	2.8	0.08	-0.41**	0.11	-0.23*	-0.01	0.00
13	345.7	-821.7*	0.22	-0.24	2.3	-1.0	2.1	1.2	0.08	0.16*	0.02	0.16	-0.01	-0.02
14	-93.0	-156.6	-0.05	-0.22	5.4	-3.8	2.6	-5.8*	0.03	0.07	0.00	0.04	-0.01	-0.05*
15	661.1*	999.0**	0.19	-0.09	13.20*	3.4	8.40*	1.0	-0.10	0.01	-0.12	-0.06	0.04	-0.01
16	99.4	-448.6	0.19	-0.08	-4.7	-1.5	-4.1	0.3	0.00	-0.03	-0.04	0.18*	0.02	0.03
18	-701.0*	-466.9	-0.28	0.15	-2.8	-0.7	-1.3	1.5	0.07	0.10	0.02	0.09	-0.03	-0.03
19	-59.4	-83.8	0.02	-0.05	-5.8	-1.0	-2.9	-2.6	0.10	0.10	0.05	-0.04	-0.01	-0.01
20	-292.9	161.2	-0.07	0.09	-4.6	-0.8	-0.5	-1.0	0.26*	0.00	0.16	0.02	-0.04	-0.01
21	371.3	-529.6	-0.01	0.05	-0.6	-4.0	3.6	1.2	-0.12	-0.02	-0.22*	0.13	-0.04	0.06*
23	428.4	110.7	0.05	-0.14	4.6	4.1	-3.5	2.6	0.00	0.03	-0.18	-0.04	0.04	0.00
24	-506.8	257.8	0.21	0.13	0.6	0.6	0.3	-2.8	0.04	0.06	0.18	-0.20*	-0.07*	-0.03
25	-384.8	500.1	0.06	-0.03	-4.3	1.8	4.8	0.7	-0.09	-0.03	0.19	-0.01	-0.03	0.00
27	233.3	-195.4	0.10	0.23	6.0	-6.4	0.6	-4.0	-0.10	0.00	-0.03	0.04	0.03	-0.02
28	584.5*	-128.0	-0.15	-0.12	0.2	5.3	-5.3	5.2*	0.05	0.08	-0.08	0.07	-0.01	-0.03
29	-433.0	-176.6	0.00	0.10	-2.0	-0.8	0.0	-2.0	-0.02	0.14	-0.02	-0.16	0.00	-0.06*
30	-131.4	604.4*	0.38*	0.21	0.4	5.0	-0.2	4.0	-0.05	-0.21	0.04	-0.14	0.01	0.00
SE	280.9	277.0	0.16	0.14	5.9	3.5	4.1	2.5	0.09	0.07	0.10	0.09	0.03	0.02

GY- grain yield; ASI - anthesis silking interval; PH - plant height; EH - ear height; EPP- ear per plant; HC - husk cover; ER - ear rot; EA - ear aspect; SE – standard error.

Table 10. Phenotypic correlation (r_P) above diagonal and genotypic correlation (r_G) below diagonal between grain yield and agronomic traits of 100 maize hybrids evaluated under low soil nitrogen condition during 2018 and 2019 cropping seasons.

Traits	GY	DS	DA	ASI	PH	EH	RL	SL	HC	PA	EA	EPP	SGA
GY		-0.20*	-0.19	-0.16	0.17	0.23*	-0.10	-0.23*	-0.41**	-0.29*	-0.54**	0.12	-0.31*
DS	-0.37**	-	0.79**	0.04	-0.23*	-0.15	0.21*	-0.12	0.18	0.12	0.25*	0.05	-0.02
DA	NA	NA	-	0.08	-0.16	-0.10	0.16	-0.10	0.09	0.01	0.17	-0.05	-0.03
ASI	NA	NA	NA	-	0.03	0.00	-0.07	0.12	0.15	0.01	0.12	-0.10	0.18
PH	-0.68**	-0.44**	NA	NA	-	0.64**	-0.08	-0.07	-0.21*	-0.37**	-0.34**	0.07	-0.01
EH	NA	NA	NA	NA	NA	-	0.07	-0.07	-0.16	-0.19	-0.43**	0.14	-0.06
RL	NA	NA	NA	NA	NA	NA	-	-0.10	0.19	0.11	0.25*	-0.19	0.20*
SL	-0.71**	-0.48**	NA	NA	-1.00**	NA	NA	-	-0.12	-0.01	0.12	0.08	0.20*
HC	-1.00**	0.34*	NA	NA	-1.00**	NA	NA	-0.56**	-	0.42*	0.33*	-0.13	0.17
PA	-0.45**	0.16	NA	NA	-1.00**	NA	NA	-0.05	0.87**	-	0.30*	-0.26*	0.09
EA	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	-	-0.16	0.35*
EPP	0.21*	0.32*	NA	NA	0.61**	NA	NA	0.11	-0.62**	-0.55**	NA	-	0.08
SGA	-0.54**	-0.01	NA	NA	-0.20*	NA	NA	0.26*	0.47**	0.12	NA	0.24*	-

