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Genetic and Agronomic Parameter Estimates of Growth, Yield and Related Traits of Maize (*Zea mays* L.) under Different Rates of Nitrogen Fertilization

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Abstract

This study evaluated the genetic and agronomic parameter estimates of maize under different nitrogen rates. The trial was established at the Njala Agricultural Research Centre experimental site during 2021 and 2022 in a split block design with three maize varieties (IWCD2, 2009EVDT, and DMR-ESR-Yellow) and seven nitrogen (0, 30, 60, 90, 120, 150 and 180 kg·N·ha^{-1}) rates. Findings showed that cob diameter and anthesis silking time (ASI) had intermediate heritability, ASI had high genetic advance, ASI and grain yield had high genotypic coefficient of variation (GCV), while traits with high phenotypic coefficient of variation (PCV) were plant height, ASI, grain yield, number of kernel per cob, number of kernel rows, ear length, and ear height. The PCV values were higher than GCV, indicating the influence of the environment in the studied traits. Nitrogen rates and variety significantly ($p < 0.05$) influenced grain yield production. Mean grain yields and economic parameter estimates increased with increasing nitrogen rates, with the 30 and 180 kg·N·ha^{-1} plots exhibiting the lowest and highest grain yields of 1238 kg·ha^{-1} and 2098 kg·ha^{-1}, respectively. Variety and nitrogen effects on partial factor productivity (PFP$_N$), agronomic efficiency (AEN), net returns (NR), value cost ratio (VCR) and marginal return (MR) indicated that these parameters were significantly affected ($p < 0.05$) by these factors. The highest PFP$_N$ (41.3 kg grain kg^{-1}·N) and

AEN (29.4 kg grain kg^{-1}·N) were obtained in the 30 kg·N·ha^{-1} plots, while the highest VCR (2.8) and MR (SLL 1.8 SLL^{-1} spent on N) were obtained in the 180 kg·N·ha^{-1}. The significant influence of variety and nitrogen on traits suggests that increasing yields and maximizing profits require use of appropriate nitrogen fertilization and improved farming practices that could be exploited for increased productivity of maize.

Keywords

Nitrogen Rates, Genetic and Agronomic Estimates, Introduced Genotypes, Grain Yield, *Zea mays*

1. Introduction

Maize (*Zea mays* L.) is a grain crop that belongs to the family Poaceae. The origin of this crop is debatable among scholars. Many historians believe that maize was first domesticated in Mexico's Tehuacan valley, and then introduced to Africa by the Portuguese in the sixteenth century and has become a contributor to the world's agricultural economy and Africa's most important staple food crop [1]. Maize is the third most important cereal crop in the world after wheat and rice with a great yield potential and leading position among cereals [2]. Moreover, the crop is widely cultivated and utilized as food for man, feed for animal and other industrial applications. In Sierra Leone, maize ranks second as the most important cereal crop after rice [3].

Despite its importance, little is known about the genetic and agronomic parameter estimates of maize grown under different nitrogen rates [4] [5] [6]. Understanding various estimates of genetic parameters is important for the better exploitation of heterosis available in the base material for desired agronomic traits including seed yield and yield attributes. Knowledge on genetic variability parameters such as genotypic coefficient of variation, heritability and genetic advance is imperative for a plant breeder to start a judicious breeding program. Moreover, heritability measures the relative amount of the heritable portion of variation, while the genetic advance measures the amount of progress that could be expected with selection in a character. High heritable estimates together with high genetic advance are more valid for selection than heritability estimates alone [7]. Estimation of genetic variability, heritability and genetic advance gives an idea of the possible improvement of the character through selection. A good understanding of genetic structure of different traits helps breeders to employ suitable breeding strategy for their improvement [8].

