Research Article

# Row Configuration and Soil Amendment Affect Performance of Popcorn (Zea mays L. var. Everta) in Semi-Arid South Africa

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**Appropriate plant spacing is vital to maximizing marginal field and expediting equitable distribution of applied plant nutrients for improved popcorn yield. Two field experiments were carried out during the summer seasons of 2017/18 and 2018/19 at the North-West University (NWU) research farm, Mafikeng campus. The study investigated the response of popcorn to different rates of compost and NPK 20-7-3 fertilizer and plant spacings in the semi-arid region of South Africa. The trial consisted of twenty treatments laid out as a split-plot in a randomized complete block design (r=3). The main plot and subplot effects were amendment rates (4 and 8 t/ha compost, 90 and 180 kg N/ha, while the unamended field served as the control); and four intra-row spacings (cm): 15×15 ($SP_1$), 20×20 ($SP_2$), 25×25 ($SP_3$), and 30×30 ($SP_4$). Data were collected on growth and yield components. Results showed that popcorn had the highest number of leaves (12.75) in plots fertilized with 8 t/ha compost under $SP_4$, while the tallest plant (205.64 cm) was recorded in plots intra-spaced at $SP_2$ and fertilized with 8 t/ha compost. The leaf area index was highest (5.1) in plots amended with 90 kg N/ha under $SP_4$. The chlorophyll content of popcorn in plots supplied with 90 kg N/ha under $SP_3$ was significantly higher, with 56.1% more than the leaf chlorophyll from unfertilized plots under $SP_1$. Biomass (178.33 g/plant) and ear number (2.08) were highest in plots treated with 180 kg N/ha under $SP_3$. The kernel yield of 3.28 t/ha and harvest index of 0.32 were lowest in unfertilized plots under $SP_1$. Popcorn yield improved in plots amended with 8 t/ha compost at $SP_2$ plant spacing, similar to the observations in fields fertilized with 90 kg N/ha mineral fertilizer. Nevertheless, the provision of balanced nutrients and the eco-friendliness of applying organic fertilizer favoured the preference for the use of compost for promoting increased popcorn production.**

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# 1. Introduction

Popcorn (*Zea mays* L. *everta*) is an annual cereal crop of economic importance cultivated for its kernels that pop, puff up, or expand in size when slightly heated[1]. This attribute distinguishes it from other varieties of corn. The popped kernels are consumed as snacks in many households and recreational parks for their low carb and nutritional benefits[2]. There has been tremendous growth in the popcorn industry around the world, particularly in the United States of America[3] and South Africa, where it is projected to increase by 0.7% above the current net worth of ZAR 174 million by 2024[4]. Most popcorn industries in South Africa rely on imported kernels to complement the little harvested from about 2000 ha of local cultivation[5]. The major constraint to popcorn production in South Africa is the paucity of information on appropriate agronomic practices, perhaps because the crop is not native to the country. Most importantly, relevant information on its nitrogen requirement and the appropriate density required per unit of land area for its cultivation is not well documented.

The value of popcorn in improving food and nutrition security cannot be overemphasized. Kumar and Prabhasankar[6] and Rebello et al.[7] reported that it is an important snack that supplies high-quality nutrients like fiber, low cholesterol[8], low carbohydrates[9] and quality proteins. It is a whole grain that supplies essential minerals and is very rich in antioxidants[10], aids digestion[11], enhances weight loss, and prevents diseases[2]. Besides, it commands triple the market price of other maize cultigens[12]. Notwithstanding these benefits, many popcorn growers lack basic information on its agronomic characteristics, especially in semi-arid regions where the grains are highly consumed. Information on the cultivation of popcorn in South Africa is still limited to a few provinces in spite of the fact that the crop can be cultivated in all the maize-growing regions, while cultivation is generally low compared to its market demand[13]. An estimated 55,000 t/year was harvested on 10,000 ha, and the crop was grown principally in the Free State and Northern Cape regions[13]. The annual popcorn produced in South Africa is approximately 1.8% of the total corn harvested on 3.1 million ha/annum[14][15]. One of the major limiting constraints to popcorn cultivation in South Africa is inadequate information on the agronomic characteristics of this crop. This is a common phenomenon in the sub-Saharan agro-ecosystem, particularly with popcorn[16].


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Crops perform optimally under favourable environmental conditions such as adequate nutrition, moisture availability, and appropriate spacing with negligible or minimal intra- or inter-competition[17]. As a major agronomic practice, crops are supplied with either organic or mineral fertilizer to augment the native nutrients, which in most cases are inadequate to support the crop all through the statutory phenological stages[18]. This inadequacy may be as a result of soil characteristics or depletion/removal of soil mineral nutrients by previous crops. Singh and Ryan[19] and Badu-Apraku and Fakorede[16] reported that in a soil-plant system, the response of maize to applied materials varies depending on several factors.

Utilization of diverse types and forms of organic fertilizers as an alternative to mineral fertilizers is gaining more attention and relevance because of its low cost, positive environmental impact, plant nutrition security, residual effect, and good mineralization values[20]. These views have been buttressed by Ghorbani et al.[21] on tomato, Matallana Gonzalez et al.[22] on vegetables, Zhao et al.[23] on rice, and Cihangir and Oktem[24] on popcorn. However, the derived benefits of application of organic fertilizer are often location-specific, based on crop genetic potentials as well as other biotic and abiotic influences according to Waldrip et al.[25].

Generally, average N recommendations for growing corn in South Africa ranged from 55 to 180 kg N/ha[26][27][28]. Application of farmyard manure for large-scale corn production is rare in South Africa, but few smallholders use organic manures like chicken or cattle manure to fertilize their arable fields. Information is sketchy on standard or recommended quantities of compost or farmyard manure for growing popcorn in South Africa. Information is scant regarding the response of popcorn to either compost or mineral fertilizer application in the tropical semi-arid region. The need to evolve appropriate rates of organic as well as mineral fertilizers that would be adequate for growing popcorn in this region is very pertinent for improving its production.

Uniformity of the crop in the field is premised on appropriate spacing, which plays an important role in optimizing solar utilization efficiency[29] and equal distribution of applied or available resources. High photosynthetic efficiency is a function of adequate plant architectural pattern and/or spatial arrangement. Inadequate architectural arrangement affects biomass accumulation, which ultimately impinges on photosynthate assimilation and partitioning negatively, according to Brodrick et al.[30] and Dong et al.[31]. The lesser the intra- or inter-competition within crops, the better the photoassimilate that is partitioned into economic yield. According to Dai et al.[32], manipulation of spatial crop arrangement is a common agronomic practice engaged to improve the physiological performance of crops.

Furthermore, the cultivable land is becoming marginal by the day owing to competition from different fronts like the proliferation of industries, infrastructural needs, and residential development[33][34]. This suggests the need for effective utilization of the available agricultural land for cultivating crops of high economic value necessary for human and livestock survival. While doing this, it is expedient to apply scientific approaches necessary to explore the potentials of all the inputs to maximize the economic gain from the process. There is a dearth of information on the appropriate mineral fertilizer or compost rate, as well as the plant density that would be adequate for enhancing the performance of popcorn with respect to growth and yield in the dry land regions of South Africa. The hypothesis of this study was that the grain yield of popcorn is affected by soil amendments and row configuration. Therefore, we investigated the influence of intra-row spacing, compost, and NPK 20-7-3 fertilizer rates on the growth, kernel yield, yield components, and biomass accumulation by *Zea mays* L. *Everta* in the tropical semi-arid region of South Africa.

