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Agronomic and physiological response of maize (*Zea mays* L.) hybrids to plant density in the dry and wet Middleveld of Eswatini

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Abstract. One of the factors limiting yield of maize in Eswatini is use of non-optimum plant density for the different maturity group of maize hybrids in different agro-ecologies. Thus, an experiment was conducted at Malkerns (wet Middleveld) and Luve (dry Middleveld) in Eswatini to determine the effects of plant density on growth, yield components and grain yield of maize hybrids. Factorial combinations of three maize hybrids [SC 403 (early maturing), SC 621 (medium maturing), SC 719 (late maturing)] and five plant densities (41,667; 44,444; 47,619; 50,000, and 57,143 plants ha^{-1}) were evaluated in Randomised Complete Block Design in three replications. The results showed that Malkerns had significantly higher crop growth rate (CGR) between V12 and R6 growth stages, relative growth rate (RGR) between V6 and V12 growth stages, mass of thousand kernels (395.60 g), aboveground dry biomass (22.71 t ha^{-1}) and grain yield (7.67 t ha^{-1}). Among maize hybrids, SC 719 produced significantly the highest CGR (18.37 g m^{-2} per day) between V12 and R6, aboveground dry biomass (23.05 t ha^{-1}), number of kernels per m^2 (2074), and grain yield (7.49 ha^{-1}). Moreover, SC 719 grown at Malkerns recorded significantly the highest leaf area index (LAI) at V6, and the highest CGR (31.35 g m^{-2} per day) between V6 and V12 and the tallest plants. The highest density of 57,143 plants ha^{-1} produced the highest LAI, aboveground dry biomass (21.53 t ha^{-1}) and grain yield (7.17 t ha^{-1}). Thus, late maturing maize hybrid SC 719 and plant density of 57,143 plants ha^{-1} (70 cm × 25 cm) can be used to enhance the productivity of maize in the Middleveld of Eswatini.

Key words: crop growth rate, grain yield, leaf area index, relative growth rate, yield components, Swaziland.

INTRODUCTION

Maize (*Zea mays* L.) is the most important crop in sub-Saharan Africa (SSA) and critical to food security with over 300 million Africans depending on it as their main staple food (Shiferaw et al., 2011). In view of its importance, the area of maize production in sub-Saharan Africa has increased by almost 60% from 2007 to 2017 (FAO, 2019). In the southern Africa (excluding South Africa), maize accounts for 19% of the average calorie intake per capita and the demand for the crop as food is increasing as a result of population growth (Shiferaw et al., 2011).

Maize is the main staple crop in Eswatini and constitutes about 95% of the country's cereal production (Dlamini & Masuku, 2011). According to FAO (2019) estimate, maize was grown on an area of 79,130 hectares with an average yield of 1.20 t ha^{-1}. On the other hand, Dlamini & Masuku (2011) reported an average maize grain yield of 4.42 t ha^{-1} on Swazi Nation Land. Thus, the yield obtained in the country is very low and highly variable as compared to the world average grain yield of 5.8 t ha^{-1} and to the yield obtained in southern Africa (4.58 t ha^{-1}) (FAO, 2019). A number of biotic and abiotic constraints contribute to low productivity such as use of inappropriate agronomic practices, drought, declining soil fertility, insufficient technology generation, lack of credit facilities, poor seed quality, diseases, insect pests and weeds (CIMMYT, 2004).

The use of non-optimal plant population per unit area is one of the agronomic practices that can negatively influence maize grain yield (Haarhoff & Swanepoel, 2018). Plant density and arrangement of plants in a unit area greatly determine resource utilisation such as light, nutrients and water; and development of crops particularly that of LAI, plant height, root length and density, yield and yield components, development of diseases and insect pests, and the seed cost (Grassini et al., 2011). Thus, optimisation of plant density is one of the main strategies for increasing yield. High plant density exposes the plant to shading resulting in reductions in leaf development, and leaf photosynthesis per plant thereby reducing the total biomass production and grain yield (Timlin et al., 2014; Yang et al., 2017). On the other hand, if sub-optimal plant density is used, yield will be low due to less number of plants per unit area resulting in less efficient utilization of growth resources. Hence, optimum plant density of maize will lead to effective utilization of soil moisture, nutrients, sunlight and thereby result in higher yields (Liu et al., 2004).

Maize is more affected by variations in plant density than other member of the grass family because of its low tillering ability (Abuzar et al., 2011). Plant density affects grain yield of maize by influencing yield components such as number of ears, number of kernels per ear, and kernel mass (Novacek et al., 2013). However, the optimum plant population of maize depends on several factors such as fertility status of the soil, soil moisture, varieties, and cultural practices (El-Hendawy et al., 2008). When provided with adequate water and nutrient, high plant density can result in an increased number of cobs per unit area, with ultimate increase in grain yield (Bavec & Bavec, 2002). For instance, Ma et al. (2005); Ren et al. (2016); and Haarhoff & Swanepoel (2018) reported that optimum plant population for maize increased with availability of soil moisture through rainfall or irrigation.

