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HYBRID MAIZE RESPONSES TO VARIABLE PLANTING DENSITIES UNDER IRRIGATED SEMI-ARID CONDITIONS

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Abstract

Maize productivity is influenced significantly by various factors, including the choice of variety and plant population density. These factors interplay to determine the growth dynamics, resource utilization, and ultimately, the yield of maize crops. To determine how maize hybrid responded to varying plant density, field trials were conducted in 2011 and 2012. The experiments were organized using a split-plot layout within the framework of a Randomized Complete Block Design (RCBD). Two maize hybrids, Pioneer-30Y87 (H_1) and Syngenta-6621(H_2) were planted in main plots with different population densities i.e. 66607, 83333, 111111, and 166667 plants per hectare in subplots keeping plant-to-plant distances 25, 20, 15 and 10 cm, respectively. Measurements of plant characteristics like phenology, growth, and yield were done using standard methods. Hybrid Pioneer-30Y87 took statically a greater number of days to tasselling (48.41 & 47.90), silking (54.40 & 53.33) as compared to Syngenta-6621 (45.66 & 44.65) for tasselling, and (51.83 & 51.20) for silking in 2011 and 2012, respectively when compared under different plant population densities. The highest grain yields were recorded at 7.66 t/ha for Pioneer-30Y87 and 7.08 t/ha for Syngenta-6621. A planting density of 111111 plants per hectare produced the highest LAI, TDM, and grain yield as compared to others. Differences in grain yield among population densities remained significant and reached to the maximum value of 6.65, 7.43, 8.26, and 8.07 t ha^{-1} for P_1, P_2, P_3, and P_4, respectively. P_3 (111111 plants ha^{-1}) attained maximum grain yield while the minimum was in P1 (66607 plants ha^{-1}). It is concluded that maize hybrid Pioneer-30Y87 should preferably be grown with a plant density of 111111 plants per hectare for obtaining high yields.

Keywords: LAI, TDM, Phenology, Grain Yield, Grain Weight, *Zea Mayse.*

INTRODUCTION

Maize also known as corn, plays a multifaceted role in global agriculture, food security, and economic development, making it one of the most important crops worldwide. The global maize area dedicated to dry grain production totals 197 million hectares, encompassing significant regions in sub-Saharan Africa, Asia, and Latin America (FAO Stat, 2021). Maize stands as a common human food crop across numerous nations globally (Shiferaw et al., 2011), serving multifaceted roles within the agricultural industry. A significant portion, over 75%, of maize production fulfills direct human dietary needs, while the remainder finds versatile applications across various sectors such as starch manufacturing, poultry feed production, and food grain marketing, among others. Additionally, maize finds its way into diverse industrial processes, including oil extraction, syrup production, and pharmaceutical applications, where it serves as a precursor for essential compounds like dextrose, used in synthesizing Vitamin C and penicillin. Moreover, maize is utilized in the production of alcoholic beverages, ethanol, and high fructose corn syrup. Notably, even its dry cobs serve a practical purpose as a source of fuel (Kellems and Church, 2010). With its nutritional profile containing moisture at 17%, ash at 3.3%, protein at 12.45%, crude fibre at 2.97%, and total carbohydrates at 60.23%, alongside other vital minerals (Qamar et al., 2017), maize emerges as a nutritionally rich resource. Remarkably, maize has the most favorable water footprint per kcal of nutritional energy, needing only 0.41 liters of water per kcal. This underscores its efficiency and sustainability as a vital component of the global food system.

Maize, characterized by its rapid growth and prolific grain production per unit area, holds promise for uplifting the livelihoods of impoverished rural farmers, potentially elevating them out of poverty. Despite favorable soil and climate conditions for maize cultivation in the country, its per-hectare yield lags that of other nations. Several factors contribute to this disparity, including the prevalence of low-potential varieties, suboptimal plant density, and inadequate land preparation. The significance of enhanced maize germplasm cannot be overstated in revolutionizing maize cultivation globally. While improved maize germplasm has gained traction worldwide, the adoption of hybrid maize remains variable (Krishna et al., 2021; Langyintuo et al., 2010). Modern maize hybrids boast considerable yield potential; however, their average performance in Pakistan falls short compared to other maize-producing countries. Efforts to address these challenges and harness the full potential of maize cultivation hold the key to maximizing its socioeconomic benefits in Pakistan and beyond. Plant density stands out as a pivotal agronomic factor shaping the grain yield and other crucial attributes of maize cultivation. Elevated plant populations extend the interval between tasseling and silking while exerting an influence on yield through key yield components such as ear count, kernels per ear, and individual kernel mass (Zhang et al., 2014). Increasing plant density, for instance, transitioning from 40,000 to 100,000 plants per hectare, serves as a strategy to bolster grain and overall plant yield, given its positive impact on factors like LAI, light interception, & crop growth rate (CGR). Notably, Cox and Cherney (2001) observed that varying row spacings had no discernible effects on maize's nutritive value parameters.

Achieving maximum grain yield is associated with an increase in plant density. However, exceeding a certain threshold can notably diminish grain yield per unit area due to the competitive impact on canopy structure and light distribution among individual plants (Borras et al., 2003; Tokatlidis and Koutroubas 2004; Liu et al., 2011). Closer rows offer a more favorable planting pattern, fostering accelerated maize growth early in the season, thereby enhancing sunlight interception, radiation use efficiency (RUE), and ultimately yield (Li et al., 2015). Optimal light interception, crucial for maximizing yield, requires a plant density of 9.72 plants per square meter, achieved by promoting early canopy closure to minimize light penetration through the canopy (Li et al., 2018). Elevated plant densities tend to reduce the maize harvest index as plants allocate fewer photosynthates to grain production at higher populations (Hamidi et al., 2010). Excessive closeness in spacing can impede normal plant development and exacerbate competition, leading to a reduction in yield, while overly wider spacings may encourage excessive vegetative growth and weed proliferation due to increased available feeding area. Consequently, employing an optimal plant population per unit area significantly mitigates weed infestation and biomass while promoting maize growth. Narrow row spacings can further suppress the growth of weeds by enhancing radiation interception by the canopy early in the growing season, potentially resulting in increased maize yields (Maqbool et al., 2006; Alford et al., 2004).