## 2. Materials and methods

### *Description of the experimental site*

The experiment was conducted at the experimental farm of North West University (NWU), Mafikeng Campus (25°49´39´´S, 25°36´ 3´´0E, 1280 m above sea level) during the 2017/2018 and 2018/2019 summer planting seasons. The farm is located in a savanna semi-arid climate in the North West Province of South Africa. The Province receives approximately 350-400 mm of rainfall annually in winter and averages 250-300 mm during the summer season, with an average temperature range of 18 °C - 22 °C in winter and 22 °C - 37 °C during summer. The relative humidity varied from 13.5-81%. Pre-trial soil samples collected at a depth of 0-30 cm and compost were analysed at the Department of Crop Science laboratory using a LECO CNS TruMac analyzer for total carbon, nitrogen, and sulphur contents. The P concentration was determined colorimetrically, and K was determined by atomic absorption spectrometry. The pH (Soil: $H_2O$, 1:1) of the compost and soil samples was determined using a pH meter (Cole-Parmer Digi-Sense® Model No. 5938-00), while the percent particle size distribution analyses was determined using the modified Bouyoucos methods described by Beretta et al.[35]. The soil was clay loam with a pH of 6.8; total N of 6.96 mg/kg; Bray-1 P of 80.0 mg/kg; and K of 235.0 mg/kg.


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### *Treatments and experimental design*

The study was a 4 × 5 factorial comprising four intra-row spacings and five fertilizer treatments planted during the 2017/18 and 2018/2019 summer growing seasons. The trial was laid out as a split plot, with each treatment arranged in a Randomized Complete Block Design (RCBD) and replicated three times. The main plot contained the fertilizer treatment, while the different within-row spacings were the subplot effect. The four intra-row (within plants) spacings were 15 cm × 15 cm ($SP_1$), 20 cm × 20 cm ($SP_2$), 25 cm × 25 cm ($SP_3$), and 30 cm × 30 cm ($SP_4$), while the inter-row (between plants) was spaced 70 cm apart. The five fertilizer treatments consisted of 90 kg N/ha and 180 kg N/ha using NPK 20-7-3, while the compost was applied at the rates of 4 t/ha and 8 t/ha, with an unfertilized plot included as a control treatment. The NPK fertilizer used contained (kg/100 kg); N = 20, P = 7, K = 3, Zn = 0.5, S = 5, Ca = 1. The compost was prepared from sorted municipal solid waste at NWU Farm using the modified heap method described by Karak et al.[36]. The applied compost had 36 g/kg nitrogen, 1.41 g/kg phosphorus, 10.22 g/kg potassium, and 134 g/kg organic carbon. The equivalent plant population per plot of 2.1 m × 3 m size was 84, 64, 52, and 44, representing 1333,333; 101,587; 82,540; and 69,841 plants/ha for $SP_1$, $SP_2$, $SP_3$, and $SP_4$, respectively.

### *Land preparation, sowing, and field management*

The experimental field was ploughed and harrowed, after which the field was marked and demarcated based on the experimental design to accommodate the treatments and blocks. The dimension of the entire experimental field was 25.5 m × 24 m, while each experimental unit (plot) had a dimension of 3 m × 2.1 m. Mineral fertilizer was applied at planting, while organic fertilizer (compost) was incorporated into the soil two weeks before sowing. Compost was applied two weeks before sowing to enhance mineralization and ease mineral uptake. Seeds of mid-altitude popcorn, obtained from the International Institute of Tropical Agriculture (IITA, Nigeria), were sown in December 2017 for the first trial and in December 2018 for the repeat experiment. One seed was sown per hole at a depth of 2 cm. The field was kept weed-free throughout the experimental period through manual hand hoeing with a Dutch hoe. The trial was rainfed; however, supplementary irrigation was applied when the soil moisture level was low, especially at the tasseling and silking stages, using visual soil examination and evaluation methods of[37]. The overhead sprinkler method was adopted for irrigation purposes.

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### *Data collection*

Four plants from the middle rows of each plot were randomly selected and tagged for data collection in each plot. Data collection followed standard procedures for determining the number of leaves and plant height. The leaf area index (LAI) was evaluated following the procedure of Fageria et al.[38] and Berdjour et al.[39] as LAI = (P × L × A)/(GA)

Where: LAI = Leaf area index, P = Plant population/ground area (ha), L = Number of fully expanded green leaves/plant, A = Single leaf area ($cm^2$), and GA = Ground area ($m^2$).

The stem diameter was measured with a vernier caliper (Mastercraft GS5071522). Chlorophyll content was collected *in situ* from fully expanded leaves per plant with a hand-held chlorophyll meter (model CCM-200 plus). Yield and its components: ear number, ear mass per plant, and 1000 seeds mass were collected following standard procedures described by Abebe and Feyisa[40]. The harvest index was evaluated as:

Harvest index = [40].

The kernel yield was determined from the 1.4 $m^2$ area at harvest maturity. Grain yield was evaluated by harvesting ears from a 1.4 $m^2$ area of the plot. The period of data collection covered the vegetative (V6), tasseling (VT/R5), and maturity (R6) growth stages in corn described by Lee[41].

### *Statistical analysis*

The data for the two planting seasons were pooled together according to Gomez and Gomez[42] and analysed using analysis of variance (ANOVA) of the general linear model (GLM) of the Statistical Analysis System (SAS, version 6.0) according to O′Rourke and Hatcher[43]. Different means were separated using the least significant difference (LSD) test at $p \leq 0.05$ following the methods of Gomez and Gomez[42].

## 3. Results

Number of leaves, diameter of stem, and ear height were not significantly ($p>0.05$) influenced by within-row plant spacing. However, height, leaf area index, chlorophyll content, ear number, ear mass/plant, and biomass were significantly affected by intra-row spacing (Table 1). The rates of fertilizer applied had a significant ($p<0.05$) effect on height, leaf area index, chlorophyll content, and ear height, as shown in

Table 1. The interaction between soil amendments and inter-row spacing had a significant effect on the number of leaves, leaf area index, chlorophyll content, and number of ears.

