RESEARCH ARTICLE

Response of popcorn (*Zea mays* L. var *Everta*) to intra row spacing, compost and nitrogen fer ilizer in semi-arid region of South Africa

Oyeyemi A Dada[1*], Funso R Kutu [2], Sydney Mavengahama[1]

Dada OA, Kutu FR, Mavengahama S. Response of popcorn (*Zea mays* L. var *Everta*) to intra row spacing, compost and nitrogen fertilizer in semi-arid region of South Africa. AGBIR 2024;40(4):1268-1275

ABSTRACT

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 summer seasons of 2017/18 and 2018/19 at the North-West University (NWU) research farm, Mafikeng campus. The study investigated response of popcorn to different rates of compost and NPK 20-7-3 fertilizer and plant spacings in semi-arid region of South Africa. The trial consisted of twenty treatments laid out as a split plot in 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 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. Popcorn had highest number of leaves (12.75) in plots fertilized with 8 t/ha compost under SP_4, while tallest plant (205.64 cm) was recorded in plots intra spaced at SP_2 and fertilized with 8 t/ha compost.

Leaf area index was highest (5.1) in plots amended with 90 kg/ha NPK under SP_4. The chlorophyll content of popcorn in plots supplied 90 kg/ha NPK under SP_3 was significantly higher with 56.1% more than leaf chlorophyll from unfertilized plots under SP_1. Biomass (178.33 g/plant) and ear number (2.08) where highest in plots treated with 180 kg/ha NPK under SP_3. 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 field fertilized with 90 kg N/ha mineral fertilizer. Nevertheless, the provision of balanced nutrients from and the eco-friendliness of applying organic fertilizer favours the preference for the use of compost for promoting increased popcorn production.

Keywords: Popcorn growth; Plant spacing; Kernel yield; Compost; Mineral fertilizer

INTRODUCTION

Popcorn (*Zea mays* L. *Everta*) is an annual cereal crop of economic importance cultivated for its kernel that pops, puffs up or expands in size when slightly heated. This attribute distinguishes it from other varieties of corn. The popped kernel is consumed as snacks in many houses and recreational parks for its low carb and nutritional benefits. There has been tremendous growth in the popcorn industry around the world, particularly in the United States of America and South Africa where it is projected to increase by 0.7% above the current net worth of ZAR 174 million by 2020. Most popcorn industries in South Africa rely on imported kernel to complement the little harvested from about 2000 ha from local cultivation. The major constraint to popcorn production in South Africa is paucity of information on appropriate agronomic practices, perhaps because the crop is not native to the country. Most importantly, relevant information on its nutritional requirements and the appropriate density required per unit of land area for its cultivation is not well documented [1].

The value of popcorn in improving food and nutrition security cannot be over emphasized. Kumar SB and Rebello CJ, reported that it is an important snack that supplies high quality nutrients like fibers, low cholesterol, low carbohydrates and quality proteins. It is a whole grain that supplies essential minerals and very rich in antioxidants, aids digestion, enhances weight loss prevent diseases. Besides, it commands triple the market price of other maize cultigens. 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 cultivation of popcorn in South Africa is still limited to 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. An estimated 55,000 t/year was harvested on 10,000 ha and the crop was grown principally in Free State and Northern Cape regions. The annual popcorn produced in South Africa is approximately 1.8% of the total corn harvested on 3.1 million ha/annum. One of the major limiting constraints to popcorn cultivation in South Africa is inadequate information on agronomic characteristics of this crop. This is a common phenomenon in sub-Saharan agro ecosystem, particularly with popcorn [2].

Crops perform optimally under favourable environmental conditions such as adequate nutrition, moisture availability and appropriate spacing with negligible or minimal intra or inter competition. 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 crop all through the statutory phenological stages. This inadequacy may be as a result of soil characteristics or the depletion/removal of soil mineral nutrients by previous crops. Singh and Ryan and Badu-Apraku and Fakorede reported that in soil plant system, response of maize to the applied materials varies depending on several factors [3].

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. These views have been buttressed by Ghorbani, Koocheki on tomato, Matallana Gonzalez, Martinez-Tome on vegetables, Zhao, Ni on rice and Cihangir and Oktem 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 [4].

Generally, average fertilizer recommendation for growing corn in South Africa ranged from 55 to 180 kg N/ha application of farmyard manure for largescale corn production is rare in South Africa but few smallholders use organic manures like chicken or cattle manure to fertilize their arable fields. There is no or sketchy information on standard or recommended quantity of compost or farmyard manure for growing popcorn in South Africa. Information is scanty regarding response of popcorn to either compost or

[1]Department of Natural and Agricultural Sciences, North-West University, Mmabatho, South Africa

[2]Department of Agricultural Sciences, University of Mpumalanga, Mbombela, South Africa

Correspondence: Oyeyemi AD, Natural and Agricultural Sciences, North-West University, Mmabatho, South Africa, Email: oadada247@yahoo.com

Received: 17-Nov-2022, Manuscript No. AGBIR-22-80109; *Editor assigned:* 21-Nov-2022, PreQC No. AGBIR-22-80109 (PQ); *Reviewed:* 05-Dec-2022, QC No. AGBIR-22-80109; *Revised:* 20-Mar-2023, Manuscript No. AGBIR-22-80109 (R); *Published*: 27-Jul-2024, DOI: 10.35248/0970-1907.24.40(4):1268-1275

mineral fertilizer application in tropical semi-arid region. The need to evolve appropriate rate of organic or mineral fertilizer that would be adequate for growing popcorn in this region is very germane [5].