Limited information exists regarding how modern maize hybrids respond to altered planting densities concerning their growth, development, and yield capabilities in semiarid environments. The current study was designed to evaluate the impact of different planting densities on the pattern of growth, development, and grain yield in autumn-planted hybrid maize.

MATERIALS AND METHODS

Two-year field experiments were conducted under semiarid conditions in Faisalabad (31.25° N, 73.09° E, and 184 m) Pakistan. The experiment was laid out using a split-plot design during both years. Two hybrids (Pioneer - 30Y87 and Syngenta – 6621) were randomized in main plots and four different planting densities i.e. 66607, 83333, 111111, and 166667 plants per hectare were allocated to the subplots, respectively. A plant-to-plant distance of 25, 20, 15 and 10 cm was kept maintaining the planting densities with a 60 cm row-to-row distance.

Hybrid maize seeds of two cultivars were planted on meticulously prepared seedbeds on the 2nd of August 2011 and the 01st of August 2012. The planting took place along ridges, adhering to the specific spacing dictated by the treatment protocols. Utilizing a dibbler, the seeds were manually placed, with two seeds per hill, at the prescribed intervals. Subsequently, crop thinning was undertaken to ensure only one plant per hill remained, thus maintaining the targeted plant population by the treatment criteria.

Before preparing the seedbeds, pre-soaking irrigation (rauni) was applied with a water depth of four inches in both years, following which the seedbeds were prepared once the soil reached its field capacity. Throughout the growth cycle, a total of seven irrigations (each of 3 inches) were applied, timed to coincide with various growth and development stages of the plant, till physiological maturity. The fertilizer was applied at a rate of 50:100:100 kg ha^{-1} of N, P_2O_5, and K_2O. The remaining nitrogen was applied in two equal splits at vegetative growth and Anthesis-Silking. Furadan at 25 kg ha^{-1} was applied twice for pest control. The growth and yield parameters were the same for both experiments in two growing seasons. A meter-long row from each plot was harvested at ground level after fifteen-day intervals. The fresh and dry weight of plant components was determined, and total dry matter was obtained by summing the weight of all components. Additionally, leaf area was measured using an area meter.

The following data was recorded: emergence, tasseling, silking, and maturity dates. The growth phases were determined to have ended when 50% of plants had completed that growth stage and the next stage had begun. For physiological maturity, the 90% criterion was used. The duration of each phase was measured in days (calendar time). Thermal time (Growing Degree Days) was calculated based on the method described by Gallagher et al. (1983). It calculates thermal time (Tt) as a function of mean temperature above a base temperature (Tb).

$$\text{Tt} \quad = \frac{\Sigma\ (T\,max + T\,min.)}{2} - Tb$$

Where Tb is the base temperature taken as 10 °C for Maize (FAO, 1978)

At harvesting data on the Plant Height at Harvest, Number of grains per ear, 1000-grain weight, Grain yield (kg ha^{-1}), Total dry matter, and Harvest index.

The collected data was statistically analyzed using Fisher’s analysis of variance technique (Steel et al., 1997). Differences among treatment means were separated using Tukey's HSD test at a 5% probability level. Additionally, appropriate regression analysis was conducted to examine and quantify the relationship between various growth and yield attributes of the crop.

RESULTS AND DISCUSSION

Figure 1 presents the summary of weather variables during 2011 and 2012 for the experimental site. During both cropping seasons, temperatures rose from August to October before dropping as the crop matured. Rainfall was received in monsoon months (August to September) that was variable during growing seasons. Overall, the experimental site received 134 mm of rainfall during 2011 and 159 mm in 2012. In general, there was more rainfall during 2012 as compared to 2011.

A) Crop Development

Thermal time (Growing Degree Days) from sowing to emergence, tasseling, silking, and physiological maturity stage were taken 116, 1008, 1229, and 2110 by Pioneer-30Y87 and 116, 959, 1170, and 2018 by Syngenta-6621 in 2011, respectively (Table 1). Equivalent values in 2012 were 142, 801, 1203, and 2140 for Pioneer-30Y87 and 133, 776, 1186, and 2084 for Syngenta-6621, respectively. On average, Pioneer-30Y87 took a greater number of days for all developmental stages as compared to Syngenta-6621.

Days to 50% Tasseling: Pioneer-30Y87 took more days 48.41 and 47.90 during 2011 and 2012 as compared to Syngenta-6621 which took 45.66 and 44.65 days during 2011 and 2012, respectively. Plant population density response was linear during both seasons. Maximum days to 50% tasselling (50.52) were taken by crop sown with P_3 treatment (111111plants ha^{-1}) that was at par with treatments P_4 (166667 plants per ha) which got 50% tasselling 50.22 days after sowing. Statistically minimum days to 50% tasselling (47.50) were taken in plots where the crop was sown with P_1 (66607 plants per ha) during 2011. Almost similar trends were observed during 2012 when maximum days to 50% tasselling (50.17) were recorded in plots sown with P_3 treatment (111111 plants per ha) followed by P_4. These treatments were found statistically at par. Minimum days to 50% tasselling were recorded in plots sown with P_1 (66607 plants per ha) during 2012 (Table 2).

Days to 50% silking: The effects of cultivars were statistically significant on days to 50% silking with a similar trend in both seasons. Pioneer 30-Y-87 took a maximum no of days to 50% silking (54.40) followed by Syngenta-6621 which took 51.82 days during 2011. Similarly,