A positive association between maize yield and plant population was reported by DeBruin et al. (2017) in modern hybrids, but a contrasting response in older hybrids. The ability of newer hybrids to tolerate increased crowding stress can be attributed to lower lodging frequencies and higher nitrogen use efficiency (Al-Naggar et al., 2011). Optimum plant population density is generally higher for short-season than for long-season maize hybrids since for short-season hybrids, more plants are needed to reach the same amount of cumulative intercepted radiation because of their small leaf area per plant and small leaf area plasticity and a shorter duration of growth (Edwards et al., 2005).

However, in Eswatini, maize population of 44,444 plants ha^{-1} (90 cm × 25 cm) has been recommended without considering the numerous morphological and maturity differences that exist among varieties as well as the existence of soil and climatic differences among the agro-ecologies (Edje & Ossom, 2016). As new maize hybrids with different maturity duration are being developed by seed companies, there is a need to develop appropriate plant population for these varieties for different agro-ecologies of Eswatini. Thus, this study was undertaken to determine the effects of plant density on growth, yield components and grain yield of maize hybrids in the dry and wet Middleveld of Eswatini.

MATERIALS AND METHODS

Description of the experimental sites

A field experiment was conducted under rain-fed conditions in Malkerns Research Station (wet Middleveld) and Luve Experimental Plot (dry Middleveld) from November 2019 to April 2020 growing season. Malkerns Research Station is situated in the upper-Middleveld agro-ecological zone of Eswatini. It is located at an altitude of 740 m, latitude of 26.55°S and longitude of 31.15 °E. Malkerns has an annual rainfall of 800–1,000 mm; and an average annual air temperature of 19.0 °C with the coldest month in June. The annual rainfall of this site is well distributed from October to February with low coefficient of variation (Edje & Ossom, 2016). The soil type is *Ferralsolic* soils or Mdutjane soil series (Murdoch, 1969). The soil at Malkerns is sandy clay, acidic (pH = 5.42) and low in organic carbon (0.82%) (Jones, 2001). Luve Experimental Plot (LEP) is located in the dry Middleveld agro-ecology. The geographical location of LEP is 26.32 °S, 31.47 °E and the elevation is 463 m. The average annual rainfall at LEP is 783 mm with an average annual air temperature of 20.9 °C. The soil at Luve is loamy sand, slightly acidic (pH = 6.08) and low in organic carbon (0.26%) (Jones, 2001).

The rainfall and temperature data of the study locations during the growing period is presented in Table 1. Higher amounts of rainfall at Malkerns and Luve were recorded in the months of November 2019, January and February 2020. Generally, higher seasonal rainfall (603.6 mm) was recorded at Malkerns than at Luve (324.1 mm). Monthly mean temperatures at Malkerns ranged between 19.89 °C and 23.17 °C whilst at Luve it ranged between 24.30 °C and 32.91 °C.

Table 1. Rainfall and temperature data of the study locations

	Rainfall (mm)		Temperature (°C)	
Location	Malkerns	Luve	Malkerns	Luve
Month				
November 2019	154.4	86.3	22.15	30.13
December 2019	57.8	15.6	21.69	28.42
January 2020	159.2	111.4	23.17	32.91
February 2020	119.8	48.0	22.76	29.70
March 2020	57.8	33.4	20.04	26.50
April 2020	54.6	29.4	19.89	24.30
Total	603.6	324.1	-	-
Mean			21.6	28.66

Treatments, experimental design and management of the experiment

The experiment was conducted using factorial combinations of three maize hybrids [(SC 403 (early maturing), SC 621 (medium maturing) and SC 719 (late maturing)] and five plant densities [41,667 (80 cm × 30 cm), 44,444 (90 cm × 25 cm), 47,619 (70 cm × 30 cm), 50,000 (80 cm × 25 cm), 57,143 plant ha^{-1} (70 cm × 25 cm)]. Randomised complete block design (RCBD) with three replications was used. The hybrids used for the study produce one ear per plant.

Gross plot size was six rows of 4.5 m row length and the net plot size was the central three rows leaving the outer two rows as border and one row for destructive sampling. Spacing of 1 m and 1.5 m was left between plots and blocks, respectively. The gross plot size was 24.30 m^2 (6 rows × 0.9 m × 4.5 m) for 90 cm inter-row spacing, 21.6 m^2 (6 rows × 0.8 m × 4.5 m) for 80 cm inter-row spacing, and 18.90 m^2 (6 rows × 0.7 m × 4.5 m) for 70 cm inter-row spacing. The corresponding net plot sizes were 12.15 m^2 (3 rows × 0.9 m × 4.5 m) for 90 cm inter-row spacing, 10.80 m^2 (3 rows × 0.8 m × 4.5 m) for 80 cm inter-row spacing, and 9.45 m^2 (3 rows × 0.7 m × 4.5 m) for 70 cm inter-row spacing.

