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Yield and Yield Components of Maize as Affected by Planting Density

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Authors' contributions

This work was carried out in collaboration among all authors. Author MFS wrote the protocol, conducted the field experiments and wrote the first draft of the manuscript. Author MMB supervised and designed the research work. Authors KMMI and TKR managed the literature searches, analyzed the data of the research and helped in manuscript preparation. Author MMKA also helped the literature searches and collected data from field. All authors read and approved the final manuscript.

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ABSTRACT

An experiment was carried out to investigate the effect of planting density on growth, development, yield and yield components contributing characteristics of maize during the period of November, 2012 to March 2013 in the Research Field and Laboratory of Crop Physiology and Ecology Department, Hajee Mohammad Danesh Science and Technology University, Dinajpur, Bangladesh. The experimental area belongs to Old Himalayan Piedmont Plain (AEZ-1) of Bangladesh having sandy loam soil with pH 6.1. The experimental treatments were five plant spacing (S_1=75 cm X 25 cm, S_2=75 cm X 20 cm, S_3=60 cm X 25 cm, S_4=65 cm X 20 cm and S_5=50 cm X 25 cm) corresponding to 35,000, 50,000, 60,000, 80,000, 95,000 plants ha^{-1} respectively with one maize variety. The experiment was laid out in a single factor Randomized Complete Block Design (RCBD) with four replications. The experiment plots were divided into four blocks each representing a

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replication. Growth parameters, some phenological parameters such and some yield and yield attributes increased with decreased in plant the plant population. The highest grain yield of 5.65 t/ ha was produced at (S_5) high planting density (95,000 plants ha^{-1}) and the lowest grain yield of 4.21 t/ha was produced at (S_1) lowest planting density (35,000 plants ha^{-1}).

Keywords: Maize; growth parameter; phenological parameters; planting density; yield and yield attributes.

1. INTRODUCTION

Maize (*Zea mays* L.) is the third most important cereal crops in Bangladesh ranks after rice and wheat [1]. Its demand is increasing day by day as various food items, fodder for livestock, feeds for poultry, fuel and raw materials for industry. The total production of maize in 2011-12 in Bangladesh was 1298 thousand metric ton [2]. The area planted for maize in Bangladesh has risen from just a few thousand ha in 2003-04 to a total of 487000 acres in 2011-12 cropping year, and expanded rapidly at an average rate of 20% per year. Hybrid maize has been introduced in our country due to its high yield potentiality. Hybrid maize, due to its high grain yield as a result of heterosis (“hybrid vigor”), is preferred by farmers over conventional varieties. Maize produces a greater quantity of epigeous mass than other cereals, so it can be used as fodder. The shortage of animal green fodder is acute in Bangladesh.

For maximum production of maize, judicious fertilizer application is very much important. On the other hand, establishment of plant population through optimum spacing is another factor for securing good yield of maize.

Depending on the variety, a maize plant produces 15 to 20 leaves [3] during its life cycle. Canopy structure of maize is such that adjoining leaves overlap one another and develop mutual shading. Yield is a function of inter plant and intra plant competition. Competitions associated with different plant population. Researchers have shown that weaker plants become barren when plant population was increased to a greater extent. These plant utilized water and nutrients but contributed to lower yield. As such there is a considerable scope for increasing yield by adjusting plant population to an optimum level [4]. Adjustment of proper plant spacing in the maize field is important to ensure maximum utilization of solar energy by the crop and reduce evaporation of soil moisture. Radiation is intercepted by the leaf surface and the efficiency of its use in developing biomass governs the total dry matter production. Optimum population levels should be maintained to exploit maximum natural resources, such as nutrients, sunlight, soil moisture etc. to ensure satisfactory yield. Very closest planting is undesirable because it encourages inter-plant competition for resources. Biomass production of a crop largely depends on the function of leaf area development and consequential photosynthetic activity [5].

In the developing countries like Bangladesh the cultivated land is decreasing year by year due to population pressure. Maximum exploitation of the yield potentiality of a crop must be ensured, developing appropriate production technologies, to feed the ever increasing population. Maximum effort must be given to realize highest yield from a limited land. There is limited information on optimization of population density per unit area for maximum harvest of maize. The present investigation was carried out to find out the effect of spacing on growth and development of maize and evaluate the effect of spacing on yield and yield contributing characteristics of maize.