| **Mean squares** | | | | | | | | |
|---|---|---|---|---|---|---|---|---|
| **Sources of variation** | **Df** | **NL** | **PHT** | **LAI** | **DS** | **CHL** | **EH** | **NE** |
| Spacing (A) | 3 | 51.67 | 3892.31* | 1.94* | 20.58 | 711.50* | 470.65 | 3.43* |
| Amendment (B) | 4 | 214.71 | 3270.40* | 0.92* | 75.47 | 1641.85* | 2219.19* | 0.77 |
| A× B | 12 | 7.29* | 1872.88 | 2.62* | 26.46 | 658.25* | 649.67 | 2.13* |
| CV (%) | | 17.86 | 20.50 | 31.95 | 94.17 | 43.80 | 30.74 | 39.79 |
| Mean | | 11.48 | 184.80 | 69.35 | 14.19 | 33.71 | 83.82 | 1.64 |
| | **Df** | **Ear/plant (g)** | **Ear/plot (Kg)** | **Cob (g)** | **1000 seeds (g)** | **Grain yield (t/ha)** | **Biomass (g)** | **Harvest index** |
| Spacing (A) | 3 | 15901.79* | 0.52 | 961.69 | 272590.30 | 42.70 | 24062.58* | 0.12 |
| Amendment (B) | 4 | 5275.51 | 1.85 | 639.55 | 237613.20 | 36.03 | 8103.74 | 0.13 |
| Ax B | 12 | 41531.10 | 4.63 | 684.16 | 55113.08 | 7.03 | 4901.38 | 0.09 |
| CV (%) | | 38.55 | 72.16 | 65.20 | 20.68 | 58.13 | 55.08 | 122.15 |
| Mean | | 160.55 | 1.45 | 46.46 | 1580.60 | 5.10 | 129.70 | 0.47 |

**Table 1.** Mean squares, coefficient of variation and means of growth and yield characteristics of popcorn as influenced by intra-row configuration and soil amendments.

*Significant at $p \leq 0.05$; Df = degree of freedom; NL= number of leaves, PHT = plant height, LAI= leaf area index, DS = diameter of stem, CHL=chlorophyll content, EH= ear height, NE = number of ears.*

## *Growth response of popcorn to different inter-row configuration*

Different intra-row spacings did not affect leaf formation and height of popcorn plants significantly ($p$>0.05) both at vegetative (V6) and tasseling (VT/R5) growth stages. However, these growth parameters


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were significantly ($p \leq 0.05$) affected by intra-row spacing at the physiological maturity stage (R6). The number of leaves produced at the narrow spacing of 15 cm x 15 cm was significantly lower than the number of leaves recorded in plants with other spacings (Figure 1a). On the other hand, the height of the crop was not affected by intra-row spacing at the V6 and VT/R5 stages. Nevertheless, at R6, the height of the crop was significantly taller at the 20 cm x 20 cm spacing but not significantly taller than plants spaced at 25 cm x 25 cm or 30 cm x 30 cm, as indicated in Figure 1b. The leaf area index (LAI) was statistically affected by intra-row spacing throughout the growth stages (Figure 1c). The LAI was significantly higher under the narrow intra-spacing (15 cm x 15 cm) than under the other intra-row spacings. The widest intra-row spacing (30 cm x 30 cm) had the lowest LAI.

The diameter of popcorn stems was not affected by different intra-row spacings at the vegetative and tasseling stages, except at the physiological maturity period, when the diameter was highest (18.40 mm) in plants spaced at 25 cm × 25 cm, as shown in Figure 1d. Intra-row spacing exerted a significant effect on leaf chlorophyll concentration at varying phenological stages. The highest concentration of leaf chlorophyll was obtained in plants intra-spaced at 25 cm × 25 cm at the vegetative phase. The lowest chlorophyll content was, however, recorded in plants intra-spaced at 15 cm × 15 cm at the tasseling and maturity phases (Figure 1e). The ear height was significantly affected by intra-row spacing, as plants spaced at 20 cm x 20 cm recorded the tallest ear height of 87.61 cm relative to other spacing treatments (Figure 1f).

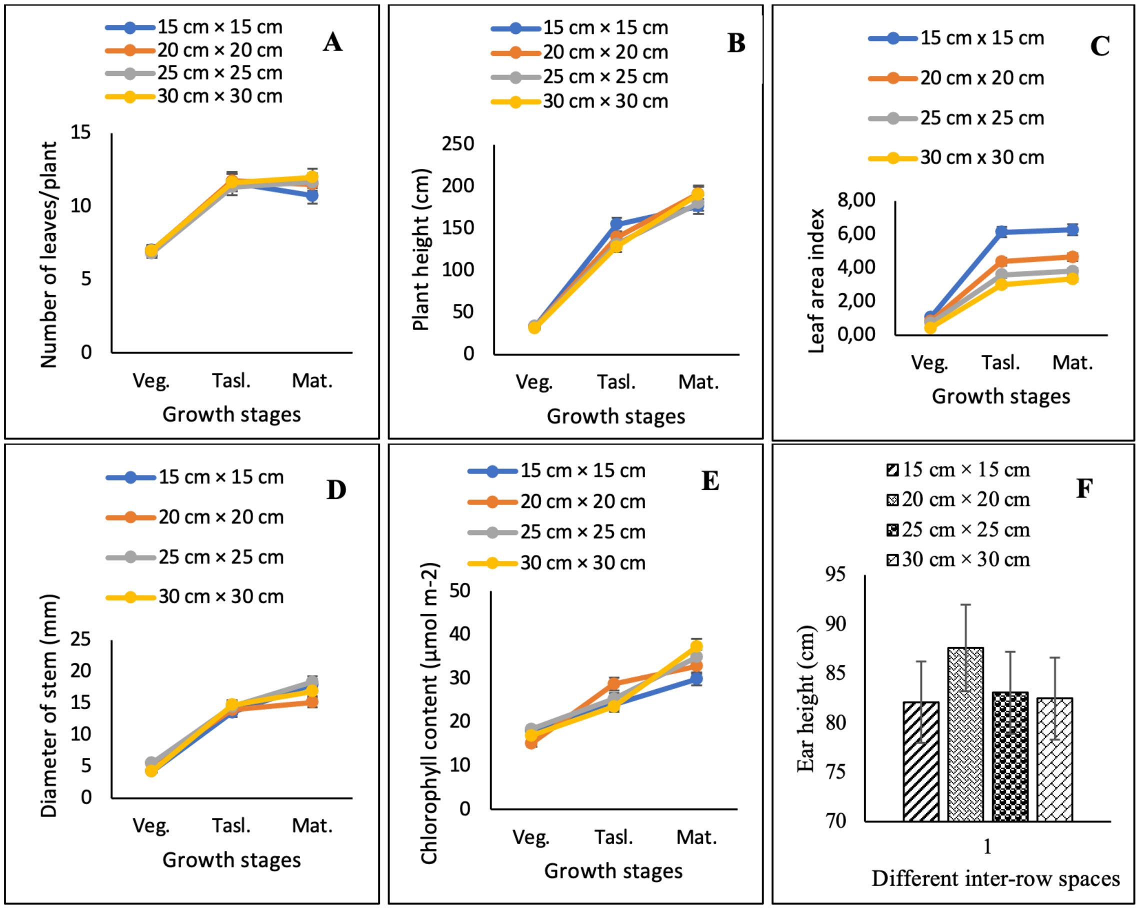


**Figure 1.** Effect of intra-row configuration on the growth of popcorn.

## *Growth response of popcorn to different rates of soil amendments*

Different rates of soil amendments had a significant influence on the growth of popcorn. The effects of the two types of soil amendments on all measured growth parameters, except stem diameter, were statistically comparable relative to the control. The effect of organic and nitrogen fertilizers was significantly similar on the number of leaves produced across the growth stages. Leaf formation improved significantly at the tasseling and physiological maturity stages in plots supplied with 8 t/ha of compost, but this was not statistically different from the number of leaves formed in plots supplied with different rates of NPK 20-7-3 fertilizer (Figure 2a). The height of the crop increased significantly at the vegetative stage in plots fertilized with 90 kg N/ha (NPK 20-7-3) compared to the unfertilized plot (Figure 2b). At the tasseling stage, the height was not influenced by soil amendments, but at physiological maturity, the crop had the tallest plants in plots supplied with 8 t/ha of compost over and above other


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rates of either organic or inorganic fertilizers. At the early growth stage, soil amendments had no effect on the leaf area index (LAI). However, over time, LAI was significantly affected by different rates of amendments, with the highest LAI recorded in plots supplied with 90 kg N/ha, which was significantly similar to the LAI recorded in fields fertilized with 4 t/ha of compost at tasseling. At physiological maturity, LAI was highest in plots supplied with mineral fertilizer at the rate of 90 kg N/ha relative to the LAI recorded in the unfertilized field, which recorded the lowest LAI (Figure 2c).