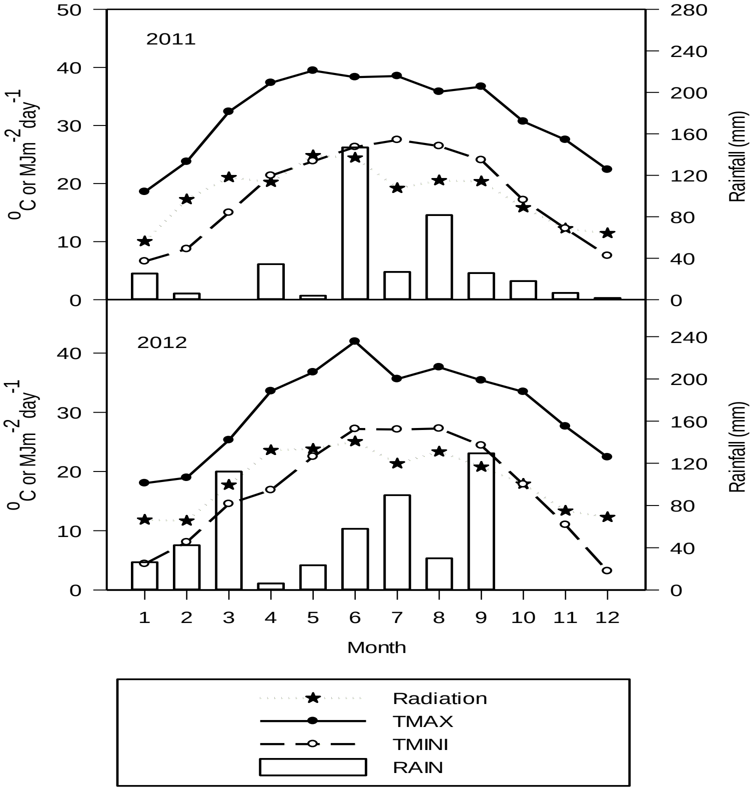


Fig 1: Monthly averages of maximum and minimum temperature, solar radiation, and total monthly rainfall at the experimental sites

The maximum no of days (53.33) to 50% silking was observed in plots sown with hybrid Pioneer-30Y87 and minimum days to 50% silking (51.20) in Syngenta-6621(Table 2).

Plant population density response was linear during both seasons. Maximum days to 50% silking (54.56) were taken by crop sown with P_3 treatment (111111plants per ha) that was at par with treatments P_4 (166667 plants per ha) and P_2 (83333 per ha) which got 50%

Silking 54.21and 52.52 days after sowing. Statistically minimum days to 50% silking (51.75) were taken in plots where the crop was sown with P_1 (66607 plants per ha) during 2011. Almost similar trends were observed during 2012 when maximum days to 50% silking (55.75) were recorded in plots sown with P_3 treatment (111111 plants per ha) followed by P_4 and P_3 (. These treatments were found statistically at par. Minimum days to 50% silking (53.17) were recorded in plots sown with P_1 (66607 plants per ha) during 2012. The most likely explanation is that

Table 1: Phenological development in maize hybrids grown under semiarid conditions

Stage	Cultivar	Calendar days		Thermal time (°C days)	
		Year-1	Year-2	Year-1	Year-2
Sowing	Pioneer-30Y87	0	0	0	0
	Syngenta-6621	0	0	0	0
Emergence	Pioneer-30Y87	4	5	116	142
	Syngenta-6621	4	4	116	133
Tasseling	Pioneer-30Y87	48	48	1008	801
	Syngenta-6621	46	45	959	776
Silking	Pioneer-30Y87	54	53	1229	1203
	Syngenta-6621	52	52	1170	1186
Maturity	Pioneer-30Y87	110	111	2110	2140
	Syngenta-6621	106	108	2018	2084

Table 2: Effect of hybrids and population density of plants on phenology of maize

Treatment	Days to Tasselling		Days to Silking	
	2011	2012	2011	2012
A) Hybrids				
P-30-Y-87	48.41 a	47.90 a	54.40 a	53.33
S-6621	45.66 b	44.65 b	51.82 b	51.20
HSD 5%	2.37	2.5	2.58	2.96
Significance	*	*	*	ns
B) Plant Population Density (Plants per hectare)				
P_1 = 66607	47.50 b	47.92 b	51.75 b	53.17 bc
P_2 = 83333	47.87 b	48.75 ab	52.52 ab	54.08 abc
P_3 = 111111	50.52 a	50.17 a	54.56 a	55.75 a
P_4 = 166667	50.22 a	49.67 a	54.21 a	55.00 ab
HSD 5%	2.09	1.47	2.31	1.97
Significance	*	*	*	*
Linear	*	*	*	*
Quadratic	NS	NS	NS	NS
Interaction	NS	NS	NS	NS
Mean	49.03	49.13	53.26	54.50

P-30-Y-87: Pioneer-30-Y-87, S-6621: Syngenta-6621, * = Significant at 5%, NS = non-significant. The means sharing different letters differ significantly at P = 0.05

Higher plant densities promoted vegetative growth which delayed the reproductive stage. Masood *et al.* (2003) reported similar outcomes as well. Interactive effects among all factors were found to be statistically nonsignificant.

B) Growth parameters

Leaf area index (LAI): LAI values gradually increased and peaked at 60 days after sowing (DAS) in both seasons. LAI then decreased in all treatments, reaching a low of less than 2.0 by 105 DAS (Figs. 2 and 3).

This decrease in LAI was more visible at lower plant population density P_1 (66607 plants per ha) than at higher P_3 and P_4 levels, owing to earlier leaf senescence in the former. The season had a significant impact on maximum LAI throughout the 2011 and 2012 growth seasons. Crop LAI was higher in 2012 than in 2011, with maximum values of 4.89 and 4.02, respectively.

Hybrid differences in maximum Leaf development were significant during 2011 and nonsignificant in 2012. Averaged over plant population densities the maximum value (4.44) of LAI was observed for hybrid P-30Y87 which was statistically more than hybrid Syngenta-6621 which had LAI 4.07.

The trend was also similar in both seasons (Fig.4.2a & 4.3 a). The conclusions of Gardner et al. (1990), showed that current hybrids displayed higher LAI than old hybrids are consistent with these findings. Dwyer et al. (1991) also found comparable variations in LAI across ancient and modern hybrids. Cox (1996) found identical LAI in four maize hybrids, which contrasts with the findings mentioned above.

The trend was also similar in both seasons (Fig.2 & 3). Averaged over cultivar peak LAI reached a value of 4.45 at 60 DAS in the P_3 (111111plants ha^{-1}) treatments that were at par with P_4 (166667 plants ha^{-1}), P_2 (83333plants ha^{-1}) and P_1 (66607 plants ha^{-1}) treatments during 2011 that gain maximum LAI of 4.27, 4.18 and 4.09, respectively.

The minimum LAI was recorded in P_1 in 2011. Almost similar trends were observed during 2012 when maximum LAI (4.88) was recorded in plots sown with P_3 treatment (111111 plants ha^{-1}) followed by P_4 and P_2.

These treatments were found statistically at par. The LAI values recorded in P_4 and P_2 were 4.60 and 4.41, respectively. An increase in LAI results in a higher interception of incident radiation than under conditions of lower plant population density (Bullock *et al*., 1988; Teasdale, 1995). LAI often grew up until the tasseling stage and then decreased till the final harvest (Fig.2 and 3).