2. MATERIALS AND METHODS

2.1 Experimental Site and Soil

A field experiment was conducted at Research Field and Laboratory of the Department of Crop Physiology and Ecology at Hajee Mohammed Danesh Science and Technology University, Dinajpur during the period of November, 2012 to March, 2013. The experimental area was located on latitude 25°38’ N and longitude 88°41’ E and at the elevation of 34.4 m above the sea level. The experimental site was medium high land and belonging to the Agro-ecological Zone-1 (AEZ-1) named Old Himalayan Piedmont Plain (FAO and UNDP 1988). The soil was sandy loam. Irrigation facilities and drain out system of excess water was well developed. Soil characteristics of experiment site at a depth of 0-15 cm were analyzed at the Regional Laboratory of Soil Resources Development Institute (SRDI), Dinajpur.

2.2 Experimental Design and Treatments

The experiment was laid out in a single factor Randomized Complete Block Design (RCBD) with four replications. The experiment plots were divided into four blocks each representing a replication. Each block was then divided into five unit plot each of 4 m×4 m size. The row to row spacing of 75 cm, 75 cm, 60 cm, 65 cm and 50 cm and the plant to plant distance was kept 25 cm, 20 cm, 25 cm, 20 cm and 25 cm being treatments 1-5, thus S_1, S_2, S_3, S_4 and S_5 respectively. The experiment consists of five different planting densities: 35,000; 50,000; 60,000; 80,000; 95,000 plants per hectare, S_1, S_2, S_3, S_4 and S_5 respectively. Each treatment was replicated four times in the research field.

2.3 Field Operation

The land was prepared properly by ploughing with a disc plough followed by harrowing and laddering until a good tilth was obtained. Clods were brokon and weeds and stubbles of the previous crops were removed from the field during the land preperation. The plots were prepared and leveled smoothly according to the design and layout of the experiment.

Fifteen days ahead of sowing whole amount of cow dung was applied. Different fertilizer was applied such as urea, TSP, MP, Gypsum, Zinc sulphate, boric acid and half of urea was applied as the basal dose. The remaining half of urea was top dressed in tow equal splits, first half at knee height stage i.e. 30 days after sowing (DAS) and the rest half at about one week before silking (50 DAS).

Table 1. Fertilizer application

Nutrients	Nutrient dosed (kg/ha)	Source
N	180	Urea
P	24	TSP
K	60	MP
S	12	Gypsum
Zn	20	Zinc sulphate
B	1.0	Boric acid

As plant material, maize hybrid variety NK-40 was used, which marketed by Syngenta, Bangladesh.

The seeds of the NK 40 were treated with vitavex-200 at the rate of 2.5 g kg^{-1} of seeds before sowing. Seeds were sown in November, 2013 in lines with plant spacing 75 cm× 25 cm, 75 cm × 20 cm, 60 cm × 25 cm, 65 cm × 20 cm, 50 cm × 25 cm corresponding to 35,000, 50,000, 60,000, 80,000, 95,000 plants ha^{-1} respectively. Two seeds were sown /hill and later thinned to one plant/hill. Thinning was done at 3-4 leaves stage. The seedlings emerged within 7 days after sowing. To maintain desired plant population, gap filling was done by sowing seeds in missing hills. All other agronomic operations were kept normal and uniform for all treatment.

During the growing period, the experimental land was irrigated three times, first at 30 DAS, the second at 55 DAS and the third at 80 DAS.

Weeding was done twice during the growing period. The first weeding was carried out at 25 DAS and the second one at 55 DAS.

Earthing-up was made twice during the growing period first at 30 days after sowing. The second one was preceded by top dressing of remaining half of urea.

2.4 Sampling and Data Collection

Records on the emergence of seeds were taken every alternate day's up to 10 days after sowing and finally the percentage of emergence was calculated. Variation of days required to emergence of seeds in each plots were also recorded.

Three plants per plot were randomly selected and data were collected at 30 days intervals starting from 30 DAS and continued till maturity. The plant height and leaf number of those plants were recorded, plant height was measured from the base to tip, after that leaves, stem, and cobs (when present) were separated and their corresponding dry weights were taken after being oven dried at 80ºC for 72 hours. Before oven drying, total leaf area per plant was measured by placing in an electronic automatic area meter (Model-L 13000, LI-COR, Nebraska, USA).