Uniformity of the crop in the field is premised on appropriate spacing which plays an important role in optimizing solar utilization efficiency 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 photosynthetic assimilation and partitioning negatively, according to Brodrick R and the lesser the intra or inter competition within crops, the better the photoassimilate that is partitioned into economic yield. According to Da J manipulation of spatial crop arrangement is a common agronomic practice engaged to improve physiological performance of crops [6].

Furthermore, the cultivable land is becoming marginal by the day owing to competitions from different fronts like proliferation of industries, infrastructural need and residential development. 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 grain from the process. There is dearth of information on the appropriate mineral fertilizer or compost rate as well as plant density that would be adequate for enhancing performance of popcorn with respect to growth and yield in dryland regions of South Africa. The hypothesis of this study was that grain yield of popcorn is affected by soil amendments and intra row spacing. Therefore, we investigated the influence of intra row spacing, compost and NPK 20-7-3 fertilizer rates on growth, kernel yield, yield components and biomass accumulation by *Zea mays* L. *Everta* in tropical semi-arid region of South Africa [7].

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 2017/2018 and 2018/2019 summer planting seasons. The farm is located in savanna semi-arid climate, in the North West Province of South Africa. The province receives approximately 350 mm-400 mm rainfall annually in winter and averages of 250 mm-300 mm during summer season, with the average temperature of 18°C-22°C in winter and 22°C-37°C during summer, while the relative humidity ranged from 13.5%-81%. Both pre-trial soil samples collected at a depth of 0 cm-30 cm and compost were analysed at the department of crop science laboratory using 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: H2O, 1:1) of the compost and soil samples were determined using a pH meter (Cole Parmer Digi Sense model no. 5938-00), while the percent particle size distribution analyses was determined using modified Bouyoucos methods described by Beretta AN. The soil was clay loam with pH of 6.8; total N of 6.96 mg/kg; Bray-1 P was 80.0 mg/kg and K was 235.0 mg/kg.

Treatments and experimental design

The study was a 4 x 5 factorial comprising four intra row spacings and five fertilizer treatments planted during 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) with three replications. The main plot contained fertilizer treatment, while the different within row spacings was 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 at 70 cm apart. The five fertilizer treatments consisted of 90 kg N/ha and 180 kg N/ha rates using NPK 20-7-3, while the compost was applied at the rates of 4 t/ha and 8 t/ha with unfertilized plot (F_5) 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. 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. The applied rates of either soil amendment was based on the range of quantities recommended for arable crops [8].

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 at two weeks before sowing. Compost was applied two weeks before sowing to enhance mineralization and ease mineral uptake. Seed of mid altitude popcorn obtained from International Institute of Tropical Agriculture (IITA, Nigeria) was sown in December, 2017 for the first trial and December, 2018 for the repeat experiment. One seed was sown per hole of 3 cm depth. The field was kept weed free throughout the experimental period through manual hand weeding with Dutch hoe. The trial was rain fed but supplementary irrigation was deployed when the soil moisture level was low, especially at the tasseling and silking stage using visual soil examination and evaluation methods Emmet-Booth J.

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. Leaf Area Index (LAI) was evaluated following the procedure of Fageria NK and Berdjour A as LAI=(P × L × A)/(GA)

Where,

LAI=Leaf Area Idex

P=Plant population/ground area (ha)

L=Number of fully expanded green leave/plant

A=Single leaf area (cm^2)

GA=Ground area (m^2)

The stem diameter was measured with a vernier caliper (Master craft GS5071522). Chlorophyll content was collected *in situ* from four fully expanded leaves per plant with 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 Z and Feyisa H. The harvest index was evaluated as:

$$\text{Harvest index} = \frac{\text{Mass of economic yield (g)}}{\text{Total biomass (g)}}$$

The kernel yield was determined from the 1.4 m^2 area at harvest maturity. Grain yield was evaluated by harvesting ears from 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.

Statistical analysis

The data for the two planting seasons were pooled together according to Gomez KA and AA Gomez and analysed using Analysis of Variance (ANOVA) of the General Linear Model (GLM) of Statistical Analysis System (SAS, version 6.0) according to O Rourke N. Different means were separated using Least Significant Difference (LSD) test at $p \leq 0.05$ following the methods of Gomez KA.

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. The rates of fertilizer applied had significant ($p<0.05$) effect on height, leaf area index, chlorophyll content and ear height as shown in Table 1.

Interaction between soil amendments and rates of amendment affected number of leaves, leaf area index, chlorophyll content and ear number statistically.

