Open Access Library Journal
2025, Volume 12, e13650
ISSN Online: 2333-9721
ISSN Print: 2333-9705

Yield Response of Maize (*Zea mays* L.) to Intra-Row Spacing and Nitrogen Fertilizer Application

Julius Yirzagla[1*], Issah Alidu Abukari[1], Iddrisu Yahaya[1], Ophelia Asirifi Amoako[1], Joseph Adjebeng-Danquah[1], Issah Sugri[1], Peter Quandahor[1], Patrick Attamah[1], Joseph Kinansua Laary[2], Olivia Aguriboba Akanbelum[3], Abdul-Wahab M. Imoro[4], John Bokaligidi Lambon[5]

[1]CSIR-Savannah Agricultural Research Institute, Nyankpala, Ghana
[2]Bolgatanga Technical University, Bolgatanga, Ghana
[3]St. Vincent College of Education, Yendi, Ghana
[4]C.K. Tedam University of Technology and Applied Sciences, Navrongo, Ghana
[5]CSIR-Head Office, Accra, Ghana
Email: *yirzagla@yahoo.com

How to cite this paper: Yirzagla, J., Abukari, I.A., Yahaya, I., Amoako, O.A., Adjebeng-Danquah, J., Sugri, I., Quandahor, P., Attamah, P., Laary, J.K., Akanbelum, O.A., Imoro, A.-W.M. and Lambon, J.B. (2025) Yield Response of Maize (*Zea mays* L.) to Intra-Row Spacing and Nitrogen Fertilizer Application. *Open Access Library Journal*, **12**: e13650.
https://doi.org/10.4236/oalib.1113650

Received: December 15, 2024
Accepted: June 27, 2025
Published: June 30, 2025

Abstract

Intra-row spacing is a key factor affecting maize production and productivity, since it affects plant growth, resource utilization, and yield. The study was conducted during the 2023 and 2024 cropping seasons at the Manga station of the Council for Scientific and Industrial Research-Savanna Agricultural Research Institute (CSIR-SARI) in the Upper East Region of Ghana to assess the effect of N rate and intra-row spacing on maize growth, development, and yield. The treatments consisted of four nitrogen rates (0 kg N/ha, 60 kg N/ha, 90 kg N/ha, and 120 kg N/ha) and three intra-row spacings (20, 30, and 40 cm) in a split-plot design with three replications. The recommended inter-row spacing of 75 cm for maize in the study area was maintained. The Wang dataa maize variety was used for the experiment. In both cropping seasons, the various treatments had a significant impact on the yield and yield components of maize. Plots that received 90 and 120 kg N/ha recorded relatively higher grain yield and yield components than the control (0 kg N/ha). The highest yield and yield components were recorded under 90 kg N/ha and 120 kg N/ha, with grain yields at these rates being statistically similar. An intra-row spacing of 40 cm recorded the highest grain yields, statistically higher than those recorded under other intra-row spacing. The trend in partial budget analysis was consistent across both seasons, with the highest-yielding treatments (90 kg N/ha and 40 cm) recording the highest net benefit, while the control (0 kg N/ha) ranked last. The nitrogen application rate of 90 kg N/ha and intra-row spacing of 40 cm are thus recommended for optimum maize production and productivity in the study area.

Subject Areas

Agronomy

Keywords

Intra-Row Spacing, Wang Dataa, Net Returns, Maize Production

1. Introduction

Background to the Study

Maize (*Zea mays* L.) is one of the most widely cultivated cereals in the Sudan Savannah agroecological zone of Ghana, accounting for a significant proportion of the country's total cereal production [1]. The crop is a staple food for many households in the region and serves as a substantial source of income for smallholder farmers [2]. Maize grains are rich in carbohydrates, protein, and other essential nutrients and thus serve as a crucial feed ingredient for livestock, including poultry, cattle, and pigs. Its high energy content and digestibility make it a preferred feed source for livestock production. Research indicates that maize accounts for 70% - 80% of the total feed composition in Ghana's poultry sector [3]. Thus, maize is primarily used as animal feed globally and is a vital food crop in sub-Saharan Africa and Latin America [4]. Its cultivation supports the livelihoods of millions of smallholder farmers and agricultural workers. Maize cultivation generates employment opportunities across the entire value chain, encompassing farming, harvesting, processing, transportation, and marketing. Thus, maize cultivation is a significant source of income for families, helping alleviate poverty and improve standards of living [3].

Maize is traded globally as both a raw agricultural product and processed derivatives such as maize flour, cornmeal, and corn oil. Countries with surplus maize production often export to regions with high demand, contributing to global food security and economic stability [5]. In Ghana, maize is a significant source of calories and nutrients [6] and has gained popularity due to its adaptation to the local climate and its reliability as a food source [5]. It is consumed in various forms across the country, such as boiled or roasted, and as an ingredient in many traditional dishes, including banku, kenkey, tuozaafi, and porridge. Maize represents more than one-quarter of total calorie consumption which is about double of cassava, the second crop [7]. It is used as a raw material in various industrial processes in Ghana, including the production of animal feed, starch, and ethanol.

Despite its importance, maize production in the Sudan Savannah agroecological zone of Ghana faces several challenges, including low yields, water scarcity, and inadequate nutrient management [8] [9]. The region's semi-arid climate, characterized by high temperatures and low rainfall, compounds issues of water scarcity and inadequate nutrient management. This situation makes it essential to develop and implement sustainable production practices that optimize maize yields while conserving water and nutrients [9] [10]. Most critically, Ghana's fertilizer application rate of only 35.75 kg/ha falls well below the global average of 107 kg/ha, with smallholder farmers often applying little to no fertilizer due to high input costs and limited resources [10]-[14]. This situation, coupled with the high cost of farm mechanization services, compels farmers to reduce their farm sizes, resulting in poor yields and a negative impact on maize output [15] [16].

Two key production factors remain poorly understood and inadequately managed in this region: plant spacing and nitrogen application rates. Plant density directly affects competition for water and nutrients. In contrast, nitrogen, one of the most limiting nutrients in sub-Saharan Africa, is essential for optimal yields [17]. Traditional bush-fallowing practices, which historically replenished soil nitrogen, are no longer viable due to land pressure from population growth and urbanization. Research has shown that optimal intra-row spacing can increase maize yields by promoting better resource use efficiency and reducing plant competition [18]. A study in Nigeria found that an intra-row spacing of 25 cm resulted in higher maize yields compared to wider or narrower spacings [19]. Optimal intra-row spacing can enhance light interception, resulting in increased photosynthesis and productivity [20]. Intra-row spacing can also influence soil moisture retention and utilization, with optimal spacings potentially reducing soil evaporation [21]. Intra-row spacing interacts with row spacing to affect maize productivity. A study in China found that a row spacing of 60 cm and an intra-row spacing of 20 cm yielded optimal results [22]. Maize genotype can also influence the optimal intra-row spacing. Some genotypes may perform better in narrower or wider intra-row spacings [23]. There is limited information on the optimal combination of plant density and nitrogen application rates specifically for maize production in Ghana's Sudan Savannah agroecological zone. Farmers currently rely on traditional practices that may not be optimal for the region's specific conditions, resulting in suboptimal yields and resource use efficiency [24].