Initially the entire sample from a plot was considered for observation. But with the advancement of growth, when bulk of sample increased, a sub-sample representing at least 25% of the fresh matter was used. Comparing the sub-sample with total harvest, leaf area and dry matter were calculated. Standard growth analyses were furnished such as leaf area index (LAI), and crop growth rate (CGR).

I) Leaf area index (LAI): It is the ratio of leaf area and ground area of a plant which was calculated from the following formula:

$$LAI = \frac{1}{P} LA$$

Where, P = Ground area
LA = Total leaf area

II) Crop growth rate (CGR): Rate of dry matter production per unit time per unit land area. The crop growth rate was calculated by using the following formula:

$$CGR = \frac{W_2 - W_1}{P(T_2 - T_1)} g/m^2/day$$

Where, W_1 = Total dry weight at time T_1
W_2 = Total dry weight at time T_2
P = Ground area

2.5 Statistical Methods of Analyses

All the necessary parameters were recorded and analyzed statistically. A program called Microsoft Excel 2000 was used for the spreadsheet analysis and numerical calculations. The collected data were analyzed statistically using the analysis of variance (ANOVA) technique with the help of computer by program. The treatment means were compared by Duncan's New Multiple Range Test (DMRT).

3. RESULTS AND DISCUSSION

Plant height is an important component which helps to determine the growth attained during the growth period. The data showed that plant height was significantly affected by plant spacing (Fig. 1). The tallest plants were recorded in S_1 (75 cm X 25 cm) at different days after sowing. Short statured plants were recorded in S_5 (50 cm X 25 cm) at different days after sowing due to crowding effect of the plant and higher intra specific competition for resources. This trend explains that as the number of plants increased in a given area the competition among the plants for nutrients uptake and sunlight interception also increased [6]. Similar result was also reported by [7], where they noticed that higher plant height were recorded in higher spacing and lower plant height was found in lower plant spacing in maize.

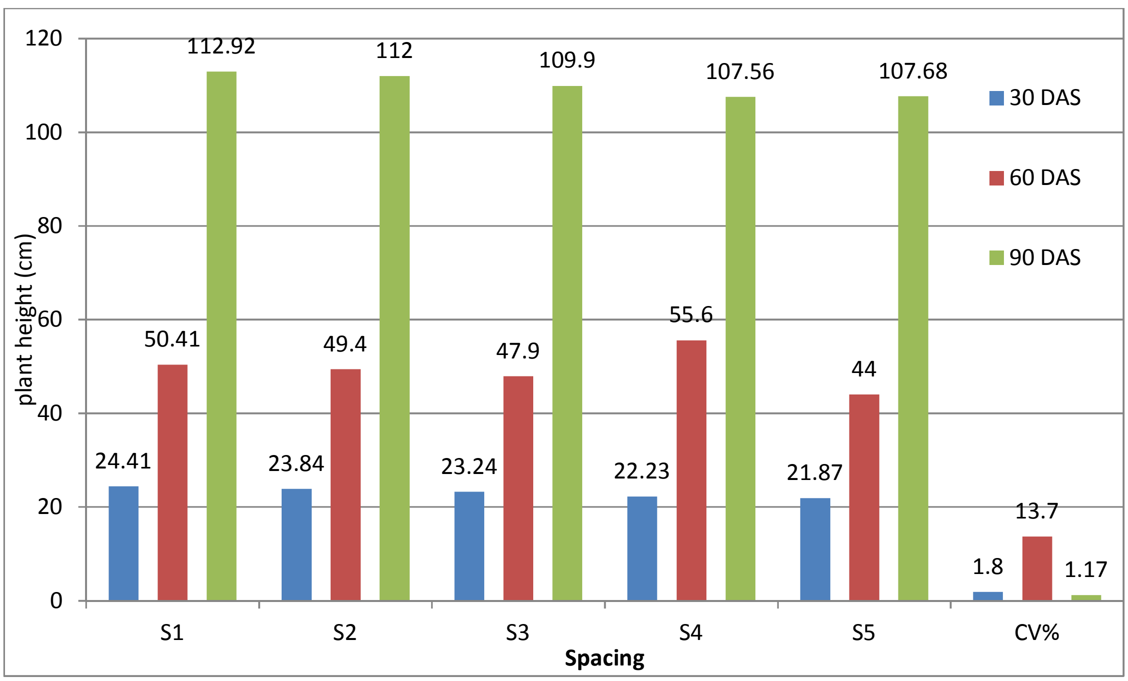

Fig. 1. Effect of plant density at different days after sowing (DAS) on plant height