The successful production of maize depends on the correct application of production inputs that sustains the environment as well as agricultural production. Some of these inputs include use of adapted cultivars, use of high-quality seeds, plant population, soil tillage, fertilization, weed, insect and diseases control, harvesting, marketing and financial resources. Use of appropriate inputs and agronomic practices contributes to yield of maize depends to a large extent on the application of fertilizers [9]. Out of the nutrients required for crop growth, nitrogen (N), as well as phosphorus (P), and potassium (K), are considered the most critical nutrients for successful cultivation of maize [9] [10]. It is standard knowledge that adequate fertilization is essential for realizing maize hybrid yield potential, but nutrient application has to be conducted both on sustainable environmental and financial considerations [11]. Yields can be obtained in a sustainable manner through balanced nutrition, which ensures adequate uptake of both macronutrients as well as micronutrients by the plants and that, in turn, ensure grains that are healthy, biofortified and nutritious [11]. Because optimal nutrient supply of the plants is related to health of the crop, it can be considered a component of Integrated Pest Management [12]. For maize crop, the pattern of nutrient uptake can vary in time, rate and duration, while also varying with each specific nutrient and its plant part where it is allocated [11]. Grain yield and nutrients accumulation in kernels are chiefly influenced by genotype and nutrients available in the soil [13]. Maize has the potential of improving the livelihoods of producers, processors, marketers and value chain actors in Sierra Leone. However, there is dearth of knowledge on the influence of nitrogen fertilization and variety on agronomic traits including yield and economic parameter estimates such as the partial factor productivity (PFP), agronomic efficiency (AE), marginal returns (MR), value cost ratio (VCR) in maize. The yields obtained from the production of maize are still low due partly to poor soil fertility and poor farmers' knowledge about the correct inputs required for increased productivity of the crop. The low yield in maize is associated with soil infertility due to the consequences of high rainfall, erosion and leaching of nutrients [14]. Soils prone to high nutrient leaching are usually gravelly in nature. The other problems that limit the increased productivity of the crop include soil degradation, low soil nutrient levels (particularly nitrogen and phosphorus), inappropriate fertilizer application, leaching of soil minerals, bush burning, pests and diseases. Inadequate fertilization is an adage that best describes the economic status of most farmers in Sierra Leone. This low nutrient status is even worse in upland soils that are gravelly because of their high susceptibility to leaching. Poor crop growth and low yields are often the major consequences of infertile soils that contribute to low incomes and poor livelihoods of farmers. The upland soils are mostly gravelly and widely cultivated but yields are usually below the average yields reported from other countries. In order to increase yields, some farmers purchase of synthetic fertilizers which when applied end up being lost to leaching and/or erosion.

Maize farmers using the gravelly upland soils face a serious challenge when it comes to providing adequate nutrients that increase productivity. Application of inorganic fertilizers does not seem to adequately improve yields whilst organic sources of nutrients cannot remedy the nutrient leaching problem for long periods. Based on the cropping system or pattern in Sierra Leone it will be easier for fertilization in maize. However, fertilization is faced with a number of constraints such as low fertility of the soils, climatic conditions especially during the drought and low level of experience on fertilizer application.

Proper management of nitrogen fertilization is essential for high grain yield in cereal crops such as maize. At harvest, nitrogen deficiency can reduce grain yield by 14 to 80% [15] [16]. Maize is socio-economically important as it is the most grown crop species worldwide [17] [18]. Among the soil nutrient fertilizers available, nitrogen (N) is the most expensive nutrient management strategy that accounts for a significant share of total production cost [19]. However, when applied to the soil, it can cause environmental damages since it is usually lost by leaching and volatilization [20]. In addition, nitrogen fertilizer manufacturing consumes much oil, which is a non-renewable energy source. Therefore, new alternatives need to be sought to streamline use of nitrogen fertilizers [21] [22], as one of the major agricultural challenges for the coming years is to produce sustainable food and optimize existing resources [23]. Nitrogen is an essential part of chlorophyll [23] and also forms a significant unit of many enzymes, nucleic acids, and proteins. Therefore, the deficiency or over application of nitrogen affects maize yields negatively [24]. An optimal nitrogen application enhances the protein content aside from the resultant significant increase in the yield of the maize crops [25]. Nitrogen deficiency stems from low crop development, which reduces the crop yield, leaf area, leaf number, and photosynthetic rate. To boost the productivity of the maize crop, various nitrogen fertilizer application regimes need to be critically examined to determine the optimum N application rate for increased maize grain production.

Nitrogen fertilizer application is critical in enhancing crop biomass and yield capacity [26] [27]. However, excessive and unreasonable application of N fertilizer leads to waste of the N resource and reduction of nitrogen use efficiency (NUE) in maize [28] [29] [30] and other crops [31] [32]. Nitrogen use efficiency parameters are high under low nitrogen levels and decrease with increasing nitrogen level. Decreased nitrogen use efficiency at high nitrogen is attributed to higher losses because the plant is unable to absorb all of nitrogen applied [33]. Maize is nitro positive and needs ample quantity of nitrogen to attain high yield. Nitrogen deficiency is a key factor for limiting maize yield [34]. Low yield of maize can be attributed to many constraints, but NPK fertilizer application is one of the major factors [35]. Maize NUE is defined as the grain production per unit of available N in arable soil. This index can quantitatively reflect the capacity of plants in taking up N and converting the available N into grain yield. Evaluation of these individual NUE components on maize cultivars has promoted the understanding of individual physiological mechanisms and biochemical processes associated with N uptake, assimilation, translocation, and remobilization [36].