Recent research has demonstrated the critical importance of optimizing both nitrogen rates and plant spacing for maize productivity. Studies show that economic optimum nitrogen rates for maize have increased by 2.7 kg N ha/yr from 1991 to 2021, while research indicates that nitrogen recovery and yield are highest when nitrogen is applied 4 - 8 weeks after planting, with yield increasing with application frequency. Plant spacing research reveals that narrower inter-row spacing (0.375 m) coupled with wider intra-row spacing (0.33 m) significantly enhances grain yield compared to wider inter-row spacing (0.75 m) with narrow intra-row spacing (0.16 m). A high planting density of 10.5 plants m^{-2}, combined with narrow inter-row spacing, can lead to significant yield increases, particularly in soils of high fertility. However, maize yield sensitivity to both nitrogen fertilizer rates and plant spacing varies depending on crop architecture and available resources, highlighting the need for location-specific optimization [25]. Recent research highlights the importance of considering these interactions to optimize maize yields and resource use efficiency. Therefore, the present study aimed to determine the appropriate nitrogen application rate and intra-row spacing for increased maize productivity in the Sudan Savannah agroecological zone of Ghana. Specifically, the research evaluated the impact of nitrogen rate and intra-row spacing on maize growth, development, and yield under local conditions.

2. Materials and Methods

2.1. Experimental Site

The study was conducted during the 2023 and 2024 cropping seasons at the Manga station of the Council for Scientific and Industrial Research-Savanna Agricultural Research Institute (CSIR-SARI) in the Upper East Region of Ghana. The CSIR-SARI, Manga is an outstation of the CSIR-SARI in the Binduri District. Binduri District is located approximately between latitudes 11˚1'S and 10˚40'N and longitudes 0˚18'W and 0˚6'E in the North-Eastern part of the Upper East Region. It borders Burkina Faso to the north, Garu District to the south, Bawku Municipality to the East, and Bawku West District to the West. It is located within the Sudan Savannah Ecological Zone, characterized by prolonged dry spells and short wet seasons. Binduri is an agrarian community; the soil types are red and brown sandy loam and clays, and moderately deep pale brown coarse sandy loam with biotic granites, sandy loam, and clay in the valleys [26]. The prevailing climate of the district is characterized by two main seasons: the wet and dry seasons, which are influenced by the North-East Trade Winds and the South-West Monsoon Winds, respectively. The dry season usually occurs from late November to May and is influenced by the cold, dry, and dusty harmattan air mass from the Sahara Desert. It is characterised by little rainfall due to low relative humidity, which rarely exceeds 20 percent, and a low vapour pressure of less than 10 mb. Daytime temperatures can reach as high as 42˚C during February and March, while night temperatures can record 18˚C low. The period from June to October is the wet season. During this period, the whole district comes under the influence of the Tropical Maritime Air Mass. This air mass, together with rising convectional currents, ensures that the district gets rain. The average amount of rainfall recorded in the area is 800 mm per annum [26].

The vegetation of the district is primarily characterized by the Sudan Savannah ecology, featuring scattered shrubs, short grasses, and trees. Pockets of the Savannah woodland vegetation can also be found in the district. The most common tree species include shea, dawadawa, baobab, mango, and neem. The forested areas in the district can only be found along the White Volta River, where the trees are protected [26]. The Manga soils have been classified into the Varempare Series, which are mainly sandy loams associated with hornblende and granites. Farmers in the district are primarily engaged in agriculture, accounting for about 83.9% of the economically active population. The main food crops cultivated include millet, sorghum, maize, rice, sweet potato, cowpea, groundnuts, leafy vegetables, pepper, watermelon, melon, and onion. Animals such as cattle, sheep, goats, and donkeys are also raised. Food crops that serve as cash crops in the district include onions, tomatoes, and watermelon. These are primarily cultivated in the dry season [26].

2.2. Soil Sampling and Analysis

The soil characteristics were determined to assess the nutrient status of the experimental site before the application of fertilizers. At the beginning of the experiment (in 2023), 15 samples were randomly collected by using an auger and composited. Soil samples were also taken from each treatment at harvesting (in 2024). The samples were air-dried, crushed with a mortar, and sieved to pass through a 2 mm mesh. The characteristics analyzed included: Soil pH, Organic matter, Total Nitrogen, Exchangeable Calcium, Magnesium, Potassium, Sodium, and Effective Cation Exchange Capacity, and Bray NO.2 Extractable Phosphorus and Potassium. The air-dried soil samples were ground at the laboratory and sieved through a 2 mm sieve. Soil pH was determined using a glass electrode (pH meter) in a soil ratio of 1:2.5 as reported by [27] and [28]. Soil organic matter was determined by the wet combustion method [29]. The total percentage of nitrogen was determined using the micro Kjeldahl technique [27]. The available phosphorus was extracted by the Bray method and determined colorimetrically [30]. Potassium was determined by flame emission photometry [27]. The exchangeable cations calcium, magnesium, potassium, and sodium were determined as recommended by [27] using EDTA Titration after extraction with 0.1 N Ammonium Acetate at pH 7. Effective Cation Exchange Capacity (ECEC) was calculated as the sum of the exchangeable bases and exchangeable acidity [27].

2.3. Experimental Treatments and Design

The experiment involved four nitrogen rates (No Nitrogen rate, 60 kg N/ha, 90 kg N/ha, and 120 kg N/ha) and three intra-row spacings (20, 30, and 40 cm) in a split-plot design with three replications. The nitrogen rate treatments were assigned to the main plot, whereas the intra-row treatments were assigned to the sub-plots. The control plants (0 kg N/ha) did not receive nitrogen fertilizer. The control rate (0 kg N/ha) is an essential baseline to measure fertilizer response and calculate nitrogen use efficiency metrics. The low rate (60 kg N/ha) represents a conservative application that might align with resource-limited farming conditions or organic matter contributions from soil. The medium rate (90 kg N/ha), often falls within the range of standard recommendations for maize in many regions, particularly where soil fertility is moderate. The high rate (120 kg N/ha) tests for potential yield maximization while exploring the upper threshold before diminishing returns occur.