Two seeds per hole were sown and later on thinned to one plant per hill when the seedlings developed three leaves. Basal fertilizer [N: P: K, 2: 3:2 (22)] at the rate of 400 kg ha^{-1} containing 25.2 kg N ha^{-1}, 37.6 kg P ha^{-1} and 25.2 kg K ha^{-1} was applied at the time of planting. Five weeks after emergence, the crop was side-dressed with Limestone Ammonium Nitrate (28% N) at the rate of 115 kg ha^{-1} (32.2 kg N ha^{-1}). Six weeks after emergence, the crop was sprayed with Masta 900 (Methomly as an active ingredient) to control the Fall armyworm (*Spodoptera frugiperda*). Weeds were controlled by hand weeding and hoeing from early stage of a crop until to maturity as required.

Crop data collected

Days to silking were recorded by counting the number of days from planting to the date when 50% of plants produced silks in the net plot. The growth parameters of maize were collected at three different growth stages. The first stage was at V6, the second stage was at V12 and the last stage was at physiological maturity (R6) as describe by Ritchie et al. (1993).

For the determination of the LAI, the leaf length and maximum width of all available leaves of five randomly selected plants per net plot were measured and the leaf area was calculated using the method described by McKee (1964) as Leaf area (LA) = Leaf length (cm) × Maximum width of leaf (cm) × 0.73. Then the LAI was calculated as the ratio of total leaf area of five plants (cm^2) to the respective area of land occupied by the plants. The plant height was measured from the ground to the base of the uppermost leaf before tasselling and from the ground to the tip of the tassel after tasselling in centimetre with a measuring tape as an average of five randomly sampled plants per net plot.

In order to determine dry matter, three plants were randomly selected from destructive row of each plot at each sampling and were uprooted for collecting necessary data. The plants were carefully uprooted by pulling just above the root crown and then the remaining roots in the soil were collected by hoeing the ground to a depth of about 70-75 cm. Then the roots were washed with tap water.

Their leaf areas were determined as described above and then the plant parts were separated into root, shoot and leaves. Then, the samples were oven dried at 80 ± 2 °C for 72 hours and the respective dry weights were recorded. Then, the following parameters were calculated as described by Hunt (1978):

a) Crop growth rate (CGR) (g m^{-2} per day) $=\left(\frac{W_2-W_1}{t_2-t_1}\right) \times \frac{1}{A}$

b) Relative growth rate (RGR) (mg g^{-1} per day) = $\left(\frac{(\ln W_2 - \ln W_1)}{t_2 - t_1}\right)$

where, W_1 = dry weight of plant at t_1, W_2 = dry weight of plant at t_2, t_1 and t_2 = time intervals in days, ln = natural logarithm, and A = ground area (cm^2).

Number of kernels per cob was recorded by counting the number of kernels using an electronic seed counter from ten randomly taken cobs from net plot area and converted to per m^2 area. Thousand kernels mass (g) was determined by counting one thousand kernels from a bulk of shelled grains per net plot using electronic seed counter and weighed using sensitive balance and the weight was adjusted to 12.5% moisture content. Aboveground dry biomass was determined by weighing five plants per net plot at harvest after sun drying to a constant weight and the weight was converted to tonnes per hectare. Grain yield was determined by multiplying the number of kernels per m^2 and kernel mass and converted to tonnes per hectare.

Data analysis

Homogeneity of variances was tested using the F-test and since the F-test showed homogeneity of the error variances of the parameters of the two sites, combined analysis of variance was carried out using SAS software version 9.1 (SAS Inistitute, 2003). Mean comparisons were done using Least Significant Difference (*LSD*) test at 5% level of significance where the analysis of variance showed significant differences.

RESULTS AND DISCUSSION

Days to 50% silking

The number of days to 50% silking was significantly ($p < 0.01$) affected by the interaction of location and hybrids (Fig. 1). Maize hybrid SC 719 grown at Malkerns recorded the longest number of days to 50% silking (70.47) which was significantly higher than that of the other hybrids grown at both locations (Fig. 1). In contrast, maize hybrid SC 403 recorded significantly the lowest numbers of days to 50% silking at both locations. The medium maturing hybrid (SC 621) and the early maturing hybrid (SC 403) showed no significance difference in days to 50% silking at the two locations. The difference among the hybrids might be due to the inherent genetic characteristics where hybrid SC 719 requiring longer growing degree days to reach 50% silking than SC 403 and SC 621. Moreover, the relatively low temperature at Malkerns might have delayed days to silking. In agreement with this result, Shafi et al. (2012) reported significant variation in days to 50% silking among four maize varieties where maize variety Jalal-2003 recorded the highest numbers of days to 50% silking (68 days) than the other varieties.

There was significant ($p = 0.0276$) interaction effect of location and plant density in the number of days to 50% silking (Fig. 1). The highest number of days to 50% silking (67.33) was recorded at the highest plant density of 57,143 plants ha^{-1} at Malkerns while, the lowest number of days to 50% silking (64.22) was recorded at the plant density of 47,619 plants ha^{-1} at Luve (Fig. 1). The longest days to silking at the highest plant density at Malkerns might be due to slow growth rate due to intense competition among the plants for growth resources and relatively lower temperature. In line with this result, Imran et al. (2015) reported increasing trend in the numbers of days to silking with increased density of maize.