The stem diameter was not affected by varying rates of organic or inorganic fertilizer (Figure 2d). Rates of soil amendments influenced chlorophyll content in popcorn plants. The plants had the lowest chlorophyll concentration in the unfertilized field, which was statistically similar to the concentration obtained from the field fertilized with 4 t/ha of compost. There was no significant difference in chlorophyll concentration of popcorn grown in plots supplied with 8 t/ha of compost, 90, or 180 kg N/ha (Figure 2e). The tallest ear height (91.66 cm) was recorded in the field fertilized with 8 t/ha of compost, which was not significantly different from the ear height recorded in the field amended with 90 kg N/ha (Figure 2f).

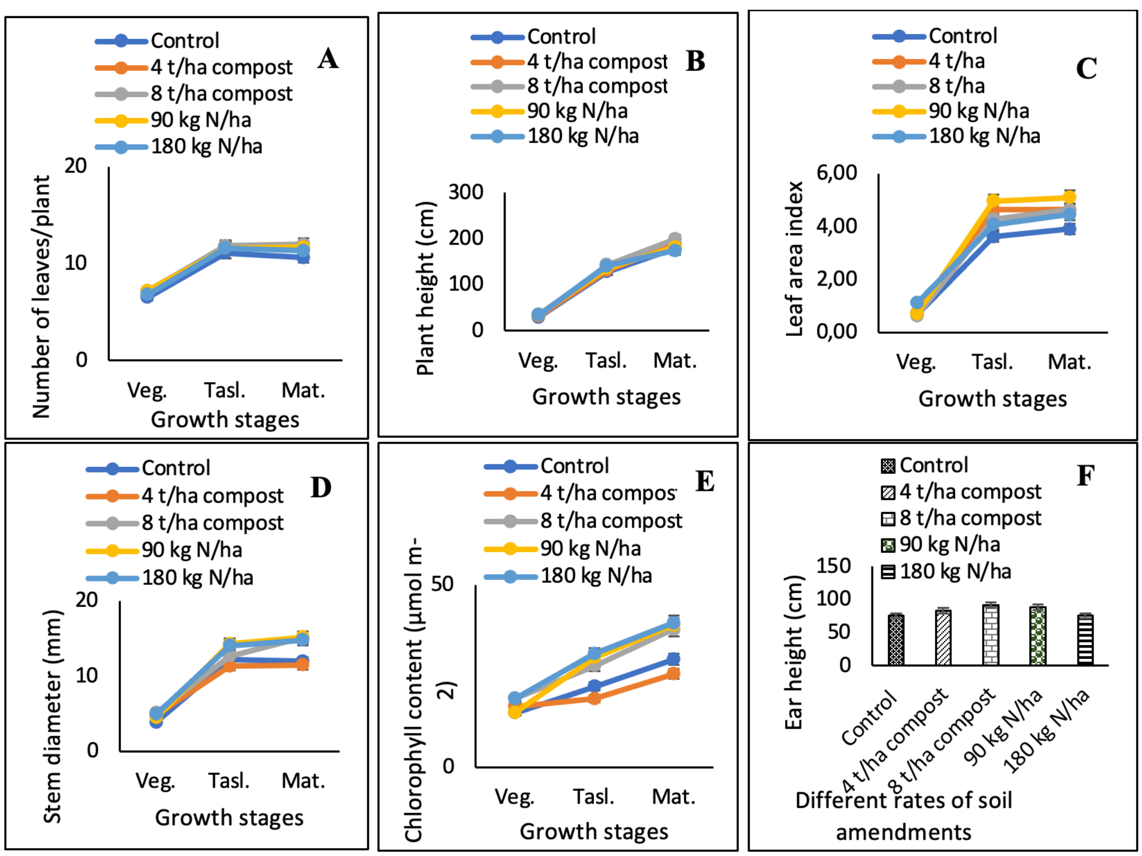


**Figure 2.** Effect of different rates of soil amendments on the growth of popcorn.

### *Effects of inter-row configuration and soil amendment rates on the growth of popcorn*

The effects of interaction between intra-row spacing and soil amendments showed that the application of 90 kg N/ha enhanced the number of leaves produced by popcorn sown at 15 cm × 15 cm at the vegetative and tasseling stages (Table 2). Although this was not significantly higher than the number of leaves recorded in the other treatments, except in the unfertilized plots with narrower spacing, where the number of leaves produced was significantly lower compared to other treatments. However, at maturity, the plant formed the highest number of leaves in plots supplied with 8 t/ha of compost and intra-spaced at 30 cm × 30 cm.

The crop had the tallest plants in plots supplied with 8 t/ha and intra-spaced at 20 cm × 20 cm, both at tasseling and maturity. The shortest plants were recorded under the narrower spacing of 15 cm x 15 cm in the unamended field (Table 2). The effect of soil amendments and intra-row spacings on LAI varies across the three phenological phases. At the vegetative stage, plots fertilized with 180 kg N/ha and intra-spaced at 20 cm × 20 cm had the highest LAI of 2.08. At the tasseling stage, the narrow intra-spacing (15 cm × 15 cm) and lower compost rate (4 t/ha) promoted the highest LAI. However, at maturity, plots fertilized with 180 kg N/ha and intra-spaced at 15 cm × 15 cm had an LAI of 7.04, which was significantly higher than the LAI (2.76) obtained in unfertilized plots under 25 cm x 25 cm intra-row spacing.

The interaction between spacing and fertilizer application had no effect on stem diameter, as shown in Table 3. Popcorn plants intra-spaced at 25 cm × 25 cm and 20 cm × 20 cm and fertilized with 8 t/ha of compost had the highest chlorophyll content (25.48 µmol $m^{-2}$ and 42.92 µmol $m^{-2}$) at the vegetative and tasseling phases, respectively. At maturity, however, popcorn had the highest chlorophyll content of 47.03 µmol $m^{-2}$ in plots where plants were intra-spaced at 25 cm × 25 cm and fertilized with 90 kg N/ha, which was statistically similar to the chlorophyll content recorded in plants intra-spaced at 30 cm × 30 cm and fertilized with 180 kg N/ha (Table 3). Plants had the lowest chlorophyll content in unamended plots with plants intra-spaced at 15 cm × 5 cm. Plants intra-spaced at 20 cm × 20 cm and amended with 90 kg N/ha had the highest ear height (93.98 cm), which was statistically similar to the ear height recorded in plots intra-spaced at 25 cm × 25 cm or 20 cm × 20 cm and amended with 8 t/ha (Table 3).