Leaf number(s) is an important component for plant growth and development. The figure showed that leaf number was significantly affected by plant spacing (Fig. 2). The higher leaf numbers per plant were recorded in S_1 (75 cm X 25 cm) at different days after sowing. Lower leaf number per plant were recorded in S_5 (50 cm X 25 cm) at 90 days after sowing due to crowding effect of the plant and higher intra specific competition for resources. Leaf number was greater at the low population density than at high population density. This decrease number of leaves resulted from greater inter-plant completion at higher plant densities [8]. Similar result was also reported by [7] and [9].

Plant density affected leaf area per plant and significant difference were observed between the highest and lowest populations. The result showed that leaf area was significantly affected by plant spacing (Fig. 3). The highest leaf area per plant (192.50a, 449.00b and 1119.75) was recorded in S_1 (75 cm X 25 cm) at different days after sowing. The lowest leaf area per plant (142.09c, 363.00b and 927.50) were recorded in S_5 (50 cm X 25 cm) at different days after sowing due to crowding effect of the plant and higher intra specific competition for resources and due to less competition for assimilates at lower plant density. Leaf area reduced with higher plant density and this might be due to less competition for assimilates at lower plant density, hence more average leaf area were produced in lower population density. Leaf area slowly increased at the early stage of plant growth and 60 days after sowing leaf area increased sharply and thereafter reduced slowly.

The effect of plant spacing on total dry matter (g/m^2) production of maize are presented in Fig. 4. Total dry matter production varied significantly due to different spacing of maize. It was observed that TDM increased gradually from 30 DAS to 60 DAS and thereafter increased sharply with the advancement of growth period. However, result indicated that TDM increased with the decreasing of plant density till 120 DAS. Higher dry matter accumulation was observed among the plants of higher population densities. Higher dry matter per unit area was obtained due to higher number of plants of the area but dry matter per plant was lower in relation to lower plant densities. In all cases, S_5 (50 *cm X 25 cm)* produced higher TDM and S_1 (*75 cm X 25 cm)* produced lower TDM in every sampling. Similar result was reported by [11,13] in maize and [14] in wheat.