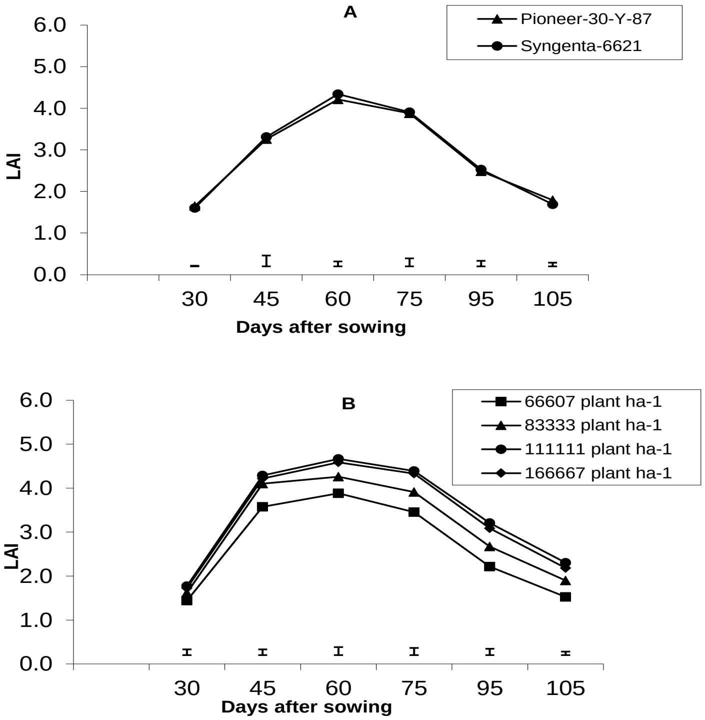
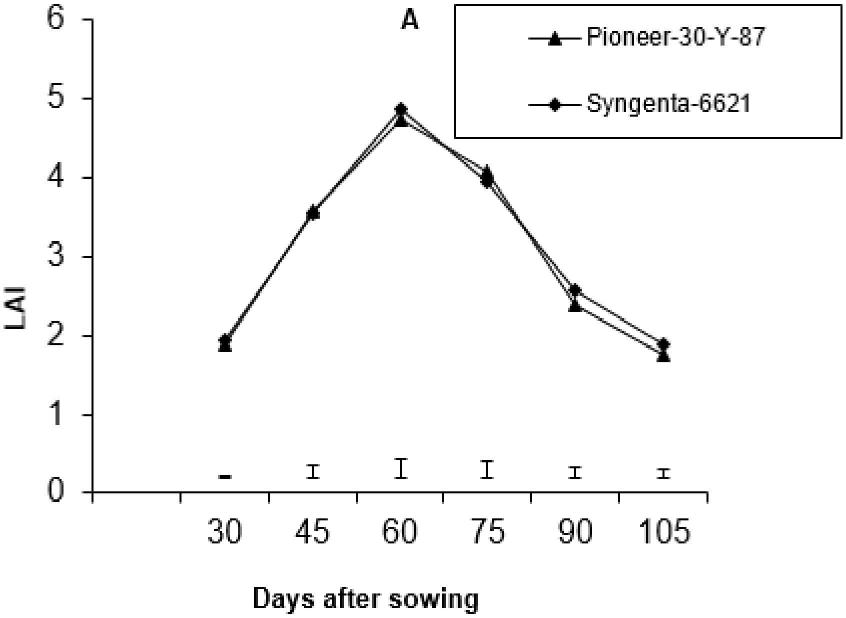


Fig 2: Temporal changes LAI with time during 2011 (a) effect of the hybrid (b) effect of plant population density; Bars represent HSD at 5%



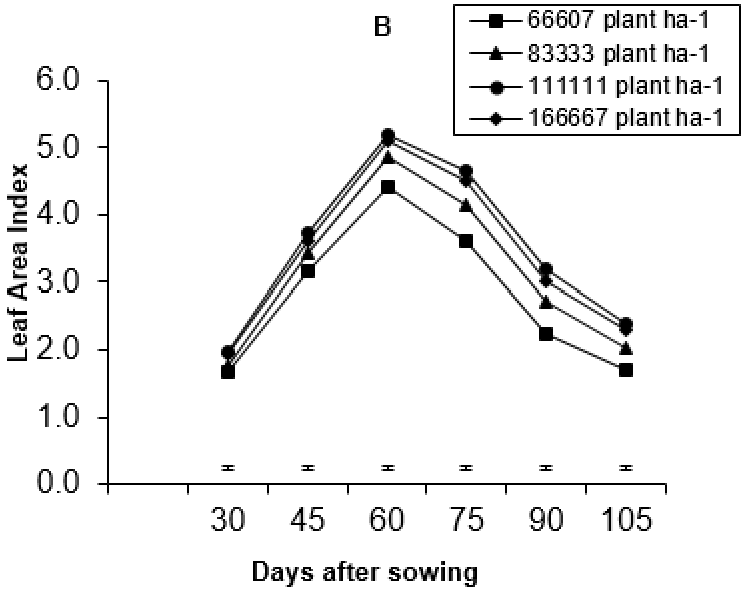
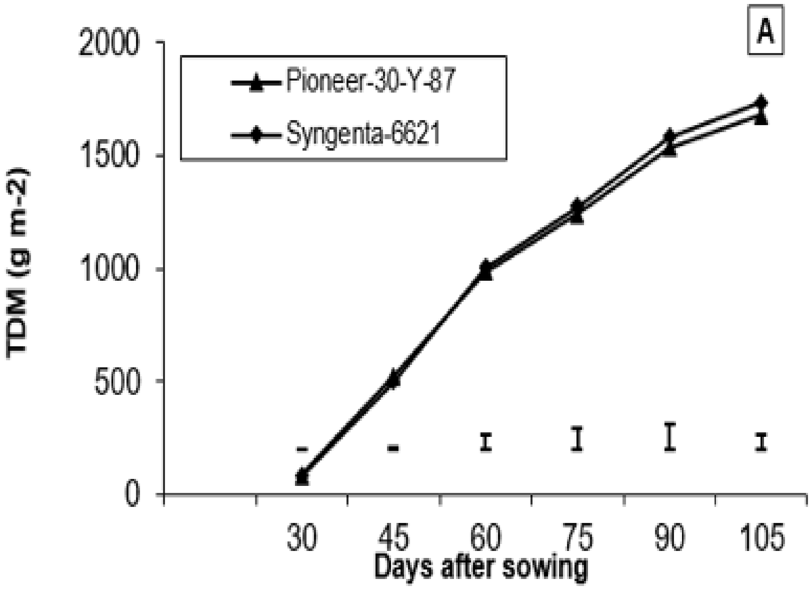