### *Yield response of popcorn to different inter-row configurations*

The mass of ear per plot, mass of cob, and harvest index were not significantly affected by intra-row spacing. Nevertheless, the highest ear mass per plant and 1000 seed mass were obtained in plots intra-


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spaced at 30 cm × 30 cm, and this was significantly similar to the ear or 1000 seed mass obtained in plots intra-spaced at either 20 cm × 20 cm or 25 cm × 25 cm (Table 4).

The grain yield was significantly influenced by intra-row spacing, as the highest grain yield was obtained in plots intra-spaced at 20 cm × 20 cm. Also, the biomass yield was highest in plots intra-spaced at 25 cm × 25 cm but not significantly higher than the biomass obtained in plots intra-spaced at 30 cm × 30 cm (Table 4). Plants intra-spaced at 30 cm × 30 cm had the highest number of ears (1.85), which was significantly higher than the number of ears from plants intra-spaced at 15 cm × 15 cm or 20 cm × 20 cm, as shown in Table 4.


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| Interactions | | Number of leaves per plant | | | Plant height (cm) per plant | | | Leaf area index per plant | | |
|---|---|---|---|---|---|---|---|---|---|---|
| Amendments | Spacing | Veg. | Tasl. | Mat. | Veg. | Tasl. | Mat. | Veg. | Tasl. | Mat. |
| Control | SP1 | 6.50bc | 11.00dc | 10.33de | 32.71c | 107.64b | 171.30c-e | 1.07ab | 5.13c-f | 4.63d-h |
| | SP2 | 6.08c | 11.00dc | 11.00b-e | 32.71c | 120.07b | 186.46a-d | 0.45b | 3.17gh | 3.22i-k |
| | SP3 | 6.42bc | 10.92d | 10.17e | 33.77c | 119.23b | 174.48b-e | 0.68b | 2.86gh | 2.76k |
| | SP4 | 6.67abc | 11.17b-d | 10.83b-e | 33.32c | 114.26b | 182.33a-e | 0.50b | 3.27f-h | 3.66g-k |
| | | | | | | | | | | |
| 4 t/ha compost | SP1 | 7.58a | 11.67a-d | 10.92b-e | 38.61a-c | 129.36b | 181.08a-e | 1.05ab | 7.62a | 6.68ab |
| | SP2 | 7.08abc | 11.50a-d | 11.08-e | 41.23a-c | 133.91b | 187.84a-d | 0.52b | 4.45c-g | 5.65b-e |
| | SP3 | 6.92abc | 12.00a-d | 11.92a-d | 36.03bc | 131.33b | 185.76a-d | 0.92ab | 3.53e-h | 3.70g-k |
| | SP4 | 7.17ab | 11.83a-d | 12.00a-c | 34.95bc | 130.21b | 195.87a-c | 0.33b | 2.33h | 3.12i-k |
| | | | | | | | | | | |
| 8 t/ha compost | SP1 | 7.33ab | 11.58a-d | 11.08b-e | 33.77a-c | 144.23b | 188.18a-d | 0.87ab | 5.31b-e | 5.87a-d |
| | SP2 | 7.25ab | 12.00a-d | 11.83a-e | 35.71bc | 153.06a | 205.64a | 0.64b | 5.32b-e | 5.34c-f |
| | SP3 | 7.00abc | 11.58a-d | 12.33ab | 33.32a-c | 137.44b | 202.21ab | 0.69b | 4.10d-h | 4.62d-h |
| | SP4 | 7.08abc | 12.17a-d | 12.75a | 34.37a-c | 137.92b | 190.68a-c | 0.40b | 2.96gh | 3.55g-k |
| | | | | | | | | | | |
| 90 kg N/ha (NPK) | SP1 | 7.67a | 12.50a | 11.50a-e | 36.03a-c | 149.22b | 182.27a-e | 0.98ab | 7.03ab | 6.50a-c |
| | SP2 | 7.33ab | 11.67a-d | 11.08b-e | 38.61ab | 147.88b | 193.58a-c | 0.74b | 5.24b-e | 6.04a-c |


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| Interactions | | Number of leaves per plant | | | Plant height (cm) per plant | | | Leaf area index per plant | | |
|---|---|---|---|---|---|---|---|---|---|---|
| **Amendments** | **Spacing** | **Veg.** | **Tasl.** | **Mat.** | **Veg.** | **Tasl.** | **Mat.** | **Veg.** | **Tasl.** | **Mat.** |
| | SP3 | 6.67abc | 11.00dc | 12.42ab | 35.26bc | 110.85b | 157.78de | 0.46b | 4.36c-g | 4.70d-g |
| | SP4 | 7.17ab | 11.17b-d | 11.83a-d | 35.71a-c | 133.78b | 193.75a-c | 0.67b | 3.23gh | 3.17i-k |
| | | | | | | | | | | |
| **180 kg N/ha (NPK)** | SP1 | 6.33bc | 11.67a-d | 10.08e | 34.95a-c | 140.62b | 152.01e | 1.16ab | 5.60b-d | 7.04a |
| | SP2 | 7.17ab | 12.00a-d | 12.25ab | 34.38a-c | 145.10b | 188.16a-d | 2.08a | 4.41c-g | 4.32f-j |
| | SP3 | 7.08abc | 11.42a-d | 11.00b-e | 41.23a | 139.32b | 170.37c-e | 0.95ab | 3.59e-h | 3.41g-k |
| | SP4 | 6.67abc | 11.25a-d | 12.08a-c | 34.37c | 139.83b | 185.32a-d | 0.26b | 2.70gh | 3.03jk |
| **LSD ($p \leq 0.05$)** | | 1.07 | 1.27 | 1.65 | 8.98 | 71.79 | 30.46 | 1.35 | 0.78 | 1.32 |

**Table 2.** Effect interactions between intra-row configuration and different rates of soil amendments on number of leaves, plant height and leaf area index of popcorn.

*LSD = Least significant difference at p<0.05, SP1 = 15 cm × 15 cm; SP2 = 20 cm × 20 cm; SP3 = 25 cm × 20 cm; SP4 = 30 cm × 30 cm, Veg. – vegetative; Tasl. = tasseling and Mat. = physiological maturity. Values with different letters are not significantly different at p<0.05 using LSD.*

## *Yield response of popcorn to different rates of soil amendments*

It was observed that the highest ear mass (195.46 g) per plant was obtained in plots supplied with 90 kg N/ha. Similarly, plots fertilized with 8 t/ha of compost produced ears with the highest mass (1.82 kg) per plot, 1000 seed mass (1,695.54 g), and total biomass (146.95 g), but these were not significantly higher than the values obtained in plots fertilized with other rates of organic or inorganic fertilizers. The grain yield was not significantly affected by fertilizer application, but the highest grain yield (6.12 t/ha) was obtained on plots amended with 90 kg N/ha. Nevertheless, the lowest kernel yield was obtained in the unfertilized field (Table 4). The number of ears per plant was significantly higher in the field amended with 180 kg N/ha than in the number of ears recorded on plots amended with 4 t/ha of compost and the unamended plots.