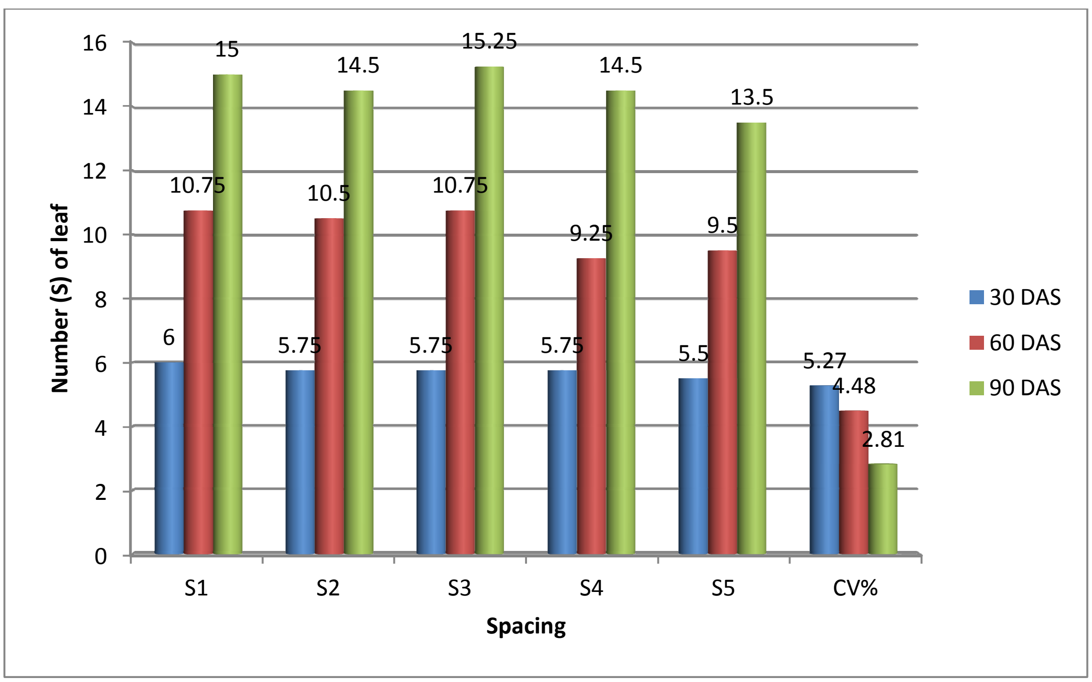

Fig. 2. Effect of plant density at different days after sowing (DAS) on leaf number (s) per plant

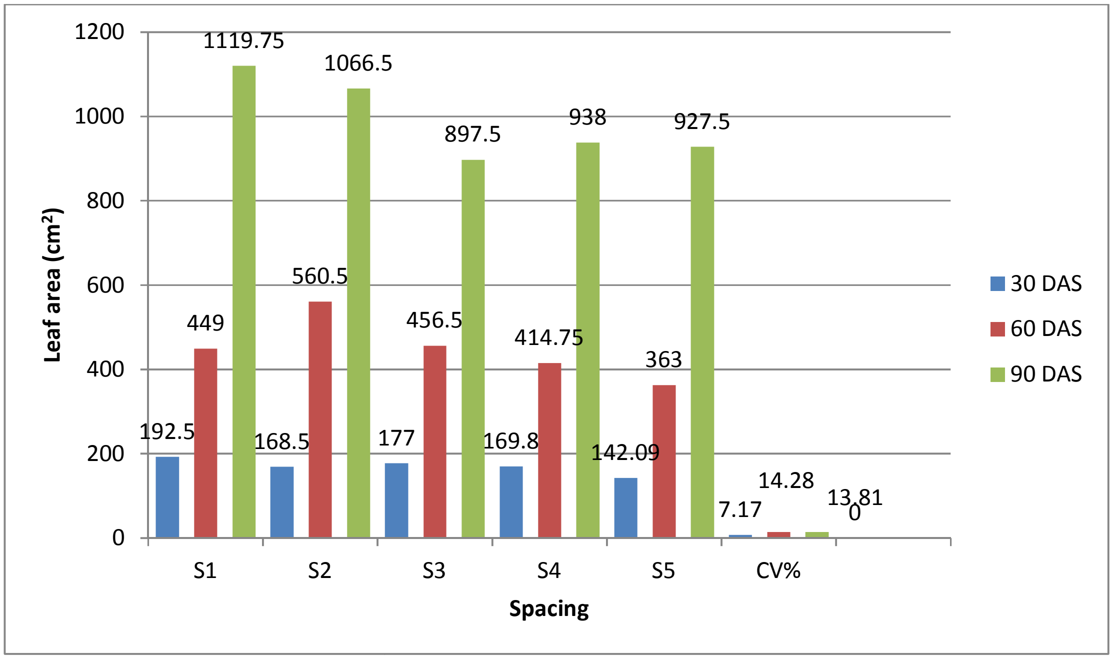

Fig. 3. Effect of plant density at different days after sowing (DAS) on leaf area per plant