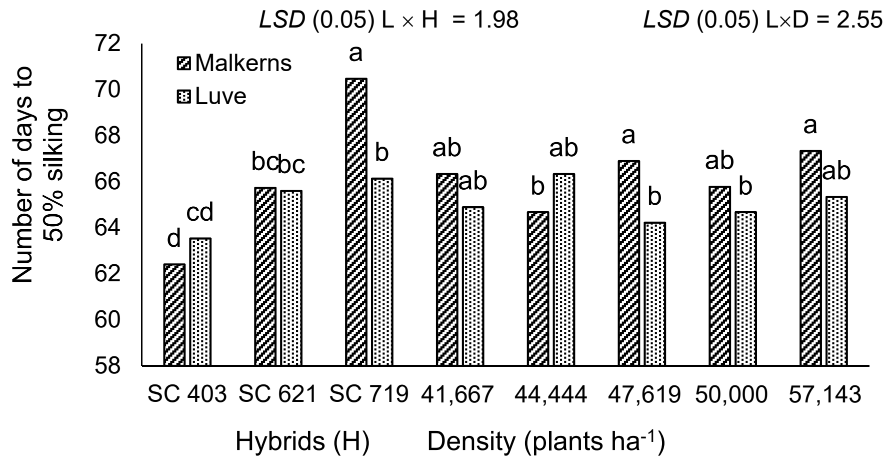

Figure 1. Number of days to 50% silking of maize as affected by the interaction of location by hybrids (H) and location (L) by plant density (D). Means in bars followed by the same letter are not significantly different at 5% level of significance according to Least Significant Difference (*LSD*) test.

Growth parameters

The LAI was significantly ($p < 0.05$) affected by the interaction of hybrids and location at V6 growth stage of maize (Fig. 2). The highest LAI (1.95) was recorded for hybrid SC 719 grown at Malkerns which was only significantly different from maize hybrid SC 403 grown at Malkerns (Fig. 2).

At V12 and R6 growth stages, location had significant ($p < 0.01$) effect on LAI where higher LAI of 4.20 at V12 and 2.70 at R6 were recorded at Malkerns than at Luve (Table 2). The higher LAI at Malkerns could be due to higher rainfall and high clay content of the soils at Malkerns that have retained more moisture and nutrients, making them available to the maize plants.

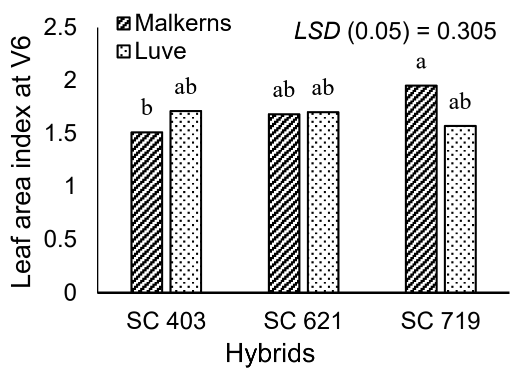

Figure 2. LAI at V6 growth stage of maize as affected by the interaction of location and hybrids. Means on the bars followed by the same letter are not significantly different at 5% level of significance according to Least Significant Difference (*LSD*) test.

Late maturing maize hybrid SC 719 produced significantly highest LAI of 4.30 and 2.67 at V12 and R6, respectively, whilst the early maturing hybrid SC 403 recorded the lowest LAI (Table 2). The highest LAI for SC 719 can be attributed to the extended vegetative growth leading to high number of leaves and rapid leaf expansion. Similar to this result, Jiang et al. (2020) reported greater leaf area and LAI for the long season hybrids than short season hybrids. The higher LAI for long season hybrids results in more light interception during grain filling (Tsimba et al., 2013).

There was significant effect of plant density on LAI at V6, V12 and R6 growth stages and the highest leaf area indexes of 2.02, 4.17 and 2.45, respectively, were recorded at the highest plant density of 57,143 plants ha^{-1} while the lowest leaf area indexes at all the growth stages were from the lowest plant density of 41,667 plants ha^{-1} (Table 2). The LAI showed a decreasing trend at R6 as compared to V12 possibly due to leaf senescence. Moreover, the decrease was highest at the highest plant density which could be due to intense competition for growth resources. In general, as the plant density was increased, the LAI was also increased. Higher LAI recorded at higher plant density can be attributed to higher number of plants per unit area producing more number of leaves which provides maximum interception of solar radiation (Sangoi, 2001). In conformity with this result, Dinh et al. (2015) reported that increasing plant density from 57,000 plants ha^{-1} to 84,000 plants ha^{-1} increased LAI from 3.52 to 4.67 in maize. Likewise,Ndzimandze et al. (2019) found increasing LAI as the density of maize was increased from 44,444 plants ha^{-1} to 57,143 plants ha^{-1}. In general, LAI is influenced by genotype, plant populations, agro-ecological factors and soil fertility (Aliu et al., 2010; Valadabadi & Farahani, 2010).