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

Mean squares								
Source of variation	**Df**	**NL**	**PHT**	**LAI**	**DS**	**CHL**	**EH**	**NE**
Spacing (A)	3	51.67	3892.31	1.94	20.58	711.5	470.65	3.43
Amendment (B)	4	214.71	3270.4	0.92	75.47	1641.85	2219.19	0.77
A x B	12	7.29	1872.88	2.62	26.46	658.25	649.67	2.13
CV (%)		17.86	20.5	31.95	94.17	43.8	30.74	39.79
Mean		11.48	184.8	69.35	14.19	33.71	83.82	1.64
	Df	**Ear/plant**	**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	272590.3	42.7	24062.58	0.12
Amendment (B)	4	5275.51	1.85	639.55	237613.2	36.03	8103.74	0.13
A x B	12	41531.1	4.63	684.16	55113.08	7.03	4901.38	0.09
CV (%)		38.55	72.16	65.2	20.68	58.13	55.08	122.15
Mean		160.55	1.45	46.46	1580.6	5.1	129.7	0.47

Note: Significant at $p \le 0.05$; 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 spacings

Different intra row spacings did not affect leaf formation and height of popcorn plant significantly ($p>0.05$) both at vegetative (V6) and tasseling (VT/R5) growth stages. However, these growth parameters were significantly ($p \le 0.05$) affected by intra row spacing at physiological maturity stage (R6). The number of leaves produced at narrow spacing of 15 cm × 15 cm was significantly lower than number of leaves recorded in plants other spacings (Figure 1A). On the other hand, the height of the crop was not affected by intra row spacing at V6 and VT/R5 stages. Nevert heless, at R6, height of the crop was significantly taller at 20 cm × 20 cm spacing but not significantly taller than plants spaced at 25 cm × 25 cm or 30 cm × 30 cm as indicated in Figure 1B. Leaf Area Index (LAI) was statistically affected by intra row spacing all through the growth stages (Figure 1C). The LAI was significantly higher under narrow intra spacing (15 cm × 15 cm) than other intra row spacings. Widest intra row spacing (30 cm × 30 cm) had the lowest LAI [11].

The diameter of popcorn stem was not affected by different intra row spacings at 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 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 vegetative phase. Lowest chlorophyll content was, however recorded in plants intra spaced at 15 cm × 15 cm at tasseling and maturity phases (Figure 1E). The ear height was significantly affected by intra row spacing as plant spaced at 20 cm × 20 cm recorded tallest ear height of 87.61 cm relative to other spacing treatments (Figure 1F).

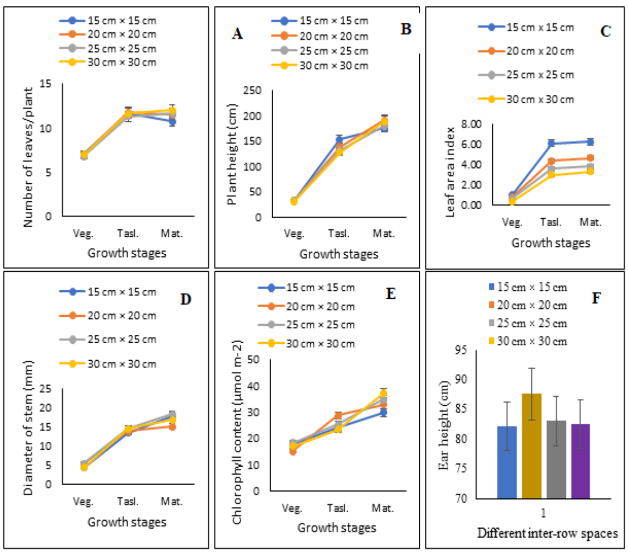

Figure 1: Effect of intra row spacing on growth of popcorn.

Growth response of popcorn to different rates of soil amendments

Different rates of soil amendments had significant influence on growth of popcorn. Effects of the two types of soil amendments on all measured growth parameters except stem diameter was 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 tasseling and physiological maturity stages in plots supplied with 8 t/ha compost, but this was not statistically different from 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 vegetative stage in plots fertilized with 90 kg N/ha (NPK 20-7-3) compared to the unfertilized plot (Figure 2B). At tasseling stage, the height was not influenced by soil amendments but at physiological maturity, the crop had tallest plants in plots supplied with 8 t/ha compost over and above other rates of either organic or inorganic fertilizers. At early growth stage, soil amendments had no effect on this 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 LAI recorded in field fertilized with 4 t/ha compost at tasseling. At physiological maturity, LAI was highest in plot supplied with mineral fertilizer at the rate of 90 kg N/ha relative to 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 plant. Popcorn plants had lowest chlorophyll concentration in unfertilized field which was statistically similar to concentration obtained from field fertilized with 4 t/ha compost. There was no significant difference in chlorophyll concentration of popcorn grown in plots supplied with 8 t/ha compost, 90 or 180 kg N/ha (Figure 2E). The tallest ear height (91.66 cm) was recorded in field fertilized with 8 t/ha compost which was not significantly different from ear height recorded in field amended with 90 kg N/ha (Figure 2F).