The recommended inter-row spacing of 75 cm for maize in the study area was maintained. The Wang dataa maize variety was used for the experiment. This variety matures in 90 days, has excellent seed quality, and is drought tolerant. It has a yield potential of 4.0 tons per hectare. Planting was done on July 15, 2023, and

July 19, 2024. Three seeds per hill were planted and later thinned out to two per hill after germination. The trial was monitored for FAW larvae infestation, and insecticide treatments commenced when a 20% field infestation was detected. This was two weeks after their emergence. The space between plot and block was 0.5 m and 1 m, respectively. The gross plot consists of 4 rows, each 3m long. The net plots were located in the middle two rows; the two outer rows of each plot were used as border rows. Thus, the size of the gross and net plot was 9 m^2 (3 m × 3 m) and 4.5 m^2 (3 × 1.5 m). Thus, the plant population corresponding to the 20 cm × 75 cm, 30 cm × 75 cm, and 40 cm × 75 cm intra-inter row spacing was 66,666, 53,333, and 33,333 plants per hectare.

2.4. Management Practices

The nitrogen fertilizer was applied two weeks after planting and by side placement using Urea (46% N) as a mineral source. Half of the N and the whole P fertilizer rate were applied 2 weeks after planting, and the remaining half of the N dose was used during the first earthing up as side dressing. Triple Super Phosphate (45% P_2O_5), Lime (CaO: 0.5 t/ha), Muriate of Potash (60% K_2O), and 20 kg/ha $MgSO_4$ were broadcast and worked into the soil two weeks before planting. This was necessary for the timely mineralization of nutrients, allowing for adequate uptake by the plants. Weeds were managed by hoeing and hand-picking. Weeding was done manually at 2 & 6 weeks after sowing (WAS) using a hand hoe. The trial was monitored for FAW larvae infestation, and insecticide treatments commenced when a 20% field infestation was detected. This was two weeks after their emergence. All other recommended cultural practices were followed.

2.5. Data Collection

Three kinds of data were collected: vegetative, yield, and economic data.

Vegetative date: Five plants were randomly selected and tagged from the two middle rows of each plot for data measurement. Vegetative data measured included plant height, Days to 50% tassel, Days to 50% silking, Leaf Area Index (LAI) and Stover weight. Plant height was measured at 8WAP when all plants had reached their full height. Plant height measurements were taken on the five previously tagged plants, summed, and an average height was calculated. The average was obtained as the height of plants for each plot. The inner rows from each plot were observed till the date when the flag leaf appeared and recorded. Plants were observed for anthesis on each plot, and the number of days to 50% anthesis was recorded. Plants were critically observed, and the number of days to 50% silking was calculated from the date of sowing.

Yield Data

These were the number of fertile cobs per plant, cob weight, 100-seed weight, grain yield, and harvest index. Grain yields were harvested from the 2 inner rows per plot, enveloped, weighed, and readings used to determine grain yield (kg/ha). From each plot, 100 grains were randomly selected and weighed to obtain the 100-grain weight.

2.6. Data Analysis

Data collected were analyzed statistically using GenStat 12th Edition. Mean separation for significant effects was performed using the least significant difference at a 5% probability level.

2.7. Economic Analysis

An economic analysis was conducted to assess the financial feasibility of the treatments. The price of maize that farmers received from the sale was calculated based on the current market price of maize at Bawku near the experimental site. The total variable costs, including the costs of fertilizers, improved seed, and labor, were also calculated based on the current prices. Costs and benefits were calculated for each treatment. The net return was calculated by subtracting total variable cost from the gross benefit. The Gross benefit was calculated with the grain yield (kg/ha) and stalk yield multiplied by the field price, that is, the money gained from the sale of the grain and stalk. Finally, to assess the costs and benefits associated with different treatments, the partial budget analysis technique proposed by [31] was applied.

3. Results and Discussion

3.1. Soil Properties

The results of the soil analysis at the study site revealed that the soil was predominantly sandy and acidic. All other plant growth requirements in the soil are below average except the levels of potassium, which are moderate (**Table 1**).

Table 1. Physical and chemical properties of the soil surface (0 - 30) of the experimental plot (2023).

Soil properties	Value
FAO-UNESCO soil classification	Plinthic Lixisol
Sand (%)	84.56
Silt (%)	12
Clay (%)	3.44
Soil texture	Loamy sand
Soil pH ($CaCl_2$)	4.26
Organic carbon (%)	0.35
Total nitrogen (%)	0.06
Available P ($mg \cdot kg^{-1}$)	7.77
Exchangeable cations cmol (+) kg^{-1}	
Ca	0.80
Mg	0.30
K	33.20
CEC [cmol (+) kg^{-1}]	2.93

3.2. Treatment Effect on Growth Parameters

3.2.1. Plant Height

Nitrogen rate and intra-row spacing significantly ($P < 0.05$) affected plant height in both cropping seasons. There was no significant ($P > 0.05$) N rate by intra-row interaction effect on plant height (Table 2). In both cropping seasons, plant height increased significantly from the lowest in plots that received 0 kg N/ha application to the highest in plots that received 90 kg N/ha, beyond which there was no significant increase. Thus, plant height increased with an increase in N rate, attaining its potential height at 90 kg N/ha application. An increase in plant height due to high nitrogen (N) levels may be attributed to improved vegetative development, resulting in increased mutual shading and internodal extension. With the higher dose of N application, the cell division, cell elongation, nucleus formation, green foliage, and chlorophyll content could have increased, leading to an increased rate of photosynthesis and extension of the stem, resulting in increased plant height. The decline in plant height after 90 kg N/ha suggests that 90 kg N/ha was the adequate application rate for plant height. This finding is consistent with studies that have reported a positive response in maize plant height to N fertilization [22]. This observation is inconsistent with those of [32] who reported that increased nitrogen levels from 120 kg N/ha to 200 kg N/ha increased the plant height of hybrid maize varieties.

Table 2. Effect of nitrogen rate and intra-row spacing and their interaction on plant height in the 2023 and 2024 cropping seasons.

Treatment	2023	2024
N rate (kg/ha)	**Plant height (cm)**	**Plant height (cm)**
0	180.20	190.20
60	220.30	215.15
90	240.10	250.20
120	245.15	260.25
LSD (0.05)	6.50	12.20
Intra-row spacing (cm)		
20	256.12	248.25
30	255.52	246.05
40	215.20	210.10
Mean	**242.28**	**234.80**
LSD (0.05)	0.20	0.50
CV (%)		
Interaction		
N rate × Intra-row spacing	ns	ns

ns = non-significant at 5% level of significance.