### *Effect of inter-row configuration and soil amendment rates on yield components of popcorn*

Interactions between intra-row spacing and soil amendments showed that ear mass (2.23 kg/plot) was highest in plots fertilized with 8 t/ha of compost and intra-spaced at 20 cm × 20 cm. The results indicated that the 1000 seeds mass was highest in plants intra-spaced at 30 cm × 30 cm and amended with 4 t/ha of compost. The kernel yield (8.18 t/ha) and harvest index (0.91) were highest in plants intra-spaced at 20 cm × 20 cm and fertilized with 90 kg N/ha (Table 4). The highest biomass and number of ears were on the field intra-spaced at 25 cm × 25 cm and fertilized with 180 kg N/ha, as shown in Table 4.


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| | | Stem diameter (mm) per plant | | | Chlorophyll content (μmol $m^{-2}$) per plant | | | Ear height (cm) per plant |
|---|---|---|---|---|---|---|---|---|
| | | Veg. | Tasl. | Mat. | Veg. | Tasl. | Mat. | |
| **Interaction** | | | | | | | | |
| **Amendments** | **Spacing** | | | | | | | |
| **Control** | SP1 | 3.11b | 10.71 | 10.66 | 13.13d | 24.23g | 20.66f | 72.67ab |
| | SP2 | 4.49ab | 11.80 | 11.02 | 16.84b-d | 28.15de-g | 30.68b-f | 81.40ab |
| | SP3 | 4.35ab | 11.66 | 11.94 | 12.33d | 36.14d-g | 29.46c-f | 70.76b |
| | SP4 | 3.57b | 13.15 | 14.30 | 15.23cd | 24.69c-g | 33.47b-d | 76.84ab |
| | | | | | | | | |
| **4 t/ha compost** | SP1 | 4.91ab | 12.99 | 13.13 | 15.52cd | 24.69fg | 23.73d-f | 84.50ab |
| | SP2 | 3.65b | 11.33 | 14.28 | 14.93cd | 28.02b-f | 28.97c-f | 83.91ab |
| | SP3 | 5.88ab | 8.38 | 12.86 | 17.82a-d | 30.35d-g | 20.20f | 81.89ab |
| | SP4 | 5.02ab | 12.73 | 13.67 | 18.36a-d | 26.01fg | 29.56c-f | 84.37ab |
| | | | | | | | | |
| **8 t/ha compost** | SP1 | 3.91ab | 13.06 | 15.32 | 21.52a-c | 33.72d-g | 37.43a-c | 90.08ab |
| | SP2 | 7.77ab | 12.84 | 14.55 | 13.41d | 42.92a | 37.30a-c | 93.85a |
| | SP3 | 4.74ab | 11.88 | 15.78 | 25.48a | 29.03d-g | 39.85a-c | 93.88a |
| | SP4 | 4.07ab | 12.95 | 15.00 | 16.42cd | 26.01b-g | 36.81a-c | 88.83ab |
| | | | | | | | | |
| **90 kg N/ha (NPK)** | SP1 | 3.79ab | 13.13 | 14.61 | 16.00cd | 30.35b-d | 33.66b-d | 86.48ab |
| | SP2 | 4.28ab | 14.61 | 13.96 | 14.06cd | 33.72a-c | 36.05a-c | 93.98a |
| | SP3 | 4.22ab | 15.17 | 16.57 | 14.86cd | 29.03b-e | 47.03a | 93.90a |
| | SP4 | 5.65ab | 14.37 | 15.68 | 15.30cd | 28.15b-f | 39.15a-c | 79.56ab |
| | | | | | | | | |


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| | | Stem diameter (mm) per plant | | | Chlorophyll content (µmol $m^{-2}$) per plant | | | Ear height (cm) per plant |
|---|---|---|---|---|---|---|---|---|
| | | Veg. | Tasl. | Mat. | Veg. | Tasl. | Mat. | |
| **Interaction** | | | | | | | | |
| **Amendments** | **Spacing** | | | | | | | |
| **180 kg N/ha (NPK)** | SP1 | 4.66ab | 13.94 | 13.70 | 16.21cd | 36.14ab | 42.49ab | 71.47b |
| | SP2 | 4.08ab | 13.88 | 14.56 | 18.86a-d | 28.02b-f | 30.20c-f | 82.46ab |
| | SP3 | 7.77ab | 15.54 | 16.17 | 21.43a-c | 36.14ab | 39.74a-c | 73.49ab |
| | SP4 | 3.28b | 12.93 | 14.95 | 18.93a-d | 24.23c-g | 45.90a | 76.42ab |
| **LSD ($p$≤0.05)** | | 4.97 | 9.23 | 18.74 | 7.74 | 18.01 | 11.87 | 20.27 |
| | | ns | ns | ns | | | | |

**Table 3.** Effect of intra-row configuration, compost and nitrogen fertilizer and their interactions on stem diameter, chlorophyll content and ear height of popcorn.

*LSD = Least significant difference at p<0.05, SP1 = 15 cm × 15 cm; SP2 = 20 cm × 20 cm; SP3 = 25 cm × 20 cm; SP4 = 30 cm × 30 cm, Veg. – vegetative; Tasl. = tasseling and Mat. = physiological maturity. Values with different letters are not significantly different at p≤0.05 using LSD, ns = not significant.*


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| | | Weight | | | | | | Ear number | Harvest index |
|---|---|---|---|---|---|---|---|---|---|
| | | Ear/plant (g) | Ear/ plot (kg) | Cob (g) | 1000 seeds (g) | Grain Yield (t/ha) | Biomass (g) | | |
| **Intra spacing** | | | | | | | | | |
| **15 cm × 15 cm** | | 131.85b | 1.97 | 38.96 | 1485.31b | 5.31ab | 114.26bc | 1.36c | 0.34 |
| **20 cm × 20 cm** | | 159.11ab | 2.81 | 47.23 | 1537.54ab | 5.80a | 103.49c | 1.58b | 0.54 |
| **25 cm × 25 cm** | | 178.81a | 2.32 | 49.19 | 1616.55ab | 4.97ab | 160.63a | 1.78ab | 0.56 |
| **30 cm × 30 cm** | | 180.41a | 1.89 | 50.43 | 1683.01a | 4.30b | 140.21ab | 1.85a | 0.44 |
| **LSD (p≤0.05)** | | 28.85 | 1.28 | 14.12 | 1.52 | 1.38 | 33.31 | 0.21 | 0.27 |
| | | | ns | ns | | | | ns | ns |
| **Amendments** | | | | | | | | | |
| **Control** | | 148.20b | 1.30ab | 41.14 | 1515.58ab | 4.53 | 116.48ab | 1.52b | 0.46 |
| **4 t/ha compost** | | 148.31b | 1.57ab | 51.20 | 1632.06a | 4.95 | 122.39ab | 1.54b | 0.48 |
| **8 t/ha compost** | | 185.18a | 1.82a | 51.02 | 1695.54a | 5.14 | 146.95a | 1.73ab | 0.40 |
| **90 kg NPK** | | 195.46a | 1.39ab | 46.85 | 1537.57ab | 6.12 | 103.95b | 1.60ab | 0.58 |
| **180 kg NPK** | | 149.31b | 1.02b | 38.45 | 1421.81bc | 4.78 | 137.39ab | 1.85a | 0.34 |
| **LSD (p≤0.05)** | | 35.34 | 0.60 | 17.30 | 186.66 | 1.69 | 40.79 | 0.26 | 0.33 |
| | | | | ns | | ns | | | ns |
| **Amendments** | | | | | | | | | |
| **Control** | SP1 | 121.60cd | 1.03ab | 32.02 | 1379.70b-d | 3.28b | 97.25c-f | 1.08f | 0.32ab |
| | SP2 | 146.33a-d | 1.67ab | 38.16 | 1486.30a-d | 5.39ab | 107.74b-f | 1.33d-f | 0.54ab |
| | SP3 | 153.87a-d | 1.26ab | 52.05 | 1611.10a-d | 5.00ab | 107.33b-f | 1.50b-f | 0.45ab |
| | SP4 | 170.44a-d | 1.22ab | 46.23 | 1585.30a-d | 3.39b | 156.04a-e | 1.75a-e | 0.43ab |
| | | | | | | | | | |
| **4 t/ha compost** | SP1 | 122.36cd | 1.84ab | 42.86 | 1473.20a-d | 5.27ab | 102.70b-f | 1.42c-f | 0.42ab |