Rapid scientific advances in soil-plant interactions from recent years have generated a ripple effect for trends on fertilizers market. As a consequence, farmers today are presented with a variety of options that promise success for their crops. From mineral to organic components, besides various formulations that stimulate soil biota or plant performance, the list of options is expanding. However, clearly defined agronomic benefits of fertilization regimes following a comparative approach requires use of best agronomic practices. Understanding the behavior of widely used or new maize hybrids under novel fertilization regimes could help in identifying elite genotypes with potential traits that might affect nutrient recommendations in regard to timing and rate [37]. Since sustainable stewardship of nutrient use in agriculture is at the nexus of successful crop-environment-economic efficiency [11] [37], investigation into interaction between environment, genotypes and fertilization on agronomic outcomes becomes an indispensable approach for food security.

Correct management practices such as use of fertilizer application needed for maximum output regarded as nitrogen use efficiency is a remedy that has proven worthwhile in increasing maize yield. Genotypes may have different physiological performances in terms of N uptake [38]. Thus, identifying and selecting maize genotypes responsive to nitrogen fertilizations is imperative for maize population improvement and reduction of nitrogen fertilizer use and respective environmental contamination [25]. The objectives of this study were: (1) to determine genetic parameter estimates of selected agronomic traits of maize varieties under different nitrogen fertilization regimes; and (2) to evaluate the effect of variety and nitrogen fertilization on grain yield and agronomic parameter estimate of maize.

2. Materials and Methods

2.1. Experimental Site

This study was conducted at the Njala Agricultural Research Centre (NARC) experimental site, Njala in the Moyamba District of Southern Sierra Leone. Njala is about 47 km from the provincial headquarter town of Bo, Southern Province and about 255 km from Freetown, the capital city of Sierra Leone. Njala Campus experiences a tropical climate that is characterized by two main seasons: a rainy season and a dry season. The rainy season normally commences in May and ends in October while the dry season follows from November to April. The mean annual temperature ranges from a minimum of 28˚C to a maximum of 33˚C. The average annual rainfall is about 2500 mm, and the elevation is 128 m above sea level (altitude), on Latitude 8˚N and Longitude 12˚W.

The soil of the trial site belongs to the Njala soil series under secondary bush [39]. Njala soils are gravelly, well drained, highly weathered and acidic with a pH of 5.5 - 6.0 [40]. The clay content occurs from 20 cm depth in the soil profile. The Njala soil is classified as an *Orthoxicpalehumult*. However, soil test conducted by the Soil Science Department, Njala University revealed the pH to be 6.0 (acidic), low level of nitrogen (5.0 - 15 mg/l), medium level of phosphorus (25 - 50 mg) and low level of potassium (50 - 150 mg). The most dominant vegetation at Njala is grassland comprising mainly *of Andropogon gayanus* (Gamba grass) [41].

2.2. Experimental Materials, Layout, Design and Management

A total of 3 genotypes comprising 2 improved white maize (2009 EVDT and

Table 1. Maize variety and fertilizer treatments utilized in the study.

Vertical factor: maize variety (a)	Horizontal factor: nitrogen rate (b)		
a0 = 2009 EVDT	b0 = 0 kg N ha^{-1}	60 kg P ha^{-1}	60 kg K ha^{-1}
a1 = IWDC2	b1 = 30 kg N ha^{-1}	60 kg P ha^{-1}	60 kg K ha^{-1}
a2 = DMR-ESR-Yellow (check variety)	b2 = 60 kg N ha^{-1}	60 kg P ha^{-1}	60 kg K ha^{-1}
	b3 = 90 kg N ha^{-1}	60 kg P ha^{-1}	60 kg K ha^{-1}
	b4 = 120 kg N ha^{-1}	60 kg P ha^{-1}	60 kg K ha^{-1}
	b5 = 150 kg N ha^{-1}	60 kg P ha^{-1}	60 kg K ha^{-1}
	b6 = 180 kg N ha^{-1}	60 kg P ha^{-1}	60 kg K ha^{-1}

P = Phosphorus, N = Nitrogen, K = Potassium, DMR-ESR-Yellow (downy mildew resistance and early streak resistance), EVDT = early maturing variety drought tolerance, IWDC2 = intermediate white drought tolerance intermediate maturing.