In both seasons, plant height increased with increasing intra-row spacing from 20 cm to 30 cm, beyond which there was a decline in plant height. Thus, plots with narrower intra-row spacing produced taller plants, while those with wider intra-row spacing produced shorter plants. This could be due to nutrient competition, which was expected to be higher under narrower intra-row spacing and vice versa. Wider intra-row spacing (40 cm) resulted in slightly shorter plants, while the narrowest spacing (20 cm) resulted in the shortest plants, possibly due to increased competition for resources. The tallest plants were recorded at 30 cm intra-row spacing, which may be due to optimal plant density and reduced competition for resources [33]. The non-significant interaction between N rate and intra-row spacing for plant height suggests that the effects of N rate and intra-row spacing on plant height are additive [34]. Thus, optimizing N rates and intra-row spacing can improve maize plant height, which can contribute to increased biomass production and potentially improve grain yield

3.2.2. Leaf Area Index

Leaf Area Index (LAI) was significantly ($P < 0.05$) affected by the main effect of Nitrogen rate and intra-row spacing, but not significantly ($P > 0.05$) affected by their interaction effect (**Table 3**). In both cropping seasons, N application significantly increased LAI compared to the control (0 kg N/ha). LAI increased significantly with increasing N rate up to 90 kg/ha, beyond which there was no further significant increase. This is consistent with studies by [22], who reported optimal N rates for maximizing LAI in maize. The increase in LAI with N application can be attributed to improved leaf growth and development, which is essential for photosynthesis and biomass production.

Table 3. Effect of nitrogen rate and intra-row spacing and their interaction on LAI in the 2023 and 2024 cropping seasons.

Treatment	2023	2024
N rate (kg/ha)	**LAI (cm^2)**	**LAI (cm^2)**
0	2.168	2.068
60	3.143	3.143
90	3.681	3.591
120	3.113	3.193
LSD (0.05)	**0.41**	**0.31**
Intra-row spacing (cm)		
20	3.411	3.501
30	3.093	3.293
40	2.218	2.998
Mean	**2.907**	**3.264**
LSD (0.05)	**0.27**	**0.19**
CV (%)	**12.1**	**10.5**
Interaction		
N rate × Intra-row spacing	**ns**	**ns**

ns = non-significant at 5% level of significance.

The largest LAI was recorded under 20 cm intra-row spacing, and the lowest was observed under 40 cm intra-row spacing. Thus, LAI increased with decreasing intra-row spacing and decreased with increasing intra-row spacing. The increase in LAI with reduced intra-row spacing might be due to the occupation of more unit area by the green canopy of the plants. This study agrees with that of [35], who indicated that in high maize density, LAI increases more than at lower density throughout the crop growing season. [36] reported maximum LAI from the lowest plant density and minimum LAI from the highest plant density. In this case, increasing the number of plants per unit area beyond the optimum level could probably reduce the amount of light availability to the individual plant, especially to lower leaves, due to shading.

The non-significant interaction between N rate and intra-row spacing for LAI in both cropping seasons suggests that the effects of N rate and intra-row spacing on LAI are additive [34]. Thus, the results indicate that optimizing N rates and intra-row spacing can enhance maize leaf area index (LAI), which may contribute to increased photosynthetic activity and potentially improve grain yield.

3.3. Treatment Effect on Phenological Parameters

3.3.1. Days to 50% Anthesis

The main effect of N rate significantly ($P < 0.05$) affected days of 50% anthesis, while intra-row spacing and the interactions did not significantly ($P > 0.05$) affect days of 50% anthesis (**Table 4**). The longest days to 50% anthesis were recorded

Table 4. Effect of nitrogen rate and intra-row spacing and their interaction on Days to 50% anthesis in the 2023 and 2024 cropping seasons.

Treatment	2023	2024
N rate (kg/ha)	**Days to 50% anthesis**	**Days to 50% anthesis**
0	82.00	81.90
60	81.22	80.93
90	79.83	81.20
120	79.10	80.10
LSD (0.05)	**1.03**	**0.1**
Intra-row spacing (cm)		
20	81.00	81.50
30	80.83	80.03
40	79.90	79.10
Mean	**80.58**	**80.21**
LSD (0.05)	**ns**	**ns**
CV (%)	**15.50**	**17.10**
Interaction		
N rate × Intra-row spacing	ns	ns

ns = non-significant at 5% level of significance.

from the control plots, which were significantly longer than the other treatments. Thus, days to 50% anthesis decreased with an increase in N rate application, suggesting that higher application of Nitrogen dose induced early anthesis in maize. The shortest duration to 50% anthesis was recorded at 90 kg N/ha, suggesting that optimal N rates can promote earliness in maize [37]. A further increase in N rate (120 kg/ha) resulted in statistically similar days to 50% anthesis compared to the 90 kg N/ha rate. This could be due to excessive vegetative growth at the 120 kg N/ha rate [38]. This result agreed with [33], who reported that the increasing nitrogen level from 120 kg·ha^{-1} to 200 kg·ha^{-1} decreased the days to 50% anthesis. The earliness associated with higher nitrogen application may be due to the rapid growth of the maize plant resulting from the availability of adequate nitrogen in the soil. The non-significant effect of intra-row spacing on days to 50% anthesis in both cropping seasons could be due to reduced competition for resources [39]. In comparison, the non-significant interaction between N rate and intra-row spacing for days to 50% anthesis suggests that the effects of N rate and intra-row spacing on days to 50% anthesis are additive [40]. Thus, optimizing N rates and intra-row spacing can influence maize phenology, which can contribute to improved crop management and potentially increase grain yield.

3.3.2. Days to 50% Silking

The main effect of N rate significantly ($P < 0.05$) affected days to 50% silking, while intra-row spacing and the interactions did not significantly ($P > 0.05$) affect days to 50% silking (**Table 5**). In both seasons, the control plots recorded the

Table 5. Effect of nitrogen rate and intra-row spacing and their interaction on Days to 50% Silking in the 2023 and 2024 cropping seasons.

Treatment	**2023**	**2024**
N rate (kg/ha)	**Days to 50% silking**	**Days to 50% silking**
0	88.23	87.13
60	85.11	86.13
90	86.58	85.10
120	85.50	85.00
LSD (0.05)	**1.10**	**0.90**
Intra-row spacing (cm)		
20	85.00	84.90
30	84.83	83.73
40	83.40	82.90
Mean	**84.41**	**83.84**
LSD (0.05)	**Ns**	**ns**
CV (%)	**14.90**	**13.00**
Interaction		
N rate × Intra-row spacing	**ns**	**ns**

ns = non-significant at 5% level of significance.

longest days, while the 120 kg N/ha rate recorded the shortest days to 50% silking, which was not significantly different from days recorded at the 90 kg N/ha rate. Thus, the number of days to 50% silking decreased with an increase in N rate application, suggesting that a higher nitrogen dose induced early silking in maize. The shorter silking duration could be attributed to adequate soil nitrogen, which promoted better phenological development of the maize plant. The period of silking is a critical time for kernel formation after pollination. Any factor that affects silking and the duration of silking can have a direct impact on grain production.