Fig 3: Temporal changes in leaf area index with time during 2012 (a) effect of the hybrid (b) effect of plant population density; Bars represent HSD at 5%

Accumulation of total dry matter (g m^{-2}): TDM accumulation increased steadily in all treatments from crop establishment to maturity (Figs. 4 and 5). The Cultivars significantly affected TDM in 2011. However, cultivar effects were nonsignificant in 2012. Hybrid Pioneer 30-Y-87



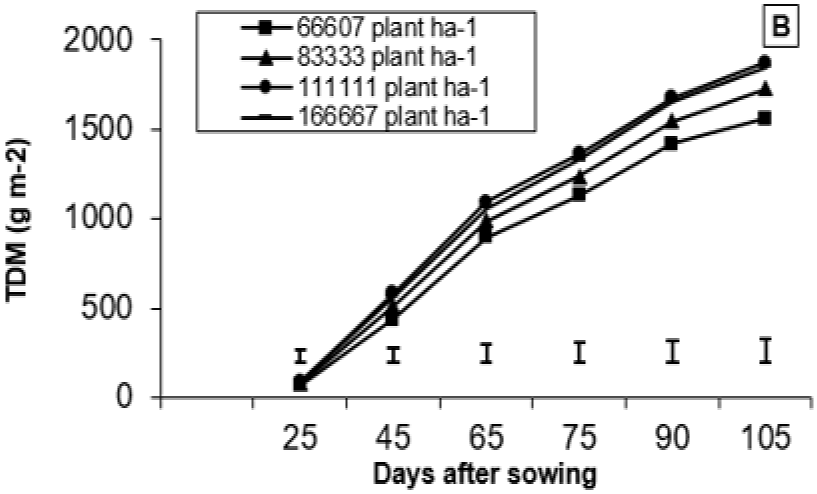
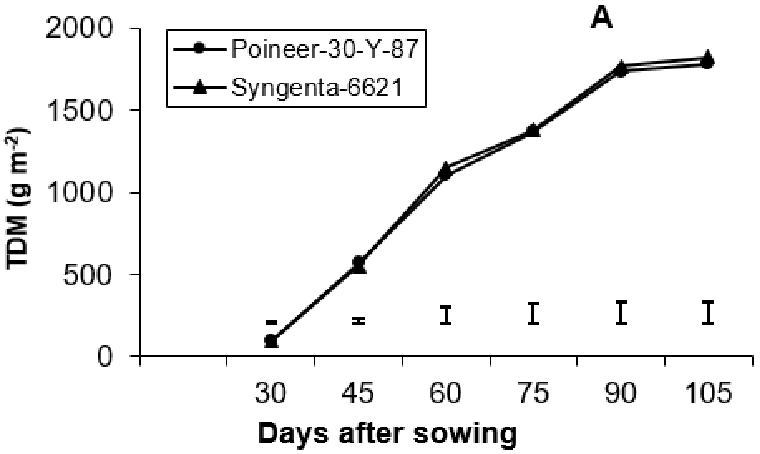


Fig 4: Temporal change in TDM accumulation with time during 2011 (A) Effect of the hybrid (B) effect of plant population density; Bars represent HSD at 5%

accumulated relatively more TDM throughout the season in both years. Averaged plant population densities, maximum TDM (17935 gm^{-2}) was accumulated by Pioneer-30Y87 as compared to Syngenta-6621 which accumulated 1682 gm^{-2} at final harvest (105 DAS). Figures 4 and 5 show that at 105 DAS, maximum TDM accumulated to a value of 1871.97 gm^{-2} in 2011 and 1895 gm^{-2} in 2012. The treatment P$_4$ produced 1847.60 and 1869.65 g m^{-2} TDM in 2011 and 2012, respectively. The minimum TDM accumulation was observed in plots where the crop was sown with a minimum plant population density of 66607 plants ha^{-1} (P1) throughout both years. The increase in plant population density resulted in improved crop growth, maximum plant height, and LAI, leading to increased biological yield.



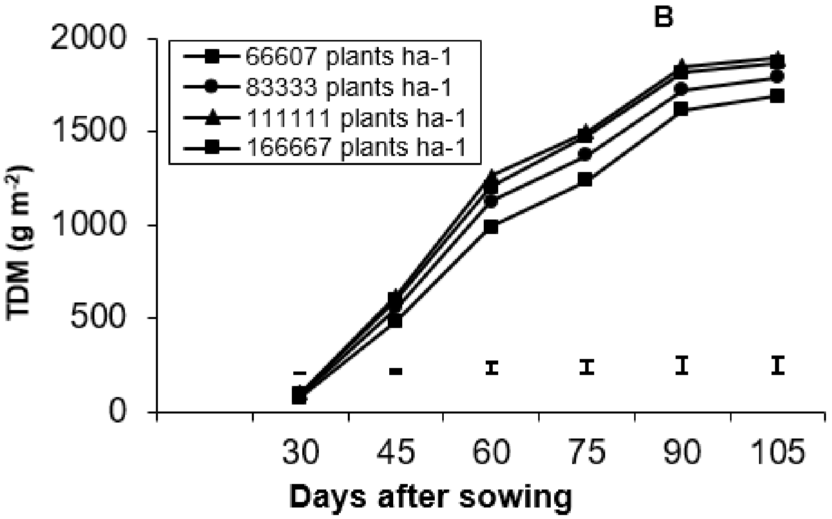
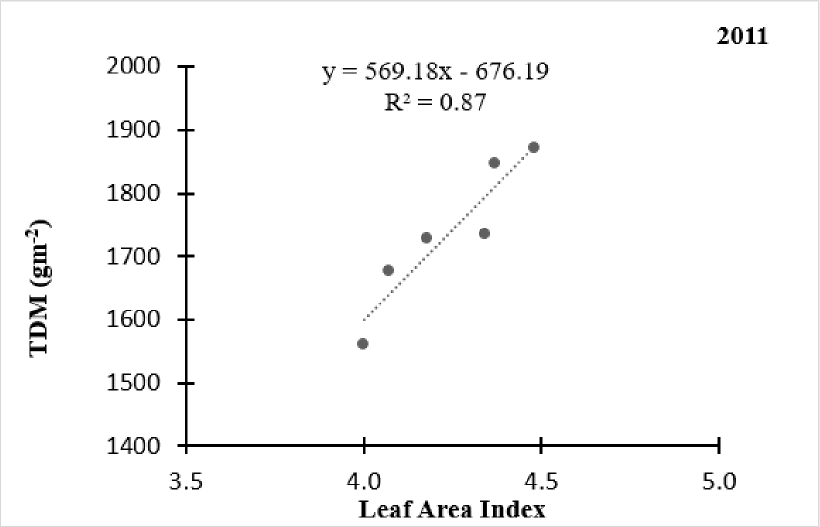