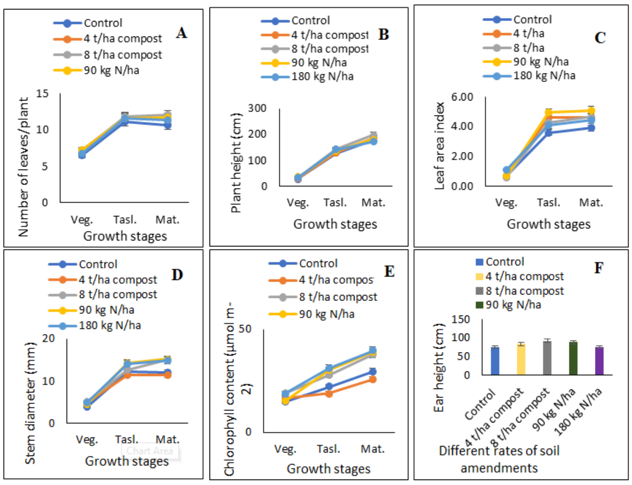

Figure 2: Effect of different rates of soil amendments on growth of popcorn.

Effects of inter row spacing and soil amendment rates on growth of popcorn

The effects of interaction between intra row spacing and soil amendments showed that application of 90 kg N/ha enhanced number of leaves produced by popcorn sown at 15 cm × 15 cm at vegetative and tasseling stages. Although, this was not significantly higher than number of leaves observed in the other treatments; except in the unfertilized plots with narrower spacing, where 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 compost and intra spaced at 30 cm × 30 cm.

The crop had tallest plant in plots supplied with 8 t/ha and intra spaced at 20 cm × 20 cm both at tasseling and maturity. Shortest plants were recorded under narrower spacing of 15 cm × 15 cm in unamended field (Table 2). The effect of soil amendments and intra row spacings on LAI varies across the three phenological phases. At vegetative stage, plots fertilized with 180 kg N/ha and intra spaced at 20 cm × 20 cm had highest LAI of 2.08. At tasseling stage, narrow intra spacing (15 cm × 15 cm) and lower compost rate (4 t/ha) promoted highest LAI. At maturity, plots fertilized with 180 kg N/ha in plots intra spaced at 15 cm × 15 cm had LAI of 7.04 which was significantly higher than LAI (2.76) obtained in unfertilized plots under 25 cm × 25 cm intra-row spacing [12].

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 compost had highest chlorophyll content (25.48 μmol m^{-2} and 42.92 μmol m^{-2}) at vegetative and tasseling phases, respectively. At maturity however, popcorn had 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 statistically similar to chlorophyll content recorded in plant intra-spaced at 30 cm × 30 cm and fertilized with 180 kg N/ha. Plant had 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 highest ear height (93.98 cm) which was statistically similar to ear height recorded in plots intra spaced at 25 cm × 25 cm or 20 cm × 20 cm and amended with 8 t/ha.

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

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	6.50^{bc}	11.00^{dc}	10.33^{de}	32.71^{c}	107.64^{b}	171.30^{c-e}	1.07^{ab}	5.13^{c-f}	4.63^{d-h}
	SP2	6.08^{c}	11.00^{dc}	11.00^{b-e}	32.71^{c}	120.07^{b}	186.46^{a-d}	0.45^{b}	3.17^{gh}	3.22^{i-k}
	SP3	6.42^{bc}	10.92^{d}	10.17^{e}	33.77^{c}	119.23^{b}	174.48^{b-e}	0.68^{b}	2.86^{gh}	2.76^{k}
	SP4	6.67^{abc}	11.17^{b-d}	10.83^{b-e}	33.32^{c}	114.26^{b}	182.33^{a-e}	0.50^{b}	3.27^{f-h}	3.66^{g-k}
4 t/ha compost	SP1	7.58^{a}	11.67^{a-d}	10.92^{b-e}	38.61^{a-c}	129.36^{b}	181.08^{a-e}	1.05^{ab}	7.62^{a}	6.68ab
	SP2	7.08^{abc}	11.50^{a-d}	11.08^{e}	41.23^{a-c}	133.91^{b}	187.84^{a-d}	0.52^{b}	4.45^{c-g}	5.65^{b-e}
	SP3	6.92^{abc}	12.00^{a-d}	11.92^{a-d}	36.03^{bc}	131.33^{b}	185.76^{a-d}	0.92^{ab}	3.53 e-h	3.70 g-k
	SP4	7.17^{ab}	11.83^{a-d}	12.00^{a-c}	34.95^{bc}	130.21^{b}	195.87^{a-c}	0.33^{b}	2.33 h	3.12 i-k
8 t/ha compost	SP1	7.33^{ab}	11.58^{a-d}	11.08^{b-e}	33.77^{a-c}	144.23^{b}	188.18^{a-d}	0.87^{ab}	5.31 b-e	5.87 a-d
	SP2	7.25^{ab}	12.00^{a-d}	11.83^{a-e}	35.71^{bc}	153.06^{a}	205.64^{a}	0.64^{b}	5.32 b-e	5.34 c-f
	SP3	7.00^{abc}	11.58^{a-d}	12.33^{ab}	33.32^{a-c}	137.44^{b}	202.21^{ab}	0.69^{b}	4.10 d-h	4.62 d-h
	SP4	7.08^{abc}	12.17^{a-d}	12.75^{a}	34.37^{a-c}	137.92^{b}	190.68^{a-c}	0.40^{b}	2.96 gh	3.55 g-k