Regarding the intra-row spacing, although the LSD values for intra-row spacing were non-significant (ns), the mean values suggest that wider intra-row spacing (40 cm) resulted in shorter days to 50% silking compared to narrower spacings. This could be due to reduced competition for resources such as light, water, and nutrients at wider spacings [41]. The non-significant interaction between N rate and intra-row spacing for days to 50% silking suggests that the effects of N rate and intra-row spacing on days to 50% silking are additive [42]. As with the days to 50% anthesis, optimizing N rates can influence days to 50% silking, which can contribute to improved crop management and potentially increase grain yield.

3.4. Treatment Effects on Maize Grain Yield and Yield Components

3.4.1. Percent Stand Count

The maize percent stand count was significantly ($P < 0.05$) affected by the main effect of N rate and intra-row spacing but not significantly ($P > 0.05$) affected by their interaction effect (**Table 6**). In both cropping seasons, the highest percent stand count was recorded at the 90 kg N rate and the lowest at the 0 kg N/ha rate. Stand count (%) increased significantly with increasing N rate up to 90 kg/ha, beyond which there was no further significant increase. This suggests that a higher nitrogen dose application promoted the stand count (%) of maize, achieving a potential stand count (%) at 90 kg N/ha.

The highest percent stand count was recorded from 40 cm intra-row spacing, while the lowest was recorded from 20 cm intra-row spacing. The percent stand count increased at wider intra-row spacing and decreased at narrow intra-row spacing. The percent plant stand decreased as plant population increased, and this might be due to the crowding effect. The other reason could be that at lower population densities, the availability of more space might have resulted in less competition for resources (nutrients, moisture, and light), whereas at high densities, competition resulted in weaker plants and mortalities by the time the crop approached maturity. This result agrees with [43] who reported a higher percent plant stand count due to a wider spacing combination of 75 cm × 30 cm than a narrow spacing of 55 cm × 20 cm. Similarly, [44] reported that wider inter and intra-row spacing of 75 cm × 26.6 cm had a greater percent stand count of maize compared to the initial count than that of narrow inter and intra-spacing of 5 cm × 17.7 cm.

Table 6. Effect of nitrogen rate and intra-row spacing and their interaction on stand count (%) in the 2023 and 2024 cropping seasons.

Treatment	2023	2024
N rate (kg/ha)	**Stand count (%)**	**Stand count (%)**
0	76.60	72.60
60	81.56	88.16
90	93.20	90.90
120	83.20	88.50
LSD (0.05)	2.16	1.26
Intra-row spacing (cm)		
20	86.60	80.10
30	90.16	88.56
40	93.20	91.90
Mean	93.20	93.20
LSD (0.05)	1.60	2.20
CV (%)	**18.10**	**17.50**
Interaction		
N rate × Intra-row spacing	ns	ns

ns = non-significant at 5% level of significance.

3.4.2. Stover Weight

Stover weight was significantly ($P < 0.05$) affected by the main effect of N rate and intra-row spacing, but not significantly ($P > 0.05$) affected by their interaction effect (**Table 7**). Increasing N rate significantly increased stover weight in both cropping seasons (2023 and 2024). This is consistent with studies that have reported positive responses of maize stover yield to N fertilization [45]. The highest stover weight was recorded at the highest N rate (120 kg/ha) in 2023. In 2024, the highest stover weight was recorded at both 90 kg/ha and 120 kg/ha, which were statistically similar. This suggests that N rates above 90 kg/ha may not always result in significant increases in stover weight. Thus, stover yield increased with an increase in nitrogen level. Similarly, [46] reported that increasing the nitrogen level from 60 kg/ha to 240 kg/ha effectively improved stover yield.

The highest stover weight was recorded at the widest intra-row spacing (40 cm) in both cropping seasons compared with narrower spacings (20 cm and 30 cm). Thus, stover weight increased with increasing intra-row spacing, which could be attributed to reduced competition for resources such as light, water, and nutrients at wider spacings [46]. The interaction between N rate and intra-row spacing was not significant for stover weight in both cropping seasons. This suggests that the effects of N rate and intra-row spacing on stover weight are additive, and there is no synergistic or antagonistic interaction between the two factors [47]. The results suggest that optimizing N rates and intra-row spacing can enhance maize stover weight, thereby contributing to increased overall biomass production and potentially improving soil health through enhanced crop residue retention.

Table 7. Effect of nitrogen rate and intra-row spacing and their interaction on stover weight in the 2023 and 2024 cropping seasons.

Treatment	2023	2024
N rate (kg/ha)	**Stover weight (kg)**	**Stover weight (kg)**
0	14.61	12.21
60	15.22	14.92
90	16.92	16.32
120	17.22	16.22
LSD (0.05)	**0.91**	**0.82**
Intra-row spacing (cm)		
20	13.91	13.61
30	15.02	15.52
40	17.92	16.92
Mean	**15.61**	**15.35**
LSD (0.05)	**0.32**	**0.22**
CV (%)	**15.92**	**14.12**
Interaction		
N rate × Intra-row spacing	ns	ns

ns = non-significant at 5% level of significance.

3.4.3. Ear Diameter

The main effect of N rate significantly ($P < 0.05$) affected maize diameter, while that of intra-row spacing and their interaction did not significantly ($P > 0.05$) affect ear diameter (**Table 8**). In both seasons, the highest ear diameters were recorded from plots that received a 90 kg N/ha application rate, while the control plots produced the lowest. The ear diameters were not significantly ($P > 0.05$) different among plots that received 90 and 120 kg N/ha. Generally, ear diameter increased with increased N rates in both cropping seasons, indicating that either the crop was efficient in its capture and use of fertilizer N or the soils were low in plant available nutrients, or both. The fact that there was no further significant increase in ear diameter beyond 90 kg/ha suggests that maize plants attained potential ear diameter at the rate of 90 kg/ha. In the environments where these studies were carried out, the soil was low in plant-available nutrients, with an average pH of 5.50. [44] reported low maize yields for soils that received no fertilizer and attributed it to reduced plant growth as a consequence of low levels of nutrients, particularly N supply and uptake. The non-significance of the intra-row effect on ear diameter might be due to low competition for resources like moisture, nutrients, and light under this intra-row spacing.

Table 8. Effect of nitrogen rate and intra-row spacing and their interaction on ear diameter in the 2023 and 2024 cropping seasons.

Treatment	2023	2024
N rate (kg/ha)	**Ear diameter (cm)**	**Ear diameter (cm)**
0	2.29	2.50
60	3.20	4.10
90	4.19	4.50
120	3.50	3.89
LSD (0.05)	0.80	0.18
Intra-row spacing (cm)		
20	3.35	3.50
30	3.50	3.90
40	3.20	3.60
Mean	**3.35**	**3.67**
LSD (0.05)	Ns	ns
CV (%)	**15.50**	**16.40**
Interaction		
N rate × Intra-row spacing	ns	ns

ns = non-significant at 5% level of significance.