IWDC2) and 1 local check variety (DMR-ESR-Yellow) were used. The improved white maize varieties were introductions from International Institute of Tropical Agriculture (IITA), Ibadan, Nigeria. The experiment was a 3 × 7 factorial laid out in a split block design with three replications. The 21 plots comprised of three varieties × seven nitrogen rates (**Table 1**). Each plot measured 3 m × 5 m with an intra-plot spacing of 0.5 m and inter block spacing of 1.0 m. Each block/replication comprised 21 plots, making a total of 63 plots. Each plot had 40 plants and 840 plants per replication. In each trial year, standard agronomic practices including site selection, land preparation, planting, weeding and harvesting were done. The seeds were planted in August during the second cropping season of 2021 and 2022. Weeding was done before fertilizer application and this was followed by two subsequent weeding before the maturity of the crop.

2.3. Data Collection

Table 2. Phenotypic traits measured in four maize varieties.

SN	Trait/descriptor	Trait/descriptor	Score code-descriptor state	Sample/time collected
1	Plant height (cm)	PHT	direct measurement: done using meter rule	on 5 plants at 8 WAP
2	Stem girth (mm)	SG	direct measurement: done using vernier caliper	on 5 plants at 8 WAP
3	Ear height (cm)	EHT	direct measurement: done using meter rule	on 5 plants at 3 MAP
4	Anthesis silking time	ASI	direct measurement	at silking (3 - 4 MAP)
5	Grain yield ($t \cdot ha^{-1}$)	GYLD	direct measurement	at harvest (4 MAP)
6	Cob diameter (mm)	CD	direct measurement: done using vernier caliper	at harvest (4 MAP)
7	Number of kernels per cob	NKC	direct measurement: done by counting	at harvest (4 MAP)
8	Number of kernel rows	NKR	direct measurement: done by counting	at harvest (4 MAP)
9	Number of kernels per row	NKPR	direct measurement: done by counting	at harvest (4 MAP)
10	Ear diameter (mm)	EARD	direct measurement: done using vernier caliper	at harvest (4 MAP)
11	Ear length (cm)	EARL	direct measurement: done using meter rule	at harvest (4 MAP)

WAP = weeks after planting; MAP = months after planting.

Table 3. Abbreviations, formulae and units of different economic parameters studied in the experiment.

Parameter	Abbreviation	Formula	Unit
Grain yield	GY	GY $m^{-2} \times 10,000$	$kg \cdot ha^{-1}$
N-partial factor productivity	PFPN	GY ha^{-1} ÷ rate of N applied	$kg \cdot grains \cdot kg^{-1} \cdot N$
Increase in GY over control	GYIOC	GY with N − GY of N-control plots	$kg \cdot ha^{-1}$
N-agronomic efficiency	AEN	GYIOC ÷ by rate of N	$kg \cdot grains \cdot kg^{-1} \cdot N$
Grain yield value	GYV	GY ha^{-1} × value of grains kg^{-1}	$SLL. \cdot ha^{-1}$
Grass returns	GR	GYV	$SLL. \cdot ha^{-1}$
Increase in GR over control	GRIOC	GR − cost that vary (CostV)	$kg \cdot ha^{-1}$
N-cost	CN	Price per bag ÷ N content in a bag	$SLL. \cdot ha^{-1}$
Net returns	NR	GRIOC − CostV	$SLL. \cdot ha^{-1}$
Value-cost ratio	VCR	GRIOC ÷ CostV	$SLL. \cdot ha^{-1}$
Marginal returns	MR	NR ÷ CostV	$SLL. \cdot ha^{-1}$

A total of 11 agro-morphological traits were collected. Data collection was based on protocols presented in the descriptor for maize variety performance evaluation trial [42] with slight modifications (**Table 2**).

The economic parameters were determined on grain yield. The parameters collected included partial factor productivity of nitrogen (PFP_N), increase in gross returns (GR) over control (PFP_N), agronomic efficiency of nitrogen (AE_N), grain yield value (GY_V), net return (NR), value cost ratio (VCR), marginal return (MR) (**Table 3**).

2.4. Data Analysis

Data were subjected to analysis of variance (ANOVA) using the GENSTAT statistical program (GENSTAT, 15th release, Rothampstead, UK). The Least Significance Difference (LSD) was used to compare between treatment means using a significance level of $\alpha = 0.05$. The residuals of data for the parameters were first checked for normality and homogeneity using the Shapiro-Wilk test and Bartlett's test to ensure that data are normally distributed.

The variance component analysis was done using the procedure described by Patterson and Thompson [43]. Various genetic parameters such as broad sense (H^2), genotypic coefficients of variation (GCV), phenotypic coefficient of variation (PCV), and expected genetic advance (GA) were determined. The GCV and PCV were determined following the formula described by Burton and Devane [44]. The GCV and PCV values were categorized using the technique proposed by Deshmukh *et al.* [45] as follows: values < 10% = low, values that are 10% - 20% = medium and values > 20% = high. The broad sense heritability was determined using a formula by Robinson *et al.* [46]. The expected genetic advance (GA) was estimated based on the equation given by Shukla *et al.* [47].