Table 2. LAI at V12 and R6 growth stages of maize as affected by location, hybrids and plant density. Means in columns followed by the same letter(s) are not significantly different at 5% level of significance according to Least Significance Difference (*LSD*) test; NS = Non-significant

Factor	LAI at V12	LAI at R6
Location		
Malkerns	4.19^{a}	2.70^{a}
Luve	2.81^{b}	1.72^{b}
LSD (0.05)	0.245	0.189
Hybrids		
SC 403	2.81^{c}	1.94^{b}
SC 621	3.40^{b}	2.03^{b}
SC 719	4.30^{a}	2.67^{a}
LSD (0.05)	0.30	0.232
Plant density (plants ha^{-1})		
41,667	2.95^{c}	2.04^{c}
44,444	3.27^{bc}	2.09^{bc}
47,619	3.64^{b}	2.10^{bc}
50.000	3.47^{b}	2.38^{ab}
57,143	4.17^{a}	2.45^{a}
LSD (0.05)	0.387	0.299

Crop growth rate (CGR) was significantly ($p < 0.05$) affected by hybrids and location interaction between V6 and V12 growth stages (Fig. 3). The highest CGR (31.35 g m^{-2} per day) between V6 and V12 growth stages were recorded for maize hybrid SC 719 grown at Malkerns while the lowest CGR (14.77 g m^{-2} per day) was for maize hybrid SC 403 at Luve (Fig. 3).

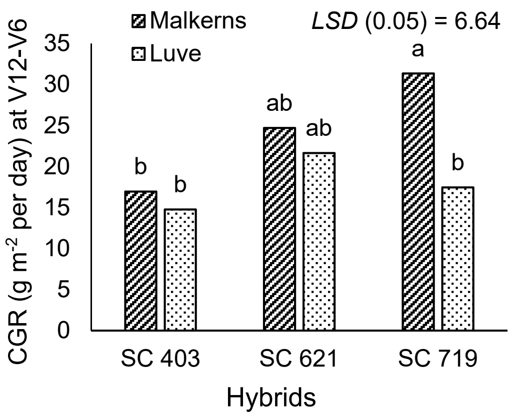

Figure 3. Crop growth rate (CGR) (g m^{-2} per day) of maize at V6-V12 growth stages as affected by the interaction of location and hybrids. Means on the bars followed by the same letter (s) are not significantly different at 5% level of significance according to Least Significant Difference (*LSD*) test.

The lower water availability at Luve might have impaired the late maturing hybrid SC719 from expressing its potential. In line with this result, Ke & Ma (2021) obtained higher grain yield loss of late maturity hybrid than early maturity hybrid with late planting due to moisture stress.

At growth stages between V12 and R6, there were significant main effects of location and hybrids on CGR (Table 3). Significantly higher CGR (18.16 g m^{-2} per day) was recorded at Malkerns than at Luve. Maize hybrid SC 719 recorded significantly the highest CGR (18.37 g m^{-2} per day) than hybrids SC 403 and SC 621 (Table 3). The higher CGR at Malkerns and for hybrid SC 719 can be attributed to higher LAI recorded resulting in the increased dry matter accumulation per day due to relatively better climatic and soil conditions at Malkerns. CGR depend on the amount of intercepted photosynthetically active radiation, where the leaf area index plays an important role. In line with this result, Adebo & Olaoye (2010) reported positive effect of availability of moisture in the early season on physiological characteristics of maize.

Although the difference was not significant, the highest CGR (17.12 g m^{-2} per day) was recorded at the highest plant density of 57,143 plants ha^{-1} which can be explained to higher accumulation of photosynthates by the maize hybrids due to higher number of plants per unit area. In agreement with this result, Valadabadi & Farahani (2010) obtained higher CGR (34.1 g m^{-2} per day) at higher plant density of 90,000 plants ha^{-1} than at 70,000 plants ha^{-1}.

In general, CGR values from V6 to V12 growth stages were higher than from V12 to R6 growth stages possibly due to rapid growth at the early growth stages owing to less competition among the plants for growth resources. Moreover, the lower CGR from V12 to R6 growth stages might be because of a higher proportion of total plant biomass is represented by non-photosynthetic tissues. Consistent with this result, Hokmalipour & Darbandi (2011) reported that during the early period especially after 30 days after germination, the crop growth rate of maize increased sharply until 90 days after germination then it gradually decreased. Similarly, Valadabadi & Farahani (2010) also reported significant increase in CGR of maize up to 60 days after planting and a sharp decline thereafter.

Table 3. Crop growth rate (CGR) and relative growth rate (RGR) of maize at different growth stages as affected by location, hybrids and plant density. Means in columns followed by the same letter are not significantly different at 5% level of significance according to Least Significance Difference (*LSD*) test; NS = Non-significant

Factor	CGR (g m^{-2} per day)	RGR (mg g^{-1} per day)	RGR (mg g^{-1} per day)
	R6-V12	V12-V6	R6-V12
Location			
Malkerns	18.16^{a}	54.80^{b}	14.74^{a}
Luve	10.29^{b}	76.70^{a}	13.85^{a}
LSD (0.05)	2.5	6.87	NS
Hybrids			
SC 403	13.26^{b}	59.20^{b}	15.05^{a}
SC 621	12.25^{b}	68.90^{a}	12.77^{a}
SC 719	18.37^{a}	69.00^{a}	15.06^{a}
LSD (0.05)	3.07	8.42	NS
Plant density (ha^{-1})			
41,667	13.39^{a}	68.40^{a}	14.57^{a}
44,444	15.59^{a}	67.50^{a}	15.37^{a}
47,619	13.40^{a}	67.60^{a}	13.12^{a}
50,000	13.65^{a}	63.70^{a}	14.44^{a}
57,143	17.12^{a}	61.40^{a}	13.98^{a}
LSD (0.05)	NS	NS	NS