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| | | Weight | | | | | | Ear number | Harvest index |
|---|---|---|---|---|---|---|---|---|---|
| | | Ear/plant (g) | Ear/ plot (kg) | Cob (g) | 1000 seeds (g) | Grain Yield (t/ha) | Biomass (g) | | |
| | SP2 | 144.92a-d | 1.57ab | 56.55 | 1607.90a-d | 4.16b | 90.95e-f | 1.50b-f | 0.53ab |
| | SP3 | 148.03a-d | 1.61ab | 52.24 | 1699.10a-c | 4.93ab | 176.98a-c | 1.42c-f | 0.57ab |
| | SP4 | 177.94a-d | 1.29ab | 53.16 | 1748.10a | 3.76b | 118.92b-f | 1.83a-d | 0.41ab |
| | | | | | | | | | |
| 8 t/ha compost | SP1 | 166.82a-d | 1.60ab | 45.69 | 1702.50a-c | 4.48b | 165.39a-e | 1.25ef | 0.34ab |
| | SP2 | 211.90a | 2.23a | 52.48 | 1742.70ab | 5.94ab | 104.16b-f | 1.58a-f | 0.43ab |
| | SP3 | 190.72a-c | 2.05a | 54.48 | 1638.30a-d | 5.99ab | 168.53a-d | 1.92a-c | 0.62ab |
| | SP4 | 171.29a-d | 1.39ab | 51.41 | 1698.80a-c | 4.15b | 149.72a-f | 1.67a-e | 0.57ab |
| | | | | | | | | | |
| 90 kg N/ha (NPK) | SP1 | 135.94b-d | 1.56ab | 39.28 | 1514.10a-d | 6.51ab | 98.74c-f | 1.50b-f | 0.34ab |
| | SP2 | 155.39a-d | 1.47ab | 45.00 | 1428.80a-d | 8.18a | 99.96b-f | 1.42c-f | 0.91a |
| | SP3 | 173.14a-d | 1.36ab | 52.52 | 1686.00a-c | 4.72b | 118.15b-f | 2.00ab | 0.60ab |
| | SP4 | 197.36ab | 1.17ab | 50.60 | 1665.50a-d | 5.09ab | 98.94c-f | 2.00ab | 0.48ab |
| | | | | | | | | | |
| 180 kg N/ha (NPK) | SP1 | 115.34d | 1.27ab | 34.61 | 1322.60dc | 6.32ab | 152.09a-e | 1.50b-f | 0.18b |
| | SP2 | 149.23a-d | 1.04ab | 40.82 | 1284.60d | 4.56ab | 84.94ef | 1.92a-c | 0.30ab |
| | SP3 | 164.46a-d | 0.64b | 31.71 | 1450.70a-d | 3.73b | 178.33a | 2.08a | 0.62ab |
| | SP4 | 168.17a-d | 1.14ab | 46.66 | 1629.40a-d | 4.51b | 136.39a-f | 1.92a-c | 0.32ab |
| LSD (p≤0.05) | | 73.67 | 1.24 | 36.69 | 385.58 | 3.41 | 81.82 | 0.52 | 0.70 |
| | | | ns | ns | | | | | |

**Table 4.** Effect of intra-row spacing, compost and nitrogen fertilizers and their interactions on yield and yield components of popcorn.


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LSD = Least significant difference at $p<0.05$, SP1 = 15 cm × 15 cm; SP2 = 20 cm × 20 cm; SP3 = 25 cm × 20 cm; SP4 = 30 cm × 30 cm, Veg. – vegetative; Tasl. = tasseling and Mat. = physiological maturity. Values with different letters are not significantly different at $p\leq0.05$ using LSD, ns = not significant.

## 4. Discussion

The poor leaf formation under narrow intra-spacing infers that closer spacing could affect leaf formation negatively. Bernhard and Below[44] have also reported similar observations in *Zea mays.* The results obtained in this study are, however, not in consonance with that of Moosavi et al.[45] on forage corn in Iran. The better performance observed under wide intra-row spacing implies the absence of competition for basic crop growth resources, particularly nutrients. Widdicombe and Thelen[46] and Murányi and Pepo[47] have also shown that the height of different maize hybrids was never affected by intra-row spacing. The height of popcorn was not adversely affected by plant configuration, which indicates that intra-row spacings may not play any important role in the tallness of popcorn plants. Nonetheless, closer spacing had been shown by Bernhard and Below[44] to improve the height of cereals like sweet corn by Williams II[48]. The observation in this trial is in consonance with that of Moosavi et al.[45] on corn.

The narrow spacing appeared adequate as it promoted the leaf area index better than other spacings. The leaf area index is a measure of leaf efficiency with respect to intercepting solar radiation per unit area of land. Under narrow spacing with a higher leaf area index, it would suffice to expect an improvement in photoassimilate production over treatments with wider spacing. The superior performance of popcorn with respect to leaf area index observed under narrow intra-row spacing is in consonance with the reports of the Board and Harville[49] and Widdicombe and Thelen[46] who suggest that rows with closer plant stands had a greater leaf area index compared with the optimal plantings in the short-season maize cultivar. Liu et al.[50] also reported that narrow planting configuration influenced light interception and radiation use efficiency in maize. However, the relatively poor performance in intra-row spacing beyond 15 cm × 15 cm could have meant a waste of important production inputs, especially fertilizer, a major input in highly weathered soil with huge monetary cost.

Plants configured in a narrow within-row spacing adversely affected the chlorophyll contents of popcorn. This perhaps could be adduced to a higher population per unit area, as intra-competition could impinge negatively on the concentration of chlorophyll produced. It appeared that chlorophyll synthesis improved with wider intra-row spacing than with narrow spacing. This could mean that wide spacing reduces intra-competition, which ultimately enhanced chlorophyll synthesis in popcorn. Our observation agrees with that of Golada et al.[51], who obtained the highest chlorophyll content (2.34 $mgg^{-1}$) in baby corn grown at wider spacing. Ear height is a parameter that showed a response to intra-row spacing, as it was affected by within-row plant spacing. This infers that ear height is a major parameter that could be negatively affected by intra-row spacing. The height of the ear has implications for calibrating harvesting machines; hence, the need to reassess the row width of corn is necessary for evolving optimal plant population density for popcorn. The better performance of the number of ears produced under wider within-plant spacing implies that a wider intra space will benefit ear development better than under narrow intra-spacing.