The Partial Factor Productivity (the ratio of the grain yield to the applied rate of fertilizer) and Agronomic Efficiency (the ratio of the increase in grain yield over fertilizer-control plots to the applied rate of fertilizer) were determined according to the procedures described by Yadav [48]. Other economic analysis such as value cost ratio, net returns, marginal return, etc., were also estimated.

3. Results and Discussion

3.1. Genetic Parameter Estimates of Agronomic Traits of Maize

The estimated genetic parameter estimates of selected agronomic traits of maize showed that the phenotypic coefficient of variation (PCV) was higher than the genotypic coefficient of variation (GCV) values for all the traits studied (**Table 4**). Traits with high PCV were plant height, anthesis silking time, grain yield, number of kernel per cob, number of kernel rows, ear length and ear height; while those with high GCV were anthesis silking time and grain yield. The broad sense heritability estimates ranged between 9.65% (stem girth) and 58.84% (anthesis silking time). Traits with intermediate broad sense heritability (30% - 60%) were anthesis silking time and cob diameter, whereas the remaining traits had low broad sense heritability values > 30.0% (**Table 4**). High GA (>20.0%) was exhibited for anthesis silking time, whilst stem girth, number of kernel per row, ear diameter and ear height had low (<10.0%) GA (**Table 4**). Anthesis silking time combined intermediate broad sense heritability and high GA, whilst cob diameter combined intermediate broad sense heritability and intermediate GA, and the remaining traits combined low broad sense heritability and intermediate GA, except for stem girth, number of kernels per row, ear diameter and ear height which combined low broad sense heritability and low GA. This study revealed the presence of useful variation in the maize varieties that could be exploited through direct selection or population improvement scheme. The higher PCV values relative to the GCV indicate that the traits were sensitive to environmental modifications or effects. These results are consistent with the findings

Table 4. Genetic parameter estimates of selected agronomic traits of maize.

Trait	Broad sense heritability (%)	Genotypic coefficient of variation (%)	Phenotypic coefficient of variation (%)	Genetic advance (%)
Plant height (cm)	24.64	11.46	23.09	11.72
Stem girth (mm)	9.35	5.83	19.08	3.67
Anthesis silking time	58.84	48.58	63.33	76.76
Grain yield ($t \cdot ha^{-1}$)	16.01	22.10	55.23	18.21
Cob diameter (mm)	45.57	8.48	12.56	11.79
Number of kernel per cob	20.11	16.11	35.94	14.89
Number of kernel rows	16.00	15.10	37.75	12.44
Number of kernel per row	23.59	9.13	18.80	9.14
Ear diameter (mm)	21.25	5.95	12.91	5.65
Ear length (cm)	18.21	15.27	35.79	13.43
Ear height (cm)	19.17	11.03	25.19	9.95

of Sravani *et al*. [49] who found slightly higher PCV values for anthesis-silking advanced population of maize. The variations in some of the traits could be due to the different maize varieties and/or environmental factors such as different plant nutrients (nitrogen levels).

The knowledge of heritability guides the plant breeder about the selection procedure to be utilized under a given situation. Broad sense heritability is an estimate of the total contribution of the genetic variance to the total phenotypic variance of trait. It measures the relative amount of heritable portion of total variability and provides information on the extent to which a particular morphogenetic trait can be transmitted to successive generation. Traits with high broad sense heritability imply that these characters were less influenced by the environment. Thus, selection would be effective for the genetic improvement of these traits. These findings concur with the views of Kharel *et al*. [50], Prakash *et al*. [51] and Supraja *et al*. [52] that characters that are less influenced by the environment are more heritable.

The Genetic advance is a more reliable index for understanding the effectiveness of selection in improving the traits because the derivation of this estimate involves heritability, phenotypic standard deviation and selection intensity. Thus, heritability coupled genetic advance provide clear picture about the effectiveness of selection for improving the plant characters [53]. Traits that exhibited high genetic advance could be considered as favorable attributes for genetic improvement through selection. These results are in conformity with those obtained by Bhadru *et al*. [54], Lal *et al*. [55] and Wedwessen and Zeleke [56] for most of the yield attributing traits. The traits that had both high heritability and high genetic advance indicate that they were under the control of additive genes. Hence, direct selection would be an effective technique for further improvement of these traits. Traits with high heritability and low genetic advance are under the control of non-additive genes. These findings agree with the view that both heritability and genetic advance should be considered for efficient predictability of response to selection [7].