The relative growth rate (RGR) was significantly ($p < 0.05$) affected by location and hybrids between V6 and V12 growth stages (Table 3). Significantly higher RGR (76.70 mg g^{-1} per day) was recorded at Malkerns than at Luve (54.80 mg g^{-1} per day) (Table 3). Among the maize hybrids, late maturing hybrid SC 719 produced the highest RGR (69.0 mg g^{-1} per day) while the early maturing hybrid SC 403 had the lowest RGR (59.2 mg g^{-1} per day) (Table 3). The highest RGR for maize hybrid SC 719 might be attributed to high accumulation of dry matter per day due to the highest LAI. In line with this result, Islam et al. (2019) reported significant difference among eight maize genotypes in RGR that ranged from 82.57 mg g^{-1} per day to 114.1 mg g^{-1} per day. Similarly, Hokmalipour & Darbandi (2011) reported significant differences among three maize cultivars for RGR.

There was no significant difference among the plant densities in RGR, however, the highest RGR (68.4 mg g^{-1} per day) was obtained at the lowest plant densities of 41,667 plants ha^{-1} whereas the lowest RGR (61.4 mg g^{-1} per day) was at the highest plant density of 57,143 plants ha^{-1} (Table 3). Relatively higher RGR at the lower plant density can be attributed to less competition among the plants for growth resources such as sunlight, nutrients and moisture. In agreement with this result, Amanullah et al. (2009) reported that increase in planting density from 4 plants m^{-2} to 10 plants m^{-2} had negative effects on RGR. Similarly, Tajul et al. (2013) found higher RGR (16 mg g^{-1} per day) at lower plant density of 53,000 plants ha^{-1} compared to RGR of 8 mg g^{-1} per day at higher plant density of 80,000 plants ha^{-1}.

The main effects of location, hybrids and density as well as all the interactions were non-significant on RGR between V12 and R6 (Table 3). However, relatively higher RGR (14.74 mg g^{-1} per day) was obtained at Malkerns than at Luve (13.85 mg g^{-1} per day). Maize hybrid SC 719 had the highest RGR (15.06 mg g^{-1} per day) while the lowest RGR (12.77 mg g^{-1} per day) was for hybrid SC 621 (Table 3). Plant density of 44,444 plants ha^{-1} produced the highest RGR (15.37 mg g^{-1} per day) while the lowest RGR (13.12 mg g^{-1} per day) was at a plant density of 47,619 plants ha^{-1}.

Generally, RGR was higher in the vegetative growth stage (V6 to V12) and it decreased sharply at V12 to R6. In conformity with this result, Valadabadi & Farahani (2010) found a sharp decline in RGR as the days after planting were increased from 20 to 80.

The interaction effect of location and hybrids was significant ($p < 0.01$) on plant height of maize at all the growth stages indicating that the hybrids height was not consistent across locations. At V6, the tallest plant (37.77 cm) was recorded for hybrid SC 621 grown at Luve while the shortest plant (29.26 cm) was for hybrid SC 403 grown at Malkerns (Fig. 4). On the other hand, at V12 and R6, the tallest plants were for maize hybrid SC 719 at Malkerns while the shortest plants were for hybrid SC 403 at Luve (Fig. 4). Higher plant height at Luve at the early growth stage (V6) might be due to relatively higher temperature which enhanced early growth of maize (Khaeim et al., 2022). Generally, late maturing hybrid SC 719 had highest plant height at Malkerns at all the growth stages which could be ascribed to higher potential of the hybrid in capturing more sunlight, water and nutrients for photosynthesis than the medium and early maturing hybrids (Sharifi et al., 2009). The hybrids height was not consistent across locations with SC 621 and SC 719 having similar height at Luve. Consistent with this result, Gayosso-Barragán et al. (2020) obtained significant line by location interaction for plant height of maize. Likewise, Sharifi et al. (2009) reported significant differences in plant height among maize hybrids that ranged from 183.9 cm to 211.59 cm.