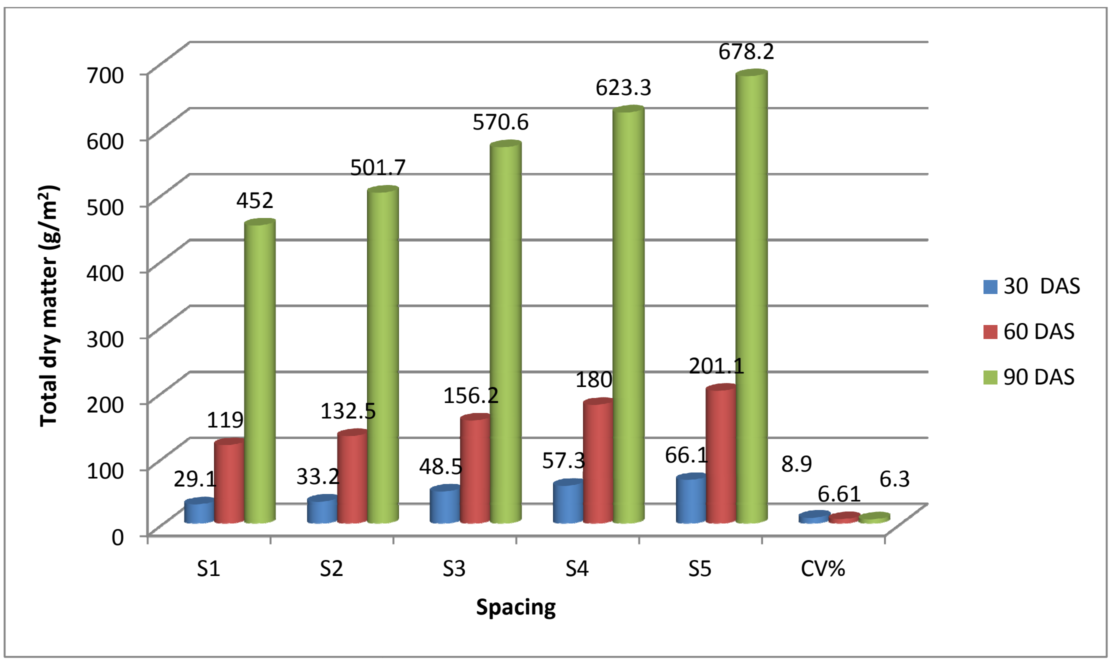

Fig. 4. Effect of plant density at different days after sowing (DAS) on total dry matter of plant

Effect of plant spacing on crop growth rate was presented in Table 2. Crop growth rate was significantly influenced due to plant spacing of maize. At the early stages of plant growth CGR was very low than increased sharply up to 90 DAS and thereafter shown a declining pattern in all cases. In all cases, S_5 produced higher CGR (5.30a, 8.00a and 24.60a) and S_1 produced lower CGR (2.40c, 5.50d and 16.70d) in every sampling. Similar result was reported by [12,15,16] in maize. They reported that CGR increased with the highest population per m^2.

The evaluation of leaf area index for different plant spacing is shown in (Table 2). Leaf area index varied significantly due to plant spacing in maize. Leaf area index values were increased progressively starting from 30DAS and up to 90DAS and afterwards declined in the same way till maturity. The declining of leaf area index after attaining a peak value was due to leaf rolling and senescence with aging. Similar result was reported by [17,18,19]. In all cases, S_5 produced higher LAI (1.02a, 2.94a and 4.70a) and S_1 produced lower LAI (0.40d, 1.17d and 2.93c) in every sampling.

The number of days required to tasseling is presented in Table 2. Days to tasseling was significantly influenced by plant spacing. Spacing S_3 (60 cm X 25 cm) showed the lowest day (56.10) required for tasseling on the other hand S_2 (75 cm X 20 cm) required the highest day (57.14) for tasseling. The other population showed the moderate day required for tasseling in maize.

An experiment was conducted by [18] with three plant densities (67000, 89000 and 95000 plants/ha) at National Livestock Research Institute in Suwan, Korea Republic, during 2001 to 2002. They observed that tassel length increased with decreasing planting density. [7] conducted an experiment with five plant densities ranging from 35,000 to 95,000 plants/ha and observed that tasseling of maize (var. Barnali) delayed with increased plant density. [20] reported that the lowest days required to 50% tasseling was needed with low planting density and also reported that, lowest days needed to 50% silking with low planting density. They also found that time of silking and maturity delayed with increased plant density.

The number of days required to silking is presented in Table 2. Days to silking was significantly influenced by plant spacing of maize. Spacing S_3 (60 cm X 25 cm) showed the lowest days (80.03) required for silking on the other hand S_5 (50 cm X 25 cm) showed the highest day (80.62) required for silking. The other population showed the moderate day required for silking. [20] reported that the lowest number of days to 50% silking was needed for low planting density.

The days required to maturity is presented in Table 2. Days to maturity was significantly influenced due to plant spacing. The minimum days (108.00 days) needed for maturity was recorded in S_1 (75 cm X 25 cm) and S_2 (75 cm X 20 cm) and the maximum days for maturity (110.20 days) were recorded in S_5 (50 cm X 25 cm).