The presence of genetic variation is a key prerequisite for genetic improvement in plant breeding and plays a pivotal role in germplasm usage in breeding programs. Thus, plant breeders and researchers benefit immensely from an understanding of sources of useful existing genetic variation in maize and ways of creating genetic variability, where it is limited, that can benefit farmers and other end users of the crop. Governments and other relevant research and development stakeholders support research and development efforts such as genetic improvement targeted at enhancing crop yields, quality and productivity parameters, as well as improving livelihoods, increasing income and reducing poverty.

3.2. Agronomic Parameter Estimates of Grain Yield of Maize

The effects of variety and nitrogen rates on maize grain yields and economic parameter estimates are presented in **Table 5**. Generally, both the variety and nitrogen fertilization significantly affected ($p < 0.05$) maize grain yields, PFP_N,

Table 5. Impacts of variety and nitrogen rates on grain yield, partial factor productivity, agronomic efficiency and economic analysis of maize in Njala.

Treatment	GY	PFP_N	GY_{IOC}	AE_N	GY_V	GR_{IOC}	NR	VCR	MR
Variety									
2009 EVDT	1672	18.7	1375	14.7	50,000,000	40,000,000	20,000,000	2.31	1.31
IWDC2	2003	25.3	1619	20.1	60,000,000	50,000,000	30,000,000	3.02	2.02
DMR-ESR-Y	1432	17.2	1038	11.9	40,000,000	30,000,000	10,000,000	1.85	0.85
N-rates									
b1	1238	41.3	881	29.4	40,000,000	20,000,000	10,000,000	1.79	0.79
b2	1301	21.7	944	15.7	40,000,000	30,000,000	10,000,000	1.8	0.81
b3	1687	18.7	1331	14.8	50,000,000	40,000,000	20,000,000	2.47	1.45
b4	1947	16.2	1584	13.2	60,000,000	40,000,000	30,000,000	2.83	1.83
b5	1943	13	1587	10.6	60,000,000	40,000,000	30,000,000	2.67	1.67
b6	2098	11.6	1736	9.7	60,000,000	50,000,000	30,000,000	2.81	1.8
LSDa	181.7	5.91	973.4	3.35	7,657,896	11,459,941	5,706,393	0.12	0.7
LSDb	154.7	2.6	256.2	0.95	7,234,275	6,521,884	5,856,943	0.21	0.2
LSDa*b	218.3	4.88	742.9	2.56	9,499,687	9549276.9	7,091,584	0.29	0.72
CV (%)	2.1	2.2	6.1	5	2.8	11.2	1.7	7	14.2

GY = grain yield, PFP_N = partial factor productivity of nitrogen, GY_{IOC} = increase in gross returns (GR) over control, AE_N = agronomic efficiency of nitrogen, GY_V = grain yield value, NR = net return, VCR = value cost ratio, MR = marginal return, b1 = 30 kg·N·ha^{-1}, b2 = 60 kg·N·ha^{-1}, b3 = 90 kg·N·ha^{-1}, b4 = 120 kg·N·ha^{-1}, b5 = 150 kg·N·ha^{-1}, and b6 = 180 kg·N·ha^{-1}.

GR_{IOC}, AE_N, GY_V, NR, VCR and MR, whereas nitrogen rates significantly affected ($p < 0.05$) the GY_{IOC}. The mean maize grain yields and economic parameter estimates increased with increasing nitrogen rates, with plots amended with 30 N·kg·ha^{-1} and 180 N·kg·ha^{-1} exhibiting the lowest and highest maize grain yields of 1238 kg·ha^{-1} and 2098 kg·ha^{-1}, respectively. Variety IWCD2 exhibited the highest grain yield of 2003 kg·ha^{-1} and economic parameter estimates, whereas the check variety DMR-ESR-Yellow exhibited the lowest values (Table 5).

The variety and nitrogen rates effects on economic parameter estimates (PFP_N, AE_N, NR, VCR and MR indicated that the mean values of these estimates were significantly affected by variety and nitrogen fertilization (Table 5). Maximum values of PFP_N (41.3 kg grain kg^{-1}·N), and AE_N (29.4 kg grain kg^{-1}·N), were obtained from plots of maize amended with 30 kg N·ha^{-1}, whereas the maximum values of NR (SLL 30,000,000 ha^{-1}), VCR (2.83) and MR (SLL 1.83 SLL^{-1} spent on N) were obtained in plots amended with 180 kg N·ha^{-1}. The minimum mean values of PFP_N (13.8 kg grain kg^{-1}·N), AE_N (14.9 kg·grain·kg^{-1}·N) were found in plots amended with 120 kg·N·ha^{-1} similar to plots amended with 150 kg·N·ha^{-1} and 180 kg·N·ha^{-1}; whereas minimum values of NR (SLL 1,000,000 ha^{-1}), VCR (1.79) and MR (SLL 0.79 SLL^{-1} spent on N) were found at 30 kg·N·ha^{-1}.