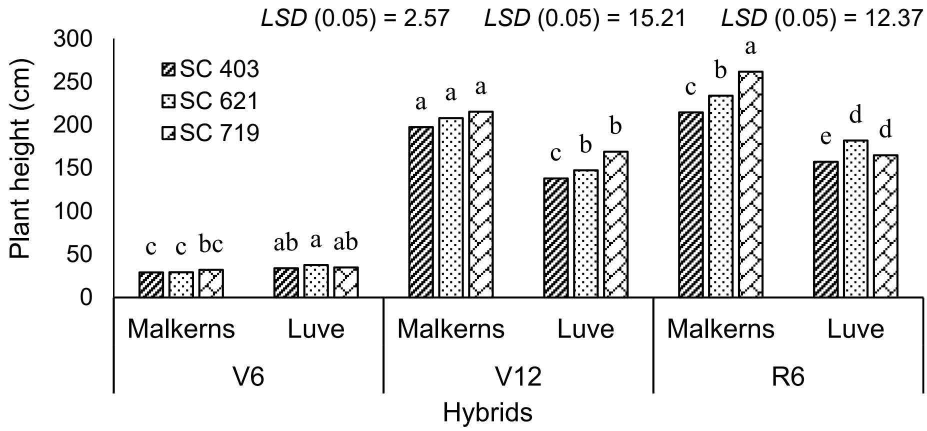

Figure 4. Plant height (cm) of maize at V6, V12 and R6 growth stages as affected by the interaction of location and hybrid. Means on the bars followed by the same letter are not significantly different at 5% level of significance according to Least Significant Difference (*LSD*) test.

Yield components and yield

The main effects of hybrids and plant density were significant on the number of kernels per m^2 whereas the effects of location and the interactions were non-significant (Table 4). Maize hybrid SC 719 produced significantly the highest number of kernels per m^2 (2074) over that of SC 403 (1863) and SC 621 (1804) (Table 4). The highest number of kernels per m^2 for the late maturing hybrid SC 719 could be due to longer vegetative growth period and later silking allowing more LAI to be achieved by the start of the critical period of kernel development. Moreover, the number of kernels depends on traits like ear diameter, ear length and kernel size which are genetically controlled. In agreement with this result, Azam et al. (2007) obtained higher number of kernels per cob for late maturing variety Baber (389 kernels per cob) than early maturing variety Cargill 707 (359 kernels per cob).

Among the plant densities, the highest density of 57,143 plants ha^{-1} produced the maximum number of kernels per m^2 (2031) while the lowest densities of 41,667 and 44,444 plants ha^{-1} produced significantly the lowest number of kernels per m^2 (Table 4). The highest number of kernels per m^2 at the highest plant density might be due to highest number of cobs produced per unit area that compensated the reduction of the kernels numbers per cob (Lashkari et al., 2011). Consistent with this result, Echarte et al. (2000) reported increasing number of kernels per m^2 as the density of maize was increased from 3 to 18 plants m^{-2}.

Mass of thousand kernels is an important yield component, which plays a major role in yield potential of a variety. The main effects of location and hybrids were significant ($p < 0.05$) on the mass of thousand kernels. Significantly higher mass of thousand kernels (395.6 g) was obtained at Malkerns than at Luve (300.4 g) (Table 4) possibly due to better rainfall, temperature and soil conditions at Malkerns. Among the hybrids, SC 621 and SC 719 recorded significantly the highest mass of thousand kernels of 366.0 g and 361 g, respectively, over that of SC 403 (329.9 g) (Table 4). Higher seed mass for medium and late maturing hybrids might be due to the genetic makeup where longer crop cycle provides more production of dry matter and partitioning to the grain. In accordance with this result, Zamir et al. (2011) obtained higher 1,000-grain weight (241.51 g) for late maturing maize hybrid than for early maturing maize hybrid (234.94 g). Similarly, Esfandiary et al. (2012) reported heavier 1,000-grain weight in late maturing maize variety SC 677 (224 g) as compared to early and medium maturing varieties; SC 500 (190 g), SC 647 (195 g) and SC 633 (209 g).

The highest 1,000 kernels mass (359.30 g) was recorded for the lowest plant density of 41,667 plants ha^{-1}, but it was not significantly different from the other densities (Table 4). Highest kernels mass at the lowest plant density might be due to availability of more photosynthates for grain development because of less interplant competition. In agreement with this result, Abuzar et al. (2011) obtained maximum 1,000 kernels weight (350.0 g) at lower density (80,000 plants ha^{-1}) and the minimum 1,000 kernels weight (166.7 g) at a higher plant population (140,000 plants ha^{-1}). Likewise, Ijaz et al. (2015) also reported decrease in 1,000 grain mass with increased plant density in maize.

Aboveground dry biomass was significantly ($p < 0.01$) affected by location and hybrids. Significantly higher aboveground dry biomass (22.71 t ha^{-1}) was recorded at Malkerns than at Luve (15.70 t ha^{-1}) (Table 4) possibly due to better growing conditions at Malkerns compared to the higher temperature and lower rainfall observed at Luve (Table 1). The late maturing maize hybrid SC 719 produced significantly the highest aboveground dry biomass (23.05 t ha^{-1}) while the early maturing hybrid SC 403 produced the lowest aboveground dry biomass (16.54 t ha^{-1}) (Table 4). The highest aboveground biomass for late maturing maize hybrid SC 719 could be due to the fact that it took more days to mature and hence had a better chance to utilize more growth resources such as sunlight, soil nutrients and soil moisture to produce higher LAI and plant height resulting in higher photosynthesis and dry matter production. In agreement with this result, Belay (2019) obtained significantly higher aboveground biomass (31.36 t ha^{-1}) for late maturing maize hybrid BH-661 than medium maturing hybrid BH-QPY-545 (20.19 t ha^{-1}). Similarly, Radchenko et al. (2022) reported