90 kg N/ha (NPK)	SP1	7.67^{a}	12.50^{a}	11.50^{a-e}	36.03^{a-c}	149.22^{b}	182.27^{a-e}	0.98^{ab}	7.03^{ab}	6.50^{a-c}
	SP2	7.33^{ab}	11.67^{a-d}	11.08^{b-e}	38.61^{ab}	147.88b	193.58^{a-c}	0.74^{b}	5.24^{b-e}	6.04^{a-c}
	SP3	6.67^{abc}	11.00^{dc}	12.42^{ab}	35.26^{bc}	110.85^{b}	157.78^{de}	0.46^{b}	4.36^{c-g}	4.70^{d-g}
	SP4	7.17^{ab}	11.17^{b-d}	11.83^{a-d}	35.71^{a-c}	133.78^{b}	193.75^{a-c}	0.67^{b}	3.23^{gh}	3.17^{i-k}
180 kg N/ha (NPK)	SP1	6.33^{bc}	11.67^{a-d}	10.08^{e}	34.95^{a-c}	140.62^{b}	152.01^{e}	1.16^{ab}	5.60^{b-d}	7.04^{a}
	SP2	7.17^{ab}	12.00^{a-d}	12.25^{ab}	34.38^{a-c}	145.10^{b}	188.16^{a-d}	2.08^{a}	4.41^{c-g}	4.32^{f-j}
	SP3	7.08^{abc}	11.42^{a-d}	11.00^{b-e}	41.23^{a}	139.32^{b}	170.37^{c-e}	0.95^{ab}	3.59^{e-h}	3.41^{g-k}
	SP4	6.67^{abc}	11.25^{a-d}	12.08^{a-c}	34.37^{c}	139.83^{b}	185.32^{a-d}	0.26^{b}	2.70^{gh}	3.03^{jk}
LSD ($p \leq 0.05$)		1.07	1.27	1.65	8.98	71.79	30.46	1.35	0.78	1.32

Note: 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 popcorn to different inter row spacing

Mass of ear per plot, mass of cob and harvest index was not significantly affected by intra row spacing. Nevertheless, highest ear mass per plant and 1000 seed mass were obtained in plots intra spaced at 30 cm × 30 cm and this was significantly similar to ear or 1000 seed mass obtained in plot intra spaced at either 20 cm × 20 cm or 25 cm × 25 cm.

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

Yield response of popcorn to different rates of soil amendments

It was observed that highest ear mass (195 g) per plant was obtained in plots supplied with 90 kg N/ha. Similarly, plots fertilized with 8 t/ha compost produced ear with 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 different from 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 highest grain yield (6.12 t/ha) was obtained in plots amended with 90 kg N/ha. Nevertheless, lowest kernel yield was obtained in the unfertilized field. Number of ears per plant was significant and higher in field amended with 180 kg N/ha than number of ears recorded in plots amended with 4 t/ha compost and unamended plots [13].

Effect of interrow spacing and soil amendment rates on yield components of popcorn

Interactions between intra row spacing and soil amendments showed that ear mass and ear mass (2.23 kg/plot) were highest in plots fertilized with 8 t/ha compost and intra spaced at 20 cm × 20 cm. The results indicated that 1000 seeds mass was highest in plants intra spaced at 30 cm × 30 cm and amended with 4 t/ha 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). Highest biomass and number of ears were highest in field intra spaced at 25 cm × 25 cm and fertilized with 180 kg N/ha.

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

		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	3.11^{b}	10.71	10.66	13.13^{d}	24.23^{g}	20.66^{f}	72.67^{ab}
	SP2	4.49^{ab}	11.8	11.02	16.84^{b-d}	28.15^{d-g}	30.68^{b-f}	81.40^{ab}
	SP3	4.35^{ab}	11.66	11.94	12.33^{d}	36.14^{d-g}	29.46^{c-f}	70.76^{b}
	SP4	3.57^{b}	13.15	14.3	15.23^{cd}	24.69^{c-g}	33.47^{b-d}	76.84^{ab}
4 t/ha compost	SP1	4.91^{ab}	12.99	13.13	15.52^{cd}	24.69^{fg}	23.73^{d-f}	84.50^{ab}
	SP2	3.65^{b}	11.33	14.28	14.93^{cd}	28.02^{b-f}	28.97^{c-f}	83.91^{ab}
	SP3	5.88^{ab}	8.38	12.86	17.82^{a-d}	30.35^{d-g}	20.20^{f}	81.89^{ab}
	SP4	5.02^{ab}	12.73	13.67	18.36^{a-d}	26.01^{fg}	29.56^{c-f}	84.37^{ab}
8 t/ha compost	SP1	3.91^{ab}	13.06	15.32	21.52^{a-c}	33.72^{d-g}	37.43^{a-c}	90.08^{ab}
	SP2	7.77^{ab}	12.84	14.55	13.41^{d}	42.92^{a}	37.30^{a-c}	93.85^{a}
	SP3	4.74^{ab}	11.88	15.78	25.48^{a}	29.03^{d-g}	39.85^{a-c}	93.88^{a}
	SP4	4.07ab	12.95	15	16.42^{cd}	26.01^{b-g}	36.81^{a-c}	88.83^{ab}
90 kg N/ha (NPK)	SP1	3.79^{ab}	13.13	14.61	16.00^{cd}	30.35^{b-d}	33.66^{b-d}	86.48^{ab}
	SP2	4.28^{ab}	14.61	13.96	14.06^{cd}	33.72^{a-c}	36.05^{a-c}	93.98^{a}
	SP3	4.22^{ab}	15.17	16.57	14.86^{cd}	29.03^{b-e}	47.03^{a}	93.90^{a}
	SP4	5.65^{ab}	14.37	15.68	15.30^{cd}	28.15^{b-f}	39.15^{a-c}	79.56^{ab}