GY- grain yield; DA-days to anthesis; DS – days to silking; ASI – anthesis-silking interval; PH - plant height; EH - ear height; EA - ear aspect; RL-root lodging; SL – stock lodging; HC - husk cover; EPP- ear per plant. SGA – stay green ability. *$P < 0.05$, **$P < 0.01$; NA – not available.

be considered when developing crosses that are tolerant to sub-optimal N environments. The absence of significant phenotypic relationship between GY and PH is consistent with the reports by Wuhaib et al. (2017) as well as Khan et al. (2018) who also found GY not to be significantly associated with PH under low N. Similarly, the absence of significant interrelationship between GY and EPP suggested that, the present study does not support the studies of (Inamullah et al., 2011; Al-Naggar et al., 2016) but consistent with the findings of Ogunniyan and Olakojo (2014). Inamullah et al. (2011) and Al-Naggar et al. (2016) reported on positive and significant association between GY and EPP under soils with limited N and optimal N conditions while Ogunniyan and Olakojo (2014) on the other hand reported on the absence of significant association. Hence EPP could be a reliable trait to be considered for yield improvement under low soil nitrogen conditions for the germplasm exploited in this study. The negative but significant correlation observed for DS and GY, and GY and SGA implied that increased GY could be achieved if the hybrids combined earliness with enhanced stay green ability after grain filling period. The hybrids that exhibited good performance under sub-optimal N could be advanced as tolerant hybrids (Wuhaib et al., 2017; Khan et al., 2018). The positive and significant phenotypic relationship between SGA

Table 11. Phenotypic correlation (r_P) above diagonal and genotypic correlation (r_G) below diagonal between grain yield and agronomic traits of 100 maize hybrids evaluated under optimal nitrogen condition during 2018 and 2019 cropping seasons.

Traits	GY	DS	DA	ASI	PH	EH	RL	SL	HC	PA	EA	EPP
GY		-0.10	-0.11	0.08	0.17	0.07	-0.07	-0.26*	-0.13	-0.42**	-0.66**	0.39**
DS	NA		0.87**	-0.14	0.00	0.15	-0.10	0.06	0.13	0.01	0.07	-0.04
DA	NA	NA		-0.10	0.04	0.22*	0.04	0.11	0.07	-0.06	0.03	-0.02
ASI	0.59**	NA	NA		0.01	0.09	0.10	0.01	-0.04	-0.09	-0.03	0.10
PH	NA	NA	NA	NA		0.56**	-0.09	0.03	-0.14	-0.20*	-0.23*	0.08
EH	NA	NA	NA	NA	NA		0.09	0.08	-0.13	-0.30*	-0.09	0.09
RL	NA	NA	NA	NA	NA	NA		0.11	0.01	0.10	0.10	0.07
SL	NA	NA	NA	NA	NA	NA	NA		0.24*	0.03	0.24*	0.01
HC	NA	NA	NA	NA	NA	NA	NA	NA		0.37**	0.17	-0.18
PA	-0.60**	NA	NA	-0.23*	NA	NA	NA	NA	NA		0.44**	-0.30*
EA	-0.60**	NA	NA	0.38**	NA	NA	NA	NA	NA	0.64**		-0.18
EPP	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	

GY- grain yield; DA-days to anthesis; DS – days to silking; ASI – anthesis-silking interval; PH - plant height; EH - ear height; EA - ear aspect; RL-root lodging; SL – stock lodging; HC - husk cover; EPP- ear per plant. $*P < 0.05$, $**P < 0.01$; NA – not available.

and EA, SGA and RL, and SGA and SL suggested that hybrids with clean ears did not suffer from the either RL nor SL therefore can contribute significantly to GY.

4. Conclusions

Genetic variation was detected among the hybrids under low and optimal nitrogen application. Both additive and non-additive gene actions controlled the inheritance of grain yield and its associated traits under experimental conditions used. Inbred line 15 was identified as the superior parent with positive GCA for grain yield sub-optimal N. Hybrids 52, 75, 81 and 37 had significantly higher grain yield and superior agronomic performance under the low and optimal N conditions than the check variety. The low N tolerant crosses identified in the present study could be further assessed in multilocation for possible release and commercialization.

Declarations

Author contribution statement

Isaac Kodzo Amegbor: Conceived and designed the experiments; Performed the experiments; Analyzed and interpreted the data; Contributed reagents, materials, analysis tools or data; Wrote the paper.

Ayodeji Abe: Conceived and designed the experiments; Performed the experiments; Analyzed and interpreted the data; Wrote the paper.

Joseph Adjebeng-Danquah: Conceived and designed the experiments; Performed the experiments; Wrote the paper.

Gloria Boakyewaa Adu: Conceived and designed the experiments; Performed the experiments; Contributed reagents, materials, analysis tools or data; Wrote the paper.

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Data availability statement

Data will be made available on request.

Declaration of interests statement

The authors declare no conflict of interest.

Additional information

No additional information is available for this paper.

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