Table 4. Yield components and yield of maize as affected by location, hybrids and plant density. Means in columns followed by the same letter are not significantly different at 5% level of significance according to Least Significance Difference (*LSD*) test; NS = Non-significant. Interactions among location, hybrid and density were not significant

Factor	Number of kernels per m^2	1,000 kernels mass (g)	Aboveground dry biomass (t ha^{-1})	Grain yield (t ha^{-1})
Location				
Malkerns	1939.1^a	395.60^a	22.71^a	7.67^a
Luve	1888.7^a	300.40^b	15.70^b	5.67^b
LSD (0.05)	NS	23.709	2.035	1.58
Hybrids				
SC 403	1863^b	329.90^b	16.54^b	6.15^b
SC 621	1804^b	366.00^a	18.03^b	6.60^b
SC 719	2074^a	361.00^{ab}	23.05^a	7.49^a
LSD (0.05)	178.2	29.038	2.492	0.75
Plant density (plants ha^{-1})				
41,667	1801^b	359.30^a	18.07^a	6.47^a
44,444	1797^b	349.40^a	18.90^a	6.28^a
47,619	1938^{ab}	343.10^a	18.59^a	6.65^a
50,000	2002^{ab}	356.80^a	18.93^a	7.14^a
57,143	2031^a	352.80^a	21.53^a	7.17^a
LSD (0.05)	230.07	NS	NS	NS

significant difference for aboveground biomass among three maize hybrids that ranged from 45.7 t ha^{-1} for hybrid DM Skarb to 55.1 t ha^{-1} for hybrid Forteza.

Maize grown at the highest plant density of 57,143 plants ha^{-1} had the highest aboveground dry biomass (21.53 t ha^{-1}) while the lowest aboveground biomass (18.07 t ha^{-1}) was recorded from the lowest plant density of 41,667 plant ha^{-1} (Table 4). The highest aboveground biomass at the highest plant density could be due to more number of plants per unit area.

Grain yield was significantly affected by location and hybrids (Table 4). Significantly higher grain yield (7.67 t ha^{-1}) was obtained at Malkerns than at Luve (5.67 t ha^{-1}) (Table 4) which can be explained to the optimum rainfall, temperature and soil at Malkerns compared to higher temperature, minimum rainfall and predominantly sandy soil at Luve. The late maturing maize hybrid SC 719 produced significantly the highest grain yield (7.49 t ha^{-1}) than SC 621 (6.60 t ha^{-1}) and SC 403 (6.15 t ha^{-1}) (Table 4). The highest grain yield for the late maturing hybrid SC 719 could be due to the highest growth parameters such as LAI, CGR, plant height and number of kernels as grain yield is positively associated with these parameters. In line with this result, Esfandiary et al. (2012) found the highest grain yield for late maturing maize varieties SC 704 (9,861 kg ha^{-1}) and SC 677 (9,800 kg ha^{-1}) compared to early and medium maturing varieties; SC 500 (9,656 kg ha^{-1}), SC 647 (9,553 kg ha^{-1}) and SC 633 (9,005 kg ha^{-1}). Belay (2019) also reported the maximum grain yield (11.09 t ha^{-1}) for late maturing maize hybrid BH661 than medium maturing maize hybrid BHQPY-545 (9.57 t ha^{-1}).

Though the difference was not significant, the highest grain yield (7.17 t ha^{-1}) was obtained at the highest plant density of 57,143 plants ha^{-1} whereas the lowest grain yield (6.28 t ha^{-1}) was recorded at plant density of 44,444 plants ha^{-1} (Table 4). In general, as the plant density increased, the grain yield showed an increasing trend. Higher grain yield at higher plant density might be due to higher number of plants per unit area which compensated the effects of decrease in other yield components specifically, due to higher grain number per unit area which compensated the decrease in grain weight. Abdul et al. (2007) also found higher grain yield of 5.80 t ha^{-1} at plant density of 90,000 plants ha^{-1} and lower grain yield (4.36 t ha^{-1}) at the lowest density of 30,000 plants ha^{-1}. In contrast to this result, Kadyrov & Kharitonov (2019) reported significant interaction of maize hybrids and seeding rates where the highest yield of early maturing and medium to early maturing hybrids were obtained at the seeding rate of 73,000 seeds ha^{-1} while the medium maturing hybrid produced the highest grain yield (7.21 t ha^{-1}) at the seeding rate of 77,000 seeds ha^{-1}.

CONCLUSIONS

Results of the study showed that maize hybrid SC 719 grown at Malkerns produced the highest LAI, crop growth rate, number of kernels per m^2, aboveground dry biomass and grain yield. As the plant density was increased from 41,667 plants ha^{-1} to 57,143 plants ha^{-1}, the leaf area index, aboveground dry biomass and grain yield showed an increasing trend. Thus, it can be concluded that late maturing maize hybrid SC 719 at the plant density of 57,143 plants ha^{-1} (70 cm × 25 cm) can be used to increase the productivity of maize in the Middleveld of Eswatini. However, further studies are required to determine the physiological variables influencing biomass accumulation and yield in each location with inclusion of higher plant densities.

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