180 kg N/ha (NPK)	SP1	4.66^{ab}	13.94	13.7	16.21^{cd}	36.14^{ab}	42.49^{ab}	71.47^{b}
	SP2	4.08^{ab}	13.88	14.56	18.86$^{a\text{-}d}$	28.02$^{b\text{-}f}$	30.20$^{c\text{-}f}$	82.46^{ab}
	SP3	7.77^{ab}	15.54	16.17	21.43$^{a\text{-}c}$	36.14^{ab}	39.74$^{a\text{-}c}$	73.49^{ab}
	SP4	3.28^{b}	12.93	14.95	18.93$^{a\text{-}d}$	24.23$^{c\text{-}g}$	45.90^{a}	76.42^{ab}
LSD ($p \leq 0.05$)		4.97	9.23	18.74	7.74	18.01	11.87	20.27
		ns	ns	ns				

Note: 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.

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

		Weight							
		Ear/plant (g)	**Ear/plot (kg)**	**Cob (g)**	**1000 seeds (g)**	**Grain yield (t/ha)**	**Biomass (g)**	**Ear number**	**Harvest index**
Intra spacing									
15 cm × 15 cm		131.85^{b}	1.97	38.96	1485.31^{b}	5.31^{ab}	114.26^{bc}	1.36^{c}	0.34
20 cm × 20 cm		159.11^{ab}	2.81	47.23	1537.54^{ab}	5.80^{a}	103.49^{c}	1.58^{b}	0.54
25 cm × 25 cm		178.81^{a}	2.32	49.19	1616.55^{ab}	4.97^{ab}	160.63^{a}	1.78^{ab}	0.56
30 cm × 30 cm		180.41^{a}	1.89	50.43	1683.01^{a}	4.30^{b}	140.21^{ab}	1.85^{a}	0.44
LSD ($p \leq 0.05$)		28.85	1.28	14.12	1.52	1.38	33.31	0.21	0.27
			ns	ns				ns	ns
Amendments									
Control		148.20^{b}	1.30 ab	41.14	1515.58^{ab}	4.53	116.48^{ab}	1.52^{b}	0.46
4 t/ha compost		148.31^{b}	1.57 ab	51.20	1632.06^{a}	4.95	122.39^{ab}	1.54^{b}	0.48
8 t/ha compost		185.18^{a}	1.82 a	51.02	1695.54^{a}	5.14	146.95^{a}	1.73^{ab}	0.40
90 kg NPK		195.46^{a}	1.39 ab	46.85	1537.57^{ab}	6.12	103.95^{b}	1.60^{ab}	0.58
180 kg NPK		149.31^{b}	1.02 b	38.45	1421.81^{bc}	4.78	137.39^{ab}	1.85^{a}	0.34
LSD ($p \leq 0.05$)		35.34	0.60	17.30	186.66	1.69	40.79	0.26	0.33
				ns		ns			ns
Amendments									
Control	SP1	121.60^{cd}	1.03^{ab}	32.02	1379.70$^{b\text{-}d}$	3.28^{b}	97.25$^{c\text{-}f}$	1.08^{f}	0.32^{ab}
	SP2	146.33$^{a\text{-}d}$	1.67^{ab}	38.16	1486.30$^{a\text{-}d}$	5.39^{ab}	107.7 4$^{b\text{-}f}$	1.33$^{d\text{-}f}$	0.54^{ab}
	SP3	153.87$^{a\text{-}d}$	1.26^{ab}	52.05	1611.10$^{a\text{-}d}$	5.00^{ab}	107.33$^{b\text{-}f}$	1.50$^{b\text{-}f}$	0.45^{ab}
	SP4	170.44$^{a\text{-}d}$	1.22^{ab}	46.23	1585.30$^{a\text{-}d}$	3.39^{b}	156.04$^{a\text{-}e}$	1.75$^{a\text{-}e}$	0.43^{ab}
4 t/ha compost	SP1	122.36^{cd}	1.84^{ab}	42.86	1473.20$^{a\text{-}d}$	5.27^{ab}	102.70$^{b\text{-}f}$	1.42$^{c\text{-}f}$	0.42^{ab}
	SP2	144.92$^{a\text{-}d}$	1.57^{ab}	56.55	1607.90$^{a\text{-}d}$	4.16^{b}	90.95$^{e\text{-}f}$	1.50$^{b\text{-}f}$	0.53^{ab}
	SP3	148.03$^{a\text{-}d}$	1.61^{ab}	52.24	1699.10$^{a\text{-}c}$	4.93^{ab}	176.98$^{a\text{-}c}$	1.42$^{c\text{-}f}$	0.57^{ab}
	SP4	177.94$^{a\text{-}d}$	1.29^{ab}	53.16	1748.10^{a}	3.76^{b}	118.92$^{b\text{-}f}$	1.83$^{a\text{-}d}$	0.41^{ab}
8 t/ha compost	SP1	166.82$^{a\text{-}d}$	1.60^{ab}	45.69	1702.50$^{a\text{-}c}$	4.48^{b}	165.39$^{a\text{-}e}$	1.25^{ef}	0.34^{ab}
	SP2	211.90^{a}	2.23^{a}	52.48	1742.70^{ab}	5.94^{ab}	104.16$^{b\text{-}f}$	1.58$^{a\text{-}f}$	0.43^{ab}
	SP3	190.72$^{a\text{-}c}$	2.05^{a}	54.48	1638.30$^{a\text{-}d}$	5.99^{ab}	168.53$^{a\text{-}d}$	1.92$^{a\text{-}c}$	0.62^{ab}
	SP4	171.29$^{a\text{-}d}$	1.39^{ab}	51.41	1698.80$^{a\text{-}c}$	4.15^{b}	149.72$^{a\text{-}f}$	1.67$^{a\text{-}e}$	0.57^{ab}