Findings on the grain yield and economic parameter estimates indicate that efficient utilization of fertilization for maize production is important for increasing maize grain yields, and maximizing economic returns. The higher grain yields in the plots amended with higher nitrogen rates relative to those with lower rates could be attributed partly to the higher nutrient availability that supported both vegetative growth and reproductive organ development of the crop. These findings are consistent with the view that improvement in leaf area index (LAI), crop growth rate (CGR) and light interception with higher N rate of maize produce remarkable increase in yield and yield components of maize as well as maximum benefits in terms of PFP_N, AE_N, NR, VCR and MR [57].

The nitrogen rates application in plots of three varieties of maize produced sharp variations with IWDC2 exhibiting the highest grain yield and economic parameter estimates whereas the check variety DMR-ESR-Yellow had the lowest values. These variations are possibly attributed to the inherent genetic variability of the varieties and difference in the amount of nitrogen and N availability, which necessitate site specific recommendation for improved and profitable nutrient management. These findings concur with Ahmad and Mahdi [58] who opined the relevance of site-specific recommendations for crops due to differential response to various nutrient inputs across growing environments. Sanchez [59] also suggested that a good understanding of concepts of ideal soil fertility level and response to nutrient management provides practical guidelines for improving nutrient management under the increasing climate variability conditions of smallholder farmers. Generally, some of the ways of improving soil fertility that could be exploited include incorporation of cover crops that add organic matter to the soil, crop rotation, tillage reduction, soil examination, intercropping legumes with cereals, utilization of inorganic and organic (crop residues, compost, farm yard manure, green manure, etc.) fertilizers. The compost, manure and other organic materials stimulate soil microbe activity, improve soil structure and supply necessary nutrients.

Findings of this study demonstrate that the application of a unit urea was economical, since the value of the increase in the grain yields due to the quantity of fertilizer added is greater than the cost of fertilizer used. Findings agree with the view that if a unit of urea applied does not increase the yield enough to pay for its cost, its application is uneconomical and unprofitable even after a constant increase in the yield [60]. Results also support the view that the efficient use of N for maize production is important for increasing grain yield, maximizing economic returns, and minimizing NO_3 leaching to ground water [61] [62]. Treatments with a VCR of 2 represents 100% return on the money invested on N-fertilizer. For smallholder farmers with low technology and limited capital, a fertilizer rate exhibiting a VCR greater than 2 is recommended [63].

3.3. Interactive Impacts of Variety and Nitrogen Rates on Yield, and Economic Parameter Estimates of Maize

The interactive effects of variety and nitrogen rates on maize grain yields and economic parameter estimates are presented in **Table 6**. Interactive effects of variety into N rates of application (a × b) in **Table 6** showed that when N was applied at the low rate of 30 kg·N·ha^{-1}, each PFP_N, AE_N, NR, VCR and MR showed positive relationship with increase in amounts of N application, except variety DMR-ESR-Yellow which exhibited negative NR (−500,000) and MR (−0.03). At the recommended (120 kg·N·ha^{-1}) and highest rates (180 kg·N·ha^{-1}) of N, maize exhibited better performance in terms of NR, VCR and MR for all the three varieties studied. Varieties 2009 EVDT, IWCD2 and DMR-ESR-Yellow exhibited the highest net return at 150 kg·N·ha^{-1}, 180 kg·N·ha^{-1} and 180 kg·N·ha^{-1}, respectively. Applications at 180 kg·N·ha^{-1} and recommended nitrogen fertilization (120 kg·N·ha^{-1}) in varieties IWCD2 and DMR-ESR-Yellow had similar net returns. These findings are in concurrence with Shah *et al.* [57], who opined that improvement in leaf area index (LAI), crop growth rate (CGR) and light interception with higher N rate of maize resulted in remarkable increase in yield and yield components of maize consequently producing maximum benefits in terms of the various economic parameters studied. These findings are consistent with those drawn by Mariga *et al.* [61] and Gehl *et al.* [62], who suggested that efficient use of N for maize production is important for increasing grain yield, maximizing economic returns, and minimizing NO_3 leaching to ground water.