Number of cobs per plant was insignificant due to different plant spacing (Table 3). The number of cob per plant was increased with increasing plant spacing. The maximum number of cob per plant (1.33) was observed in S_1 and S_3 and the minimum number of cob per plant (1.25) was observed in S_4 plants. [7] and [21] reported a significantly higher number of cobs per plant at lower plant density compared to higher plant density. Significant variation in cob length was found with the changing of plant spacing (Table 3). The maximum cob length (92.50 cm) was found in S_1 and the minimum cob length (88.75 cm) was observed in S_5. This result was supported by the findings [22] and [23]. They found that higher plant densities produced smaller cob compared with the traditional plant density of maize.

Table 2. Effect of plant density on crop growth rate, leaf area index and phenological parameters of maize

Spacing	Effect of plant density at different days after sowing (DAS) on								
	Crop growth rate (CGR)			Leaf area index (LAI)			Some phenological stages		
	30-60 DAS	60-90 DAS	90-120 DAS	30 DAS	60 DAS	90 DAS	Days to tasseling	Days to silking	Maturity
S_1	2.40c	5.50d	16.70d	0.40d	1.17d	2.93c	56.20	80.07	108.00
S_2	3.70bc	6.25c	18.30cd	0.53c	1.72c	2.92c	57.14	80.04	108.00
S_3	4.00b	6.60c	20.10c	0.64b	1.95b	3.67b	56.10	80.03	109.30
S_4	5.10a	7.30b	22.20b	0.71b	2.01b	3.94b	56.48	80.05	109.70
S_5	5.30a	8.00a	24.60a	1.02a	2.94a	4.70a	56.85	80.62	110.20
CV%	10.8	4.40	5.90	7.45	3.69	12.93	1.47	0.81	2.79

Table 3. Yield and yield attributes of maize as influenced by different plant spacing

Spacing	Number of cob per plant	Cob length	Cob length with cover	Cob length without cover	Cob diameter	Number of grain rows per cob	Number of grains per row	100-grain weight	Yield (t/ha)	Harvest index (HI)
S_1	1.33a	92.50a	39.25a	21.50ab	4.50a	13.75a	32.50a	35.03a	4.21d	38.96a
S_2	1.28ab	92.25a	35.50b	22.00a	4.50a	13.75a	32.50a	34.39ab	4.60cd	38.02ab
S_3	1.33a	90.00ab	33.00bc	20.50bc	4.34b	13.25ab	31.00ab	33.85b	5.15bc	36.91ab
S_4	1.25b	90.25bc	33.00bc	20.00c	4.28b	12.75bc	29.75bc	32.35c	5.60ab	35.88ab
S_5	1.30ab	88.75c	32.25c	20.75abc	4.25b	12.25c	28.50c	31.81c	5.65a	33.96b
CV%	2.72	1.32	5.84	4.04	1.74	3.67	3.84	1.99	7.4	7.3

In a column, figures having same letter (s) do not differ significantly at $p < 0.05$ by DMRT. Here, S_1= 75 cm X 25 cm, S_2= 75 cm X 20 cm, S_3= 60 cm X 25 cm, S_4= 65 cm X 20 cm and S_5= 50 cm X 25 cm

Significant variation in cob length with cover was found with the variation of spacing (Table 3). The maximum cob length with cover (39.25 cm) was found in S_1 and the minimum cob length with cover (32.25 cm) was observed in S_5. The present result was supported by the findings of [23]. They found that higher plant densities produced smaller cob compared with the traditional plant density of maize.

Significant variation in cob length without cover was found with the variation of spacing (Table 3). The maximum cob length without cover (22.00 cm) was found in S_2 and the minimum cob length without cover (20.00 cm) was observed in S_4. The present result was supported by the findings of [22,23]. They found that higher plant densities produced smaller cob compared with the traditional plant density of maize.

Significant variation in cob diameter was found with the variation of spacing (Table 3). The maximum cob diameter (4.50 cm) was found in S_1 and S_2 and the minimum cob diameter (4.25 cm) was observed in S_5. The present result was supported by the findings of [22,23]. They found that decreasing spacing increased the cob diameter of maize.