Fig 5: Change in total dry matter with time during 2012 (A) effect of the hybrid (B) effect of plant population density; Bars represent HSD at 5%

The relationship between final TDM and maximum LAI (Fig. 6 &7) was significant and positive during 2011 ($R^2 = 0.87$) and 2012 ($R^2 = 0.94$). These findings are in line with Manzoor (2010) who also reported similar results for hybrid and population density.

C-Observations at Harvest

Plant Height at Harvest: The effect of cultivars on plant height was significant in both years. Pioneer-30Y87 gave the maximum plant height (168.47 cm) followed by Syngenta-6621 which gave 158.14 cm in 2011 and a similar trend was seen in 2012 where Pioneer-30Y87 gave the maximum plant height (167.64 cm) and Syngenta-6621 gave 156.66 cm (Table 3).



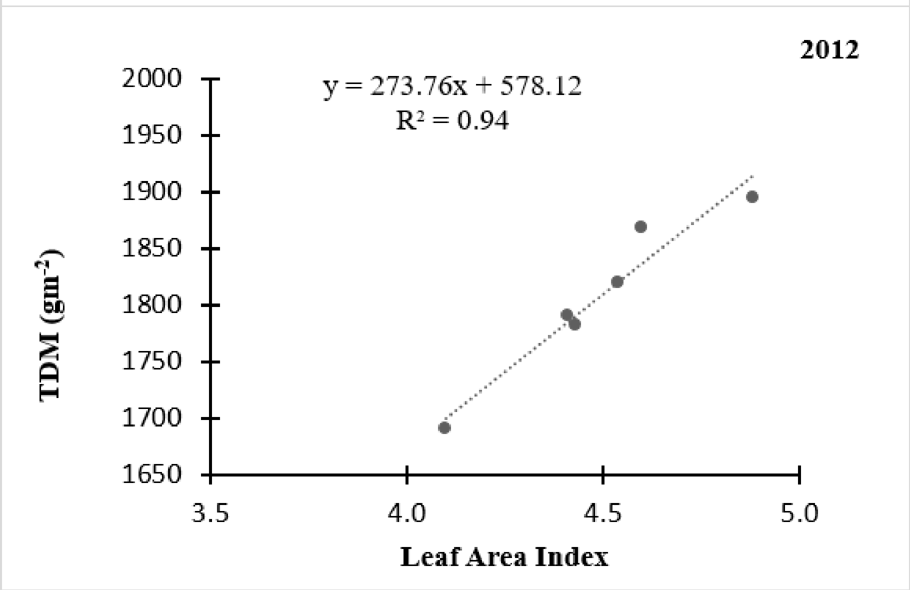


Fig 6: Relationship between final TDM and Maximum LAI of maize sown with different population densities

The varying genetic potential of cultivars may account for the different responses of maize hybrids to plant height. According to Sangoi and Salvador (1998), maize hybrids with prolonged growing seasons have taller plants. Plant height was also found to be strongly impacted by maize hybrids, (Sener et. al. (2004).

The effects of plant population density were significant. Averaged over seasons maximum plant height (168.56 cm) was at P_3 treatment (111111 plants ha^{-1}) followed by treatments P_2 (83333 plant ha^{-1}) that produced 164.08 cm tall plants. The minimum plant height was recorded in P_4 (166667 plant ha^{-1}) which produced 157.53 cm tall plants.

Greater vegetative growth may have contributed to higher plant height by causing more mutual shadowing and internodal extension. These findings support those of Fernandes et al*.* (1998), who examined that plant height varied greatly among intra-row spacings and was significantly influenced by maize hybrids.

Number of grains per ear: Maize hybrids produced a wide range of grains per cob (Table 3). Hybrid Pioneer-30Y87 produced the most grains per cob (507 and 503), which was 12.46 and 20.82% more than the number of grains produced by hybrid Syngenta-6621, where the number of grains per cob was 451 and 417 in 2011 and 2012, respectively.

Table 3 shows that the number of grains per cob (504) was recorded in plots where planting density was 111111 plant ha^{-1} followed by P_2 (83333 plant ha^{-1}). Plants with the highest planting density (166667 plants per hectare) produced the lesser grains per cob (438).

The current studies' observations of a reduction in the number of grains per cob at higher planting densities are like those made by Gokeman *et al*. (2001), who hypothesized that the observed decrease in grains per cob at high population density could be attributed to interplant competition for light, soil nutrients, and water.

Different authors have noted variations in the quantity of grains per ear. According to Sangoi and Salvador (1998), a high plant population reduces the number of grains per year in dwarf lines but does not affect other hybrids. According to Gokeman et al. (2005), increasing plant density from 5.7 to 14.0 plants per m-2 reduced the number of grains per ear by about 5%.

During 2011 and 2012, hybrid into population density effects on the number of grains per ear were also discovered to be significant (Table 4). When hybrid Pioneer-30Y87 (H1) was sown with a population density of 111111 plant ha-1 (P3), the highest number of grains per ear (549) was achieved. While the lowest number of grains per ear (427) was recorded in plots where hybrid Syngenta-6621(H2) was planted with plant population density P4 (166667 plants per ha), this was statistically equivalent to H1P1 (Syngenta-6621 with 66607 plants per ha), which produced grains per ear (435) in 2011 (Table 4).