3.4.4. Ear Length

The analysis of variance showed that ear length was significantly ($P < 0.05$) affected by the main effect of N rate, intra-row spacing, and their interaction. The longest ear (37.90 cm) was recorded from a 90 kg N/ha rate under 40 cm intra-row spacing, while the shortest ear length (21.20 cm) was obtained from a 0 kg N/ha rate at an intra-row spacing of 20 cm (Table 9). In general, ear length decreased with decreased intra-row spacing (increased plant density). The longer

Table 9. Interaction of N rate and intra-row spacing on ear length at harvest of green cob maize during the 2023 and 2024 cropping seasons.

Nitrogen rate (kg N/ha)	Intra-row spacing (cm)		
	20	**30**	**40**
0	21.20	27.2	28.30
60	23.32	30.1	32.50
90	32.50	32.2	37.90
120	33.01	33.30	35.10
LSD (0.05)	2.20		
CV (%)	4.6		

LSD = least significant difference, NS = non significance, CV = coefficient of variation in percent. Means columns within a parameter followed by the same letter(s) are not significantly different at the 5% level of significance.

ear at lower plant population (increased intra-row spacing) may be due to less competition for resources at lower plant population density. [44] Also observed was decreased maize ear length under increased population densities, and it was attributed to the fact that plant populations above and below the critical density hurt yield per plant due to inter-plant competition for light, water, nutrients, and other potential yield-limiting environmental factors. Reduction of ear length and diameter with narrower row spacing is attributed to limitation of assimilates as a result of low photosynthetic processes of leaves at narrow row spacing due to less availability of growth-influencing factors, which resulted in low ear length and diameter.

3.4.5. Grain Yield

Nitrogen rate and intra-row spacing significantly ($P < 0.05$) affected grain yield in both cropping seasons (**Table 10**). The highest grain yields were achieved in plots that received 90 kg N/ha, beyond which there was no further significant increase in grain yield. Minimum grain yields were obtained under 0 kg N/ha, which were statistically lower than grain yields obtained under other application rates. In contrast, maximum grain yields were obtained at 120 kg N/ha, which were statistically similar to those obtained at 90 kg N/ha. Higher grain yields at higher nitrogen levels might be due to the lower competition for nutrients and the positive effect of N on plant growth, leaf area expansion, and thus increase solar radiation use efficiency that ultimately increases in grain yield. These results are in line with those of [44], who reported that increasing the N rates significantly increased grain yield in maize. An increase in grain yield at higher N levels might be due to the lower competition for nutrients, which leads to a larger canopy of the plant contributing higher photosynthetic activity to accumulate more biomass with the bold grain. Nitrogen is a vital plant nutrient and a major yield-determining factor required for maize production [45]. The fact that grain yield started declining after 90 kg N/ha, suggests that 90 kg N/ha was the adequate application rate for grain yield. [46] reported that the nitrogen fertilizer levels are significant for grain yield, plant height, dry stover weight, cob length, and grain depth at nitrogen levels of 0, 45, and 90 kg N/ha. The observed trend in grain yield confirms the results of [47], who observed significant differences in the cob weight at different N rates. The results support the findings of [48], who reported that winter maize grain yield increased with increasing levels of NPK fertilizers. [46] also reported that with the increasing Nitrogen dose, the maize grain yield also increased. An increase in grain yield at higher N levels might be due to the lower competition for nutrients, which leads to more canopy of the plant contributing to higher photosynthetic activity to accumulate more biomass and bold grain.

An intra-row spacing of 40 cm recorded the highest grain yields, statistically higher than those recorded under other intra-row spacing. There was an increase in maize grain yield under increased spacing, possibly due to less competition for available resources (nutrients, water, and light). Wider intra-row spacing provides available nutrient elements, while narrow row spacing creates more competition for nutrients and light [46]. Higher grain yield production with wider intra-row spacing might be due to less competition for plant resources and availability of maximum solar radiation [49]. This finding agrees with [50] who reported that intra-row spacing of 25 cm resulted in the highest (23.11) cob per plot than 30 cm, followed by (21.56); while 20 cm resulted in the least (17.78) cob per plot. In that study, the reason assigned for the 25 cm intra-row spacing recording higher cob yield per ha was the higher plant population under the 25 cm than those of 30 and 35 cm intra-row spacing; In comparison, while 20 cm intra-row spacing might be affected by a limitation factor than the others [43].

Table 10. Effect of nitrogen rate and intra-row spacing and their interaction on grain yield in the 2023 and 2024 cropping seasons.

Treatment	2023	2024
N rate (kg/ha)	**Grain yield (kg)**	**Grain yield (kg)**
0	1310	1510
60	2510	3110
90	3520	4120
120	3600	4150
LSD (0.05)	**200**	**150**
Intra-row spacing (cm)		
20	1750	1640
30	3210	3310
40	3900	3850
Mean	**2953**	**2933**
LSD (0.05)	**130**	**270**
CV (%)		
Interaction		
N rate × Intra-row spacing	ns	ns

ns = non-significant at 5% level of significance.

3.5. Treatment Effects on Economic Data

Partial Budget Analysis

The economic analysis of the treatments was carried out using the benefit-cost ratio (BCR) method. This involved determining variable costs, gross returns, and net benefits for all treatments. In both seasons, the net benefits (NBs) were generally higher in plots that received Nitrogen fertilizer application than in the control plots (**Table 11**). This could be a result of the higher grain yield of maize in the treated. Thus, differences in NBs and BCRs among treatments were basically due to differences in maize grain yield obtained from the different treatments. This is supported by the fact that treated plots with the highest grain yields consistently also accounted for the highest NBs and BCRs. Thus, the trend is consistent, with the highest yielding treatment recording the highest NB and BCR. The trend on partial budget analysis was consistent in both seasons, with the highest yielding treatments (90 kg N/ha and 40 cm) recording the highest net benefit, while the control (0 kg/ha) ranked last. The application rate of 90 kg N/ha and intra-row spacing of 40 cm are thus recommended for optimum maize production and productivity.

Table 11. Net benefit and benefit-cost ratio of various treatments during the 2023 and 2024 cropping season.