Number of grain rows per cob was significantly influenced by plant spacing (Table 3). Number of grain rows per cob increased with increasing plant spacing. The maximum number of grain rows per cob (13.75) was observed in S_1 and S_2 and the minimum number of grain rows per cob (12.25) was observed in S_5 plants. The result was supported by [20]. The number of grain rows per cob decreased as the plant population increased. Usually under high population stress, the late developing distal spikelets fail to set kernels and when the slow growing silks finally emerge, little or no pollen is available for fertilization. Also, high stand density reduces ear shoots growth, which results in fewer spikelets primordial was transformed into functional florets by the time of flowering. The limited carbon and nitrogen supply to the cob finally stimulates young kernel abortion immediately after fertilization [24].

The number of grains per row is an important yield parameter. Number of grains per row was significantly influenced by spacing (Table 3). Number of grains per row increased with increasing spacing. The maximum number of grains per row (32.50) was observed in S_1 and S_2 and the minimum number of grains per row (28.50) was observed in S_5 plants. These result was supported by the findings of [25,26] where they observed that an increase in plant density decrease the number of grains per row in maize.

100-grain weight was significantly influenced by plant spacing (Table 3). 100-grain weight increases with increasing spacing. The maximum 100-grain weight (35.03 g) was observed in lowest spacing of S_1 and the minimum 100-grain weight (31.81 g) was observed in S_5. The result was supported by [22], where they found that decreased 100-grain weight with decreasing spacing.

Grain yield is the main target of crop production. Plant spacing significantly influenced the grain yield of maize (Table 3). The highest grain yield (5.65 t/ha) was observed in S_5 spacing followed by S_4 (5.60 t/ha) and the minimum grain yield (4.21t/ha) was observed in widest spacing S_1. Similar effect of spacing on grain yield was reported by [27,22].

The closest spacing put the crop under high intra and inter-specific competition cause low rate of nutrient absorbing and capturing at vegetative and grain filling stages, resulting in relatively low magnitude of all the yield attributes coupled with shortening of crop life and forced maturity during vegetative phase and maturity adversely affected plant height, the number of cob per plant and the number of grains per cob, which ultimately reduced the grain yield per plant. On the other hand, the higher yield obtained from S_4 and S_5 condition were mainly favored for all supportive factors, probably supported the physiological processes and thereby attributed to higher number of plant per hectare lead to higher number of cob per hectare as well as higher number of total grains per hectare and higher 100 grain weight [7] also found similar results in their experiments.

The results are also in agreement with findings of [25] where they observed the minimum grain yield per plant at the highest population densities. [28] also found that grain yield per plant is decreased due to decreasing light and other environmental resources. A similar trend in yield differences across planting density had been reported by [29]. [30] also reported that grain yield increased with increase plant density. [31] also found that high plant density causes stress to plants and reduces plant growth in maize resulting lower yield per plant.

The physiological efficiency and ability of a crop for converting the total dry matter into economic yield is known as harvest index (HI). Plant densities showed significant difference for harvest index. On the other hand, harvest index gradually decreased with increasing plant density. Among the different spacing, S_1 showed highest (38.96%) HI and S_5 had the lowest (33.96%) HI.

Mobasser et al. [32] reported that harvest index in rice declines when plant density increases above the critical plant density. The yield/plant may be reduced due to the effects of interplant competition between plants for using of light, water, nutrients and other yield-limiting environmental factors. Similar results was reported by [33] in maize hybrids of their experiment. Means comparisons indicated the maximum (0.34%) harvest index was recorded for SC-504 hybrid and minimum value was recorded for DC -370 hybrids (0.26%).

4. CONCLUSION

The phenological parameters (days to tasseling, silking and maturity) growth parameters (plant height, leaf number, leaf area, TDM, LAI, CGR, Stem and cob) and yield and yield attributes (cob length, Number of cob per plant, Cob length with cover, Cob length without cover, Cob diameter, Number of grain rows per cob, Number of grains per row, 100-grain weight, grain yield and harvest index) were significantly affected by plant spacing. These trends explain that as the number of plants increased in a given area the competition among the plants for nutrients uptake and sunlight interception also increased. So it can be concluded that the higher yield attributes and grain yield per plant of maize could be obtained from higher planting density S_5. So higher grain yield of maize (5.65 t/ha) would be obtained from higher planting density and this influence on grain yield per unit area was due to greater number of plant per unit area.

COMPETING INTERESTS

Authors have declared that no competing interests exist.

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