During season 2012 similar trend was observed where the maximum number of grains per ear (549) was produced when hybrid Pioneer-30Y87 (H_1) was sown with population density 111111 plant ha^{-1} (P_3) while grains per ear (365) produced were minimum in number and recorded in plots where hybrid Syngenta-6621 (H_2) was planted with plant population density P_4 (166667 plants per ha).

Table 3: The impact of hybrids and population density of plants on yield components of maize yields

Treatment	**Plant height (cm)**		**No of grains per ear**		**1000-grain weight (g)**	
	2011	**2012**	**2011**	**2012**	**2011**	**2012**
A) Hybrid						
H_1 = P-30-Y-87	168.47 a	167.64 a	507.00 a	502.83 a	339.71	349.98
H_2 = S-6621	158.14 b	156.66 b	450.83 b	416.17 b	317.22	340.73
HSD 5%	1.9434	1.882	9.272	5.726	33.47	44.93
Significance	*	*	*	*	NS	NS
B) Plant Population Density (plants ha^{-1})						
P_1 = 66607	161.74 c	159.76 c	467.00 b	435.33 c	283.67 c	299.81 c
P_2 = 83333	164.82 b	163.33 b	487.33 b	480.33 b	325.83 b	330.26 ab
P_3 = 111111	168.80 a	168.31 a	518.33 a	490.33 a	362.53 a	367.20 a
P_4 = 166667	157.86 d	157.20 d	443.00 c	432.00 c	346.58 a	346.41 ab
HSD 5%	1.633	1.3978	23.712	6.318	19.42	25.53
Significance	*	*	*	*	*	*
Linear	*	*	*	*	*	*
Quadratic	NS	*	NS	NS	*	*
Interaction	NS	NS	*	*	NS	NS
Mean	163.31	162.15	478.92	459.5	329.65	335.92

Table 4: The interaction between hybrids and population density of plants on the number of grains per ear of maize

Treatment	**No of grains per ear**	
	2011	**2012**
H_1P_1	499.33 bc	458.67 c
H_1P_2	523.33 ab	504.67 b
H_1P_3	546.67 a	549.33 a
H_1P_4	458.67 d	498.67 b
H_2P_1	434.67 de	412.00 e
H_2P_2	451.33 de	456.00 c
H_2P_3	490.00 c	431.33 d
H_2P_4	427.33 e	365.33 f
HSD 5%	18.54	11.45
Mean	478.92	459.50

1000-grain weight: During both years, the maximum 1000-grain weight (339.71and 349.98 g) recorded for maize hybrid Pioneer-30Y87 was statistically at par with Syngenta-6621 which produced 1000-grain weight (317.22 and 340.73 g) during 2011 and 2012, respectively (Table 3). Plant population densities showed significant effects on the 1000-grain weight during 2011. The plant population density P3 (111111 plants ha^{-1}) had the highest 1000-grain weight (362.53 g), followed by P4 (166667 plants ha^{-1}) and P2 (83333 plants ha^{-1}). These treatments produced 346.58 and 325.83 g 1000-grain weight, respectively. The minimum grain weight per ear (283.67 g) was recorded in plots of treatment P_1 (66607 plants ha^{-1}) during the year 2011. In 2012, plots sown with P_3 treatment (111111 plants ha-1) had the highest 1000-grain weight (367.20 g), followed by P2 (83333 plants ha^{-1}) and P_4 (166667 plants ha^{-1}). During 2012, the minimum 1000-grain weight (299.81 g) was recorded in P_1 (66607 plants per hectare). Lemcoff and Loomis (1994) and Cox (1998) reported adverse impacts of increased planting density on 1000-grain weight (1996). Plant density had a favourable impact on the amount of grain produced per ear (Gokmen *et al*., 2001). The reduction in the number of grains per ear was the cause of the drop in 1000-grain weight with increasing population density. Lemcoff and Loomis (1994) and Thakur and Malhotra (1991) reported that increasing planting densities had a suppressive effect on grain weight per ear. The interactions between hybrid and plant population density were also found nonsignificant in both seasons.

Grain Yield (kg ha^{-1}): Hybrid differences in grain yield were found significant in both seasons (Table 5). The values of grain yield for both hybrids were 8.56 and 8.25 t ha^{-1} in 2011. Hybrid Pionner-30Y87 yielded more (7.66 t ha^{-1}) than Syngenta-6621 (7.08 t ha^{-1}). Plant population densities showed significant effects on the grain yield during 2011 & 2012. Average over seasons maximum grain yield (8.26 t ha^{-1}) was recorded in plant population density P_3 (111111 plants ha^{-1}) followed by P_4 (166667 plants ha^{-1}) and P2 (83333 plants ha^{-1}). These treatments produced 8.07 and 7.43 t ha^{-1}, respectively. The minimum grain yield (6.65 t ha^{-1}) was recorded in plots of treatment 66607 plants ha^{-1} (P_1). In general, when plant population density rises, yield per unit area rises but yield from a single maize plant generally declines (Bangarwa et al., 1988). Like this, Sangoi and Salvador (1998) observed that hybrids enhance grain output for each increment of 25,000 plants ha^{-1} within the range of plant densities tested. The interactions between hybrid and plant population density were also found nonsignificant in both seasons. Overall, mean values for grain yield were 7.40 and 7.81 t ha^{-1} during 2011 and 2012, respectively. The grain yield of different treatments was linearly related to TDM in both seasons. The common regression accounted for 97 and 99 % for TDM during 2011 and 2012 (Fig-7).