Table 6. Impacts of variety and nitrogen rates on grain yield, partial factor productivity, agronomic efficiency and economic analysis of maize in Njala.

a × b	GY	PFP_N	GY_{IOC}	AE_N	GY_V	GY_{IOC}	NR	VCR	MR
a0 × b1	924	30.81	627	20.9	30,000,000	10,000,000	1,000,000	1.09	0.09
a0 × b2	1320	21.99	1023	17	40,000,000	30,000,000	10,000,000	1.84	0.89
a0 × b3	1550	17.22	1253	13.9	50,000,000	30,000,000	20,000,000	2.19	1.14
a0 × b4	1854	15.45	1557	13	60,000,000	40,000,000	30,000,000	2.65	1.65
a0 × b5	2273	15.15	1976	13.2	70,000,000	50,000,000	40,000,000	3.29	2.29
a0 × b6	2114	11.74	1817	10.1	60,000,000	50,000,000	30,000,000	2.83	1.83
a1 × b1	1637	54.56	1253	41.8	50,000,000	40,000,000	20,000,000	2.69	1.69
a1 × b2	1668	27.8	1284	21.4	50,000,000	40,000,000	20,000,000	2.59	1.59
a1 × b3	2267	25.19	1883	20.9	70,000,000	50,000,000	40,000,000	3.66	2.66
a1 × b4	2282	19.02	1898	15.8	70,000,000	50,000,000	40,000,000	3.49	2.49
a1 × b5	1892	12.62	1508	10.1	60,000,000	40,000,000	20,000,000	2.57	1.57
a1 × b6	2271	12.37	1887	10.5	70,000,000	50,000,000	40,000,000	3.14	2.12
a2 × b1	1152	38.4	764	25.5	30,000,000	20,000,000	8,000,000	1.6	0.6
a2 × b2	914	15.23	526	8.8	30,000,000	10,000,000	−500,000	0.96	−0.03
a2 × b3	1246	13.84	858	9.5	40,000,000	20,000,000	8,000,000	1.56	0.56
a2 × b4	1703	14.19	1297	10.8	50,000,000	40,000,000	20,000,000	2.35	1.35
a2 × b5	1665	11.1	1277	8.5	50,000,000	30,000,000	20,000,000	2.14	1.14
a2 × b6	1910	10.61	1504	8.4	60,000,000	40,000,000	20,000,000	2.46	1.46

GY = grain yield, PFPN = partial factor productivity of nitrogen, GY_{IOC} = increase in gross returns (GR) over control, AE_N = agronomic efficiency of nitrogen, GY_V = grain yield value, NR = net return, VCR = value cost ratio, MR = marginal return, a0 = 2009 EVDT; a1 = IWCD2; a2 = DMR-ESR-Yellow (check variety); b1 = 30 kg·N·ha^{-1}, b2 = 60 kg·N·ha^{-1}, b3 = 90 kg·N·ha^{-1}, b4 = 120 kg·N·ha^{-1}, b5 = 150 kg·N·ha^{-1}, and b6 = 180 kg·N·ha^{-1}.

4. Conclusion

This study demonstrates the variation in genetic parameter estimates across different nitrogen applications that could be exploited for multilocational testing of varieties and site-specific recommendations of varieties sequel to commercial deployment and recommendations for release. Genotypes IWDC2 (2171 $kg \cdot ha^{-1}$) and 2009 EVDT (1761 $kg \cdot ha^{-1}$) were identified with high grain yields. Based on the pooled values, traits identified with high genotypic coefficient of variation (GCV) were anthesis silking time and number of kernels per cob and those with high phenotypic coefficient of variation (PCV) were anthesis silking time, weight of kernels, weight of dry cob, and number of kernels per cob. Trait heritability and genetic advance are useful genetic parameter estimates utilized for identification and selection of elite varieties in a maize breeding program. Moreover, increasing yields and maximizing profits require adequate use of nitrogen fertilizer, production environment, and improved farming practices by farmers. Findings established significant influence of fertilizer on grain yield and agronomic parameter estimates in maize that could be exploited for increased productivity of the crop. The wide genetic variability and good trait values of maize would serve as useful resources for the genetic conservation, management, short term recommendation for release and genetic improvement of the crop. The application of high nitrogen level that maximizes crop yields and net returns is critical to sustain the current maize productivity and improve yields to meet the demands of the growing population. Application of higher rate of nitrogen increased yield and net income to varying degree depending on the variety used. Variety effects on grain yield and agronomic parameter estimates indicate that N recommendations for increasing maize productivity to get maximum net benefits cannot easily be transposed among diverse agro ecological zones of Sierra Leone. This problem poses a challenge for the development of technical recommendations targeted for diverse environments in the country.

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Conflicts of Interest

The authors declared no conflicts of interests with respect to the research, authorship, and/or publication of this article.

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