90 kg N/ha (NPK)	SP1	135.94$^{b\text{-}d}$	1.56^{ab}	39.28	1514.10$^{a\text{-}d}$	6.51^{ab}	98.74$^{c\text{-}f}$	1.50$^{b\text{-}f}$	0.34^{ab}
	SP2	155.39$^{a\text{-}d}$	1.47^{ab}	45.00	1428.80$^{a\text{-}d}$	8.18a	99.96$^{b\text{-}f}$	1.42$^{c\text{-}f}$	0.91^{a}
	SP3	173.14$^{a\text{-}d}$	1.36^{ab}	52.52	1686.00$^{a\text{-}c}$	4.72^{b}	118.15$^{b\text{-}f}$	2.00^{ab}	0.60^{ab}
	SP4	197.36^{ab}	1.17^{ab}	50.60	1665.50$^{a\text{-}d}$	5.09^{ab}	98.94$^{c\text{-}f}$	2.00^{ab}	0.48^{ab}
180 kg N/ha (NPK)	SP1	115.3 4^{d}	1.27^{ab}	34.61	1322.60^{dc}	6.32^{ab}	152.09$^{a\text{-}e}$	1.50$^{b\text{-}f}$	0.18^{b}
	SP2	149.23$^{a\text{-}d}$	1.04^{ab}	40.82	1284.60^{d}	4.56^{ab}	84.94^{ef}	1.92$^{a\text{-}c}$	0.30^{ab}
	SP3	164.46$^{a\text{-}d}$	0.64^{b}	31.71	1450.70$^{a\text{-}d}$	3.73^{b}	178.33^{a}	2.08^{a}	0.62^{ab}
	SP4	168.17$^{a\text{-}d}$	1.14^{ab}	46.66	1629.40$^{a\text{-}d}$	4.51^{b}	136.39$^{a\text{-}f}$	1.92$^{a\text{-}c}$	0.32^{ab}
LSD ($p \leq 0.05$)		73.67	1.24	36.69	385.58	3.41	81.82	0.52	0.70
			ns	ns					

Note: 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.

DISCUSSION

The poor leaf formation under narrow intra spacing infers that closer spacing could affect leaf formation negatively. Bernhard has also reported similar observations in *Zea mays*. The results obtained in this study is however, not in consonance with that of Moosavi S on forage corn in Iran. The better performance observed under wide intra row spacing implies absence of competition for basic crop growth resources particularly nutrients. Muranyi E and Pepo P, have also shown that height of different maize hybrids was never affected by intra row spacing. Height of popcorn was not adversely affected by within row spacing, which indicates that intra row spacings may not play any important role in tallness or shortness of popcorn plant. Nonetheless, closer spacing had been shown by Bernhard BJ to improve height of cereal as well as sweet corn by Williams MM. The observation in this trial is in consonance with that of Moosavi S on corn.

The narrow spacing appeared adequate as it promoted leaf area index better than other spacings. 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 photo assimilate 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 J 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 also reported that narrow planting pattern 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.

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

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

It is clear from the trial that either of the organic or inorganic fertilizer has similar effects on growth of popcorn, but the quantity required to produce the expected response is very important. The comparative effect of organic and inorganic fertilizer on performance of popcorn has been well documented in many arid environments, but there is scanty information of such reports in South Africa. Our observations on improving performance of popcorn with either organic or inorganic fertilizer agree with earlier findings of Laxminarayana K on sweet potato and corn.