Table 5: Effect of hybrids and plant population density on yield and yield components

Treatment	Grain Yield (kg ha^{-1})		Total dry matter (t ha^{-1})		Harvest Index (%)	
	2011	2012	2011	2012	2011	2012
A) Hybrid						
H$_1$ = P-30-Y-87	7.39 a	7.92 a	17.36 a	18.21 a	42.59	43.52
H$_2$ = S-6621	7.08 b	7.70 b	16.78 b	17.82 b	42.22	43.19
HSD 5%	0.281	0.207	0.48	0.35	2.5	2.87
Significance	*	*	*	*	NS	NS
B) Plant Population Density (plants ha^{-1})						
P$_1$ = 66607	6.26 c	7.04 c	15.62 c	16.91 c	40.11 bc	41.62
P$_2$ = 83333	7.17 b	7.70 b	17.28 b	17.91 b	41.47 ab	43.00
P$_3$ = 111111	8.17 a	8.34 a	18.72 a	18.95 a	43.67 a	44.01
P$_4$ = 166667	7.98 a	8.16 a	18.48 a	18.70 a	43.20 a	43.65
HSD 5%	0.75	0.52	0.8	0.94	2.73	2.71
Significance	*	*	*	*	*	NS
Linear	*	*	*	*	*	NS
Quadratic	*	*	*	*	NS	NS
Interaction	NS	NS	NS	NS	NS	NS
Mean	7.4	7.81	17.52	18.12	42.11	43.07

P-30-Y-87: Pioneer-30-Y-87, S-6621: Syngenta-6621, * = Significant at 5%, NS = non-significant. The means sharing different letters differ significantly at P = 0.05

Total dry matter (t ha^{-1}): Averaged over location maximum TDM was accumulated by Pioneer-30Y87 (17.78 t ha^{-1}) that was statistically different with Syngenta-6621 that produced total dry matter 17.30 t ha^{-1} (Table 5). Plant population densities showed significant effects on the total dry matter (TDM) during 2011 & 2012. Average over seasons maximum TDM (18.83 t ha^{-1}) was recorded in plant population density P3 (111111 plants ha^{-1}) followed by P$_4$ (166667 plants ha^{-1}) and P2 (83333 plants ha^{-1}). These treatments produced 18.59 and 17.59 t ha^{-1}, respectively. The minimum TDM (16.26 t ha^{-1}) was recorded in plots of treatment 66607 plants ha^{-1} (P$_1$). Several researchers have documented differences in the dry matter (DM) production of maize at various planting densities, which supports the present study's conclusions. According to Bangarwa et al. (1988), noticed an increase in DM accumulation per unit area. According to Tollenaar and Bruulsema (1988), the crop showed identical behaviour at PPDs of 3.9, 8, or 10 plants m^{-2}. Overall, mean values for grain yield were 17.52 and 18.12 t ha^{-1} during 2011 and 2012, respectively.

Harvest Index: Data (Table 5) showed that cultivar's effects were nonsignificant on the harvest index of maize in both seasons. However, values ranged from 42.22 to 43.52% between hybrids.

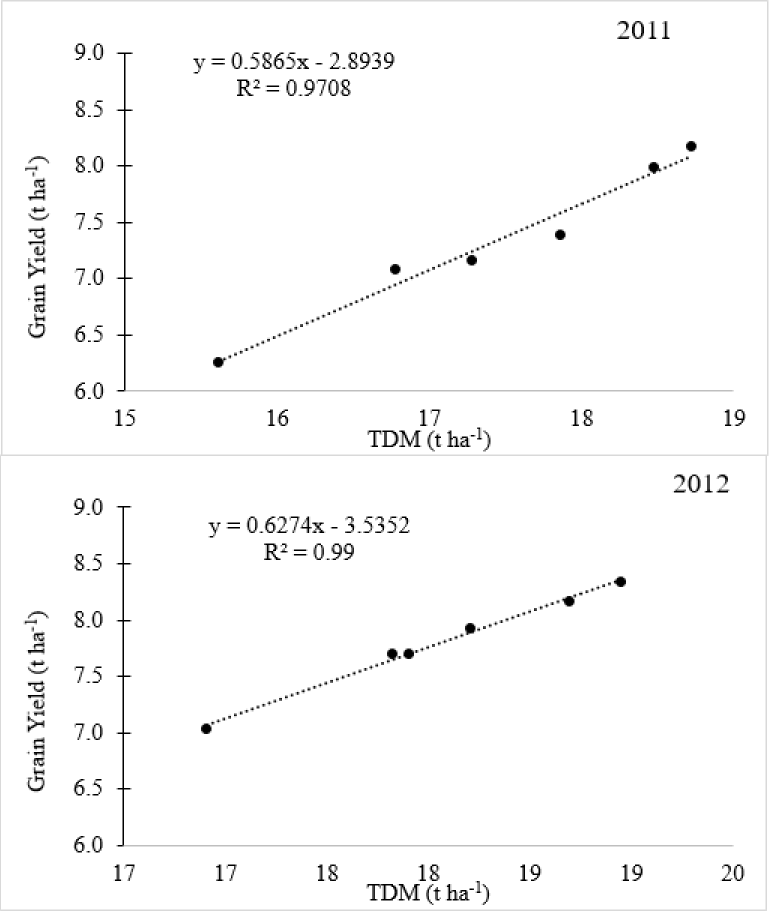


Fig 7: Relationship between grain yield and TDM of maize sown with different planting densities

Plant population densities showed significant effects on the Harvest Index (HI) during 2011 & 2012. Average over seasons maximum HI (43.84%) was recorded in plant population density P3 (111111 plants ha^{-1}) followed by P4 (166667 plants ha^{-1}) and P2(83333 plants ha^{-1}). These treatments produced 43.53 and 42.24 t ha^{-1}, respectively. The minimum HI (40.87 t ha^{-1}) was recorded in plots of treatment 66607 plants ha^{-1} (P_1). This suggests that HIs could be enhanced up to a specific planting density and that additional increases in plant population would lead to lower values for harvest indices. More cob-yielding plants per unit area and more grains per cob may be the cause of better harvest indices at higher planting densities. It has been determined by more recent investigations (Tollenaar and Lee, 2006) to be the outcome of increasing barrenness at higher concentrations. According to Kiniry et al. (2005), HI generally responds to plant density. When plant density was below 10 plants per m^2, HI stayed steady, but once it exceeded this point, HI fell at a rate of -0.012 units per plant per m2. With plant densities under 10 plants m^{-2}, Kiniry et al. (2005) observed an essentially constant HI.

CONCLUSIONS

Optimizing maize productivity involves selecting appropriate varieties suited to local conditions and managing plant population density to balance resource competition and environmental factors. Both factors are interdependent and must be considered together to achieve maximum yield and sustainable production. Based on the results, it is determined that maize hybrid Pioneer-30Y87 should preferably be grown with a planting density of 111111 per hectare keeping plant-to-plant spacing of 20 cm and row-to-row spacing of 60 cm for obtaining high yields.

Contribution Statements: Wasi-ud-din executed the field research whereas AK, AT, and AW conceived the idea and supervised the work.

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