Treatment	Net benefit (NB) GHC		Benefit-cost ratio (BCR)	
	2023	2024	2023	2024
N rates (kg N/ha)				
0	80.00	78.00	0.90	0.86
60	225.10	252.50	1.30	1.20
90	390.10	385.50	1.72	1.88
120	382.10	375.50	1.02	1.10
Intra-row spacing (cm)				
20	210.20	215.40	0.80	0.80
30	262.18	251.10	0.96	0.90
40	279.10	260.30	1.91	1.80

4. Conclusion

The study was conducted to assess the effect of N rate and intra-row spacing on maize growth, development, and yield. Generally, the various treatments significantly affected yield and yield components of maize. Plots that received 120 and 90 kg N/ha recorded relatively higher grain yield and growth parameters than 0 kg N/ha. The highest yield and yield components were recorded under 120 kg N/ha and 90 kg N/ha with grain yields at these rates being statistically similar in both cropping seasons. An intra-row spacing of 40 cm recorded the highest grain yields, statistically higher than those recorded under other intra-row spacing. The increase in maize grain yield under increased spacing, which might be due to less competition for available resources (nutrients, water, and light). The trend on partial budget analysis was consistent in both seasons, with the highest yielding treatments (90 kg N/ha and 40 cm) recording the highest net benefit, while the control (0 kg/ha) ranked last. The application rate of 90 kg N/ha and intra-row spacing of 40 cm are thus recommended for optimum maize production and productivity.

Conflicts of Interest

The authors declare no conflicts of interest regarding the publication of this paper.

References

[1] MOFA (2019) Agricultural Statistics. Ministry of Food and Agriculture.

[2] Kanton, R.A.L., Buah, S.S.J., Larbi, A., Mohammed, A.M., Bidzakin, J.K. and Yakubu, E.A. (2017) Soil Amendments and Rotation Effects on Soybean and Maize Growths and Soil Chemical Changes in Northern Ghana. *International Journal of Agronomy*, **2017**, Article ID: 4270284. https://doi.org/10.1155/2017/4270284

[3] Kwame, O.W. and Arhin, G.K. (2017) The Poultry Sector in Ghana. *World's Poultry Science Journal*, **73**, 891-902.

[4] Grote, U., Fasse, A., Nguyen, T.T. and Erenstein, O. (2021) Food Security and the Dynamics of Wheat and Maize Value Chains in Africa and Asia. *Frontiers in Sustainable Food Systems*, **4**, Article 617009. https://doi.org/10.3389/fsufs.2020.617009

[5] Erenstein, O., Chamberlin, J. and Sonder, K. (2021) Estimating the Global Number and Distribution of Maize and Wheat Farms. *Global Food Security*, **30**, Article ID: 100558. https://doi.org/10.1016/j.gfs.2021.100558

[6] Adu, G.A., Abdulai, M S., Alidu, H., Nustugah, S.K., Buah, S.S., Kombiok, J.M., Etwire, P.M., *et al.* (2015) Recommended Production Practices for Maize in Ghana.

[7] MoFA & IFPRI (2020) Ghana's Maize Market. MoFA-IFPRI Market Brief No. 1.

[8] Agyare, W.A., *et al.* (2017) Effects of Plant Density and Nitrogen Fertilizer on Maize Yield and Water Use Efficiency in the Sudan Savanna Zone of Ghana. *Journal of Agricultural Science and Technology*, **17**, 537-548.

[9] Kwaku, R.S., *et al.* (2017) Effects of Conservation Agriculture on Maize Yield and Water Use Efficiency in the Sudan Savanna Zone of Ghana. *Journal of Environmental Science and Health*, *Part B*, **52**, 137-145.

[10] Adiaha, M.S. (2017) Economic Value of Maize (*Zea mays* L.) in Nigeria and Its Impacts on the Global Food Production. *International Journal of Scientific World*, **6**, 27-30. https://doi.org/10.14419/ijsw.v6i1.8771

[11] Liu, X., *et al.* (2017) Effects of Plant Density on Maize Yield and Water Use Efficiency in the Loess Plateau of China. *Agricultural Water Management*, **194**, 137-145.

[12] Asamoah, L.K. and Gyamfi, D.O. (2017) Maize Production in Ghana under Threat.

[13] CIMMYT (2015) Managing Nitrogen-Use-Efficient Maize Trials. Part 1-4.

[14] Avatim, R.W., Migwe-Kagume, C. and Fincham, L. (2021) Why Does Ghana Need a Fertilizer Dashboard? Development Gateway. https://developmentgateway.org/blog/why-does-ghana-need-a-fertilizer-dashboard/

[15] Ordóñez, R. (2022) Russia-Ukraine Conflict and Global Food Security. https://www.cimmyt.org/news/russia-ukraine-conflict-and-global-food-security/

[16] Ghana-News-Agency (2022) Farmers in Upper East Express Worry about High Input Cost. https://newsghana.com.gh/upper-east-farmers-express-worry-about-high-input-cost/

[17] Buah, S.S.J., Ibrahim, H., Derigubah, M., Kuzie, M., Segtaa, J.V., Bayala, J., *et al.* (2017) Tillage and Fertilizer Effect on Maize and Soybean Yields in the Guinea Savanna Zone of Ghana. *Agriculture & Food Security*, **6**, Article No. 17. https://doi.org/10.1186/s40066-017-0094-8

[18] Begizew, G., Adugnaw, M. and Merkeb, G. (2020) Effect of Nitrogen Rate and Intra-row Spacing on Yield and Yield Components of Maize at Bako, Western Ethiopia, *African Journal of Agricultural Research*, **16**, 1464-1471. https://doi.org/10.5897/AJAR2018.13515

[19] Azam, M., Akbar, N., Akhter, M.J. and Sajjad, A. (2017) Production Potential of

Various Maize (*Zea mays* L.) Hybrids under Different Intra-Row Plant Spacing. *Pakistan Journal of Agricultural Science*, **54**, 117-121.

[20] Khan, Z.H., Khalil, S.K., Iqbal, A., *et al.* (2017) Nitrogen Doses and Plant Density Affect the Phenology and Yield of Sweet Corn. *Fresenius Environmental Bulletin*, **26**, 3809-3815.

[21] Mupangwa, M. and Wegary, D. (2018). Closing the Gap between the Potential Yield and Obtained Results of Improved Maize Varieties: Case for Ethiopia. *African Seed Association* (*AFSTA*) *Congress*, Cairo, 28 February 2018.

[22] Mohseni, M., Sadarov, M. and Haddadi, H.M. (2013) Study of Tillage, Plant Pattern and Plant Densities on Kernel Yield and Its Component of Maize in Iran. *International Journal of Agriculture and Crop Sciences*, **5**, 1682-1686.

[23] Abakemal, D., Shimelis, H. and Derera, J. (2016) Genotype-by-Environment Interaction and Yield Stability of Quality Protein Maize Hybrids Developed from Tropical-Highland Adapted Inbred Lines. *Euphytica*, **209**, 756-769. https://doi.org/10.1007/s10681-016-1673-7

[24] Baloyi, C. (2024) Do Row Spacing and Plant Density Influence Maize Productivity under Reduced Tillage? Grain SA Magazine.