The growth response of popcorn to different rates of soil amendments varies at different growth stages. For instance, the effects of either type of amendments did not show any observable variation at the early stage, possibly because the native nutrients were sufficient to support the growth up to that point. It is also unlikely that popcorn is more efficient in fertilizer utilization better than other corn genotypes. White, et al. has 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. The diameter of popcorn stem was similar irrespective of variation in fertilizer application. This is in line with different observations by Sener O on corn and Gozubenli H on popcorn. The increase in concentration of chlorophyll with increases in rates of organic or inorganic fertilizers suggests that adequate synthesis of chlorophyll in plant could be linked to availability of sufficient mineral nutrients. 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 Meena B and on maize and popcorn, respectively.

The positive response of popcorn to mineral and organic fertilizers could be linked to 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 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 the one 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. Pardey PG and JC Greyling had reported similar effects on sewage co compost on agricultural field and rice wheat cropping system.

The superior performance of popcorn plant 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 J and Soltani J 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 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 condition had been shown to improve canopy formation, photosynthate production at the maize silking stage according to Liu T. 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 content was observed with number of ears per plant. Popcorn tends to show better performance with a much wider spacing in an adequately fertilized environment than a narrower spacing irrespective of fertilizer type with regards to photo assimilate partitioning.

The interaction between intra row spacing and fertilizer treatments influenced components of yield and 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 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 90 kg N/ha rate and 20 cm × 20 cm plant spacing indicates 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 were 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. have reported high harvest index and nitrogen use efficiency in *Zea mays* fertilized with CaC_2 and NPK fertilizers in derived savannah ecology.

CONCLUSION

Performance of popcorn improved tremendously with application of compost or NPK fertilizer. 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 plant spacing 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 could affect performance of popcorn adversely. Yield and its components improved with application of 8 t/ha compost supplied to plots intra spaced at 20 cm × 20 cm. In the same vein, application of 90 kg N/ha using NPK 20-7-3 fertilizer enhanced 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 promotes eco-friendly agro ecosystem, applying compost is preferred over mineral fertilizers for promoting increased popcorn production.

AUTHORS' CONTRIBUTIONS

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

ACKNOWLEDGMENTS

The technical support provided by the field staff of crop science department; North-West university is gratefully acknowledged. Equally, the support provided to the first author by the food security and safety research Niche of Mafikeng campus, North-West university is well appreciated. The South Africa National Research Foundation (NRF) provided financial support for the compost project (NRF UID: 90762) to which the study is linked.

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.

REFERENCES

1. Nguyen V, Cooper L, Lowndes J, et al. Popcorn is more satiating than potato chips in normal weight adults. Nutr J. 2012;11(1):1-6.
2. Ranum P, Pena-Rosas JP, Garcia-Casal MN, et al. Global maize production, utilization, and consumption. Ann NY Acad Sci. 2014;1312(1):
3. Kumar SB, Prabhasankar P. Low glycemic index ingredients and modified starches in wheat based food processing: A review. Trends Food Sci Technol. 2014;35(1):32-41.
4. Rebello CJFL, Greenway JW. Finley, Whole grains and pulses: A comparison of the nutritional and health benefits. J Agric Food Chem. 2014;62(29):7029-49.
5. Grandjean AC, Fulgoni III VL, Reimers KJ, et al. Popcorn consumption and dietary and physiological parameters of US children and adults: analysis of the National Health and Nutrition Examination Survey (NHANES) 1999-2002 dietary survey data. J Am Diet Assoc. 2008;108(5):853-56.
6. Park D, Allen KG, Stermitz FR, et al. Chemical composition and physical characteristics of unpopped popcorn hybrids. J Food Compos Anal. 2000;13(6):921-34.
7. Junior SDPF, Rangel RM, Viana AP, et al. Genetic gains in popcorn by full sib recurrent selection. Crop Breed Appl Biotechnol. 2009;9(1).
8. Jele P, Derera J, Siwela M, et al. Assessment of popping ability of new tropical popcorn hybrids. Aust J Crop Sci. 2014;8(6):831-39.
9. Tokatlidis IS. Crop adaptation to density to optimise grain yield: breeding implications. Euphytica. 2017;213(4):1-25.
10. Wu W. Integrated Nutrient Management (INM) for sustaining crop productivity and reducing environmental impact: A review. Sci Total Environ. 2015;512:415-27.
11. Ghorbani R, Koocheki A, Jahan M, et al. Impact of organic amendments and compost extracts on tomato production and storability in agro ecological systems. Agron Sustain Dev. 2008;28(2): 307-11.
12. Jele P, Derera J, Siwela M. Assessment of popping ability of new tropical popcorn hybrids. Aust J Crop Sci; 2014;8(6):831-39.
13. Pardey PG, Greyling JC. Measuring maize in South Africa: The shifting structure of production during the twentieth century 1904–2015. Agrekon. 2019:58(1):21-1.