A fairly wide spacing promoted higher photoassimilate production better than narrow spacing, which explains why better grain yield was obtained at the medium spacing of 20 cm × 20 cm. Thus, popcorn appeared to be more efficient at partitioning assimilate into economic yield at wider widths than at somewhat close or narrow intra-spacing. A similar observation had been reported by Sheth et al.[52] on sweet potato yield.

It is clear from the trial that either organic or inorganic fertilizer has similar effects on the growth of popcorn; however, the quantity required to produce the expected response is very important. The comparative effect of organic and inorganic fertilizer on the performance of popcorn has been well documented in many arid environments, but there is scant information on such reports in South Africa. Our observations on improving the performance of popcorn with either organic or inorganic fertilizer agree with earlier findings of Laxminarayana et al.[53] on sweet potato and Dada et al.[54] *Amaranthus cruentus*.

The growth response of popcorn to different rates of soil amendments varies at different growth stages. For instance, the effects of either type of amendment did not show any observable variation at the early stage, possibly because the native nutrients were sufficient to support growth up to that point. It is also unlikely that popcorn is more efficient in fertilizer utilization than other corn genotypes. White et al. [55] have shown that popcorn does not demand high nutrients unlike other *Zea* species. This could possibly explain the negligible effect of the supplied soil amendments during the early growth stage. This presupposes that previous fertilization history, crop requirements, and other factors such as soil inherent characteristics may influence the amount of fertilizer needed by certain crops across different growing phases[56]. The diameter of popcorn stems was similar irrespective of variation in fertilizer application. This is in line with different observations by Sener et al.[57] on corn and Gözübenli[58] on popcorn. The increase in the concentration of chlorophyll with increases in rates of organic or inorganic fertilizers suggests that adequate synthesis of chlorophyll in plants could be linked to the availability of sufficient mineral nutrients, especially nitrogen. A similar observation was recorded in the number of ears produced per plant. This implies that assimilate partitioning of photosynthate into economic yield may be linked to adequate chlorophyll synthesis by crops. Similar results were obtained by Sener et al.[57] and Meena et al.[56] on maize and popcorn, respectively.

The positive response of popcorn to mineral and organic fertilizers could be linked to the mineral nutrient constituents of the applied fertilizers. The comparable positive influence of 8 t/ha compost or 90 kg N/ha inorganic soil amendments on components of yield, such as the number of ears and harvest index, proposes that either rate was adequate for popcorn cultivation in dryland environments. The compost had superfluous essential mineral nutrients comparable with those supplied by inorganic NPK 20-7-3 fertilizer. It is equally possible that the compost was excellently mineralized, thereby making the minerals available for uptake by the crop for growth and yield. Pérez-Lomas et al.[59] and Vargas-García and Suárez-Estrella[60] have reported similar effects of sewage co-compost on agricultural fields and rice-wheat cropping systems.

The superior performance of popcorn plants in a well-fertilized field with closer plant stands suggests that when crops are grown in an adequately fertilized field, despite the high population density, leaf formation may not be adversely affected. This is similar to the view of Hamzei and Soltani[61] on rapeseed biomass accumulation. Conversely, popcorn plants appeared sensitive to spacing and nutrient availability, considering the fact that the crop grew taller under wide row spacing in an adequately manured field. This may imply that popcorn plants fared better under wide intra-row spacing, perhaps due to minimal intra-plant competition in contrast to closer spacing.

The leaf area index was affected by intra-row spacing and soil amendments, particularly at wider intra-row spacing and maximum fertilizer application. Wider row spacing under well-fertilized conditions had been shown to improve canopy formation and photosynthate production at the maize silking stage, according to Liu et al.[62]. The implication of the results is that popcorn responds to fertilizer application and spacing differently at each phenological phase.

Chlorophyll content of popcorn was affected by intra-spacing and fertilizer application, but this varied across the phenological phases. This shows that popcorn will synthesize chlorophyll content better under a wider intra-row spacing that is adequately fertilized. The same trend recorded for chlorophyll

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content was observed with the number of ears per plant. Popcorn tends to show better performance with much wider spacing in an adequately fertilized environment than with a narrower spacing, irrespective of fertilizer type, with regards to photoassimilate partitioning[24].

The interaction between intra-row spacing and fertilizer treatments influenced components of yield and the grain yield of popcorn significantly. This suggests that at much wider intra-spacing, popcorn requires minimal fertilizer to produce bigger grains. This implies that better partitioning of photosynthate into economic benefits may also be achieved with a lower fertilizer rate, but certainly not at wider intra-spacing. Hence, the need to equilibrate plant density with soil fertility management cannot be overemphasized. The observed results at the 90 kg N/ha rate and 20 cm × 20 cm plant spacing indicate a better combination that could promote popcorn yield in the region. The greater harvest index of close to a unit indicated that a higher percent of the biomass synthesized was converted to economic value, which makes this combination more appropriate for popcorn cultivation in semi-arid regions. It emphasizes that the crop may have used the applied amendments efficiently under medium intra-row competition to form economic yield. Sakariyawo et al.[63] have reported a high harvest index and nitrogen use efficiency in *Zea mays* fertilized with $CaC_2$ and NPK fertilizers in derived savannah ecology.

## 5. Conclusion

The performance of popcorn improved tremendously with the application of compost or NPK fertilizer. The growth and kernel yield response of the crop to different intra-row spacing varied across the vegetative, tasseling, and maturity stages. The damaging effect of poor within-row plant configuration may go unnoticed at the early stage of popcorn phenology, as shown in this study. It became clearer at the physiological maturity phase that intra-row spacing affected the performance of popcorn adversely. Yield and its components improved with the application of 8 t/ha of compost supplied to plots intra-spaced at 20 cm × 20 cm. In the same vein, the application of 90 kg N/ha using NPK 20-7-3 fertilizer enhanced the vegetative and reproductive development of popcorn sown at 20 cm × 20 cm intra-row spacing in the dryland of South Africa. Nevertheless, since organic fertilizer could supply balanced nutrients and promote an eco-friendly agroecosystem, applying compost is more preferred to mineral fertilizers for promoting increased popcorn production.

## Statements and Declarations

**Authors' contributions:** Oyeyemi A. Dada conceived the research idea, prepared the proposal, collected and analysed data, and wrote the manuscript. Funso R. Kutu hosted and supervised the activities of O. A. Dada, while Sydney Mavengahama assisted in field experimentation, design, and data analysis. All authors contributed equally and approved the final manuscript.

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**Data Availability:** The data sets used and/or analyzed during the current study are available from the corresponding author on request.

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**Conflicts of Interest:** We complied with standard ethical practices while conducting the trial. In the same vein, the authors declare that there is no conflict of interest relating to this study.

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