[25] Frantová, N., Porčová, L., Jovanović, I., Elzner, P., Cerkal, R. and Rábek, M. (2024) Spacing Strategies for Enhancing Drought Resilience and Yield in Maize Agriculture. *Open Agriculture*, **9**, Article ID: 20220329. https://doi.org/10.1515/opag-2022-0329

[26] Service-GHS and ICF International (2015) Ghana Demographic and Health Survey 2014.

[27] IITA (1979) Selected Methods for Soil and Plant Analysis. Manual Series No. 1. IITA.

[28] McLean, E.O. (1982) Soil pH and Lime Requirement. In: Page, A.L., Miller, R.H. and Keaney, D.R., Eds., *Methods of Soil Analysis* (*Number* 9 *Part* 2), American Society of Agronomy, Salt Lake City, 199-224. https://doi.org/10.2134/agronmonogr9.2.2ed.c12

[29] Walkley, A. and Black, I.A. (1934) An Examination of the Degtjareff Method for Determining Soil Organic Matter, and a Proposed Modification of the Chromic Acid Titration Method. *Soil Science*, **37**, 29-38. https://doi.org/10.1097/00010694-193401000-00003

[30] Bray, R.H. and Kurtz, L.T. (1945) Determination of Total, Organic, and Available Forms of Phosphorus in Soils. *Soil Science*, **59**, 39-46. https://doi.org/10.1097/00010694-194501000-00006

[31] CIMMYT (1988) From Agronomic Data to Farmer Recommendation: An Economic Work Book. 31-33.

[32] Dawadi, D.R. (2012) Growth and Yield of Hybrid Maize (*Zea mays* L.) in Relation to Planting Density and Nitrogen Levels during Winter Season in Nepal. *Tropical Agricultural Research*, **23**, 218-227.

[33] Liu, S.B. (2017) A Method to Estimate Plant Density and Plant Spacing Heterogeneity: Application to Wheat Crops. *Plant Methods*, **13**, 38.

[34] Akhtar, K., Afridi, M.Z., Akbar, M., *et al.* (2015) Planting Densities and Nitrogen Levels Impact Yield and Yield Components of Maize. *Pure and Applied Biology*, **4**, 217.

[35] Saberali, S.F. (2007) Influence of Plant Density and Planting Pattern of Corn on Its Growth and Yield under Competition with Common Lambesquarters (*Chenopodium album* L.). *Pajouhesh and Sazandegi*, **74**, 143-152.

[36] Imran, S., Arif, M., Khan, A., Khan, M.A., Shah, W., *et al.* (2015) Effect of Nitrogen

Levels and Plant Population on Yield and Yield Components of Maize. *Advances in Crop Science and Technology*, **3**, Article ID: 1000170.

[37] Nalivata, P.C., Munthali, M.W., Makumba, W.I., Mbewe, E. and Manase, H. (2017) Optimizing Fertilizer Use within the Context of Integrated Soil Fertility Management in Malawi. In: Wortmann, C.S. and Sones, K., Eds., *Fertilizer Use Optimization in Sub-Saharan Africa*, CABI, 113-124. https://doi.org/10.1079/9781786392046.0113

[38] Negash, D. and Bekele, I. (2017) Optimizing Fertilizer Use within the Context of Integrated Soil Fertility Management in Ethiopia. In: Wortmann, C.S. and Sones, K., Eds., *Fertilizer Use Optimization in Sub-Saharan Africa*, CAB International, 52-66.

[39] Wortmann, C.S. and Sones, K. (2017) Fertilizer Use Optimization in Sub-Saharan Africa. CAB International, 228.

[40] Shumi, D., Demissie, A., Tekalign, A. and Belachew, D. (2018) Effect of Phosphorus Rates in Blended Fertilizer (NPS) and Row Spacing on Production of Bushy Type Common Bean (*Phaseolus vulgaris* L.) at Midland of Guji, Southern Ethiopia. *Journal of Plant Biology and Soil Health*, **5**, Article 7.

[41] Ngode, L. (2017) Effect of Spatial Arrangement and Variety on Performance of Common Bean (*Phaseolus vulgaris* L) in Western Kenya. *African Journal of Education, Science and Technology*, **4**, 195-204.

[42] Merga, J.T. (2020) Evaluation of Common Bean Varieties (*Phaseolus vulgaris* L.) to Different Row-Spacing in Jimma, South Western Ethiopia. *Heliyon*, **6**, e04822.

[43] Eskandarnejada, S., Khorasani, S., Bakhtiaric, A. and Heidarian, R. (2013) Effect of Row Spacing and Plant Density on Yield and Yield Components of Sweet Corn (*Zea mays* L.). *Journal of Crop Science*, **3**, 81-88.

[44] Adamtey, N., Musyoka, M.W., Zundel, C., Cobo, J.G., Karanja, E., Fiaboe, K.K.M., *et al.* (2016) Productivity, Profitability and Partial Nutrient Balance in Maize-Based Conventional and Organic Farming Systems in Kenya. *Agriculture, Ecosystems & Environment*, **235**, 61-79. https://doi.org/10.1016/j.agee.2016.10.001

[45] Wang, X., Jia, Z., Liang, L., Yang, B., Ding, R., Nie, J., *et al.* (2016) Impacts of Manure Application on Soil Environment, Rainfall Use Efficiency and Crop Biomass under Dryland Farming. *Scientific Reports*, **6**, Article No. 20994. https://doi.org/10.1038/srep20994

[46] Ali, A. (2017) Inter- and Intra-Row and Plant Spacing Impact on Maize (*Zea mays* L.) Growth and Productivity: A Review. *International Journal of Advanced Science and Research*, **2**, 10-14.

[47] Temesgen, T. (2019) Effects of Varieties and Intra Row Spacing on Yield of Maize (*Zea mays* L) under Supplementary Irrigation in an Arid Region of Western Ethiopia. *Advances in Applied Sciences*, **4**, 52-58.

[48] Adhikary, B.H., Baral, B.R. and Shrestha, J. (2020) Productivity of Winter Maize as Affected by Varieties and Fertilizer Levels. *International Journal of Applied Biology*, **4**, 85-93. https://doi.org/10.20956/ijab.v4i1.10192

[49] Maddonni, G.A. and Otegui, M.E. (2006) Intra-Specific Competition in Maize: Contribution of Extreme Plant Hierarchies to Grain Yield, Grain Yield Components and Kernel Composition. *Field Crops Research*, **97**, 155-166. https://doi.org/10.1016/j.fcr.2005.09.013

[50] Sabo, M., Wailare, M., Aliyu, M. and Sanusi, J. (2016) Effect of Variety and Spacing on Growth and Yield of Maize (*Zea mays* L.) in Bauchi State, Nigeria. *International Journal of Plant & Soil Science*, **9**, 1-6. https://doi.org/10.9734/ijpss/2016/23225