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Research Article

# Plant population is the function of grain yield of maize

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## Abstract

A field experiment on hybrid maize with different plant population density was conducted at the Agronomy field of BARI, Joydebpur, Gazipur during the consecutive *rabi* season of 2019-2020 and 2020-2021. Five plant population density viz; $T_1$= 66666 plants/ha (75cm × 20cm spacing: 6.67 plants/m$^2$), $T_2$= 83333 plants/ha (60cm × 20cm spacing:8.33 plants/m$^2$), $T_3$=100000 plants/ha (50cm × 20cm spacing:10 plants/m$^2$), $T_4$=125000 plants/ha (40cm × 20cm spacing:12.5 plants/m$^2$) and $T_5$=166666 plants/ha (30cm × 20cm spacing:16.67 plants/m$^2$) were used in the experiment. LAI (leaf area index) and TDM (total dry matter) increased with the increase of plant population, those influenced grain yield of maize. The highest grain yield (10.12-10.78 t/ha) was recorded in $T_3$ (100000 plants/ha) and the lowest (5.02-5.33t/ha) in $T_5$ (166666 plants/ha) treatment. Functional relationship between plant population and grain yield of maize was established as $Y = 2.0795x-0.1067x^2$; ($R^2 = 0.92$). The effect of plant population on the grain yield of maize could be explained 92% by the functional model. The co- efficient indicated that increase of one plant/m$^2$ would increase grain yield at the rate of 2.0795 t/ha up to a certain limit. The estimated optimum plant population was 9.74 plants/m$^2$ (974000 plants/ha) through functional model. Then the predicted maximum grain yield would be 10.13 t/ha at that optimum plant population of 9.74 plants/m$^2$ (974000 plants/ha). There existed a good consistency between observed and predicted grain yield of maize ($r=0.96$ at $p<0.01$ and $R^2=0.97$; using the developed functional model).

## Introduction

Maize (*Zea mays* L.) plays an important role for meeting up the high food demand of the growing human population of the world and is globally one of the most widely cultivated crops [1]. Both the land area and yield of maize for grain production have been boost up in the recent years [1]. Maize productivity has increased globally as a result of improved genetics and agronomic practices [2]. Plant population and row spacing are two key agronomic factors having a great influence on maize grain yield [3]. Maize grain yield increased as the plant population increased [4,5]. The optimum plant population depends on several crucial factors, including soil fertility, soil water-holding capacity, hybrid group and crop management [6,7]. Interaction between plant genotype and plant population have influence on grain yield showing a positive relationship between maize grain yield and plant population in modern hybrids [8]. Agronomic practices like fertilization, irrigation, effective weed control and tillage practices can change the relationship between population density and maize grain yield. Plant populations affect most of the growth parameters of maize even under optimal growth conditions. Therefore, it is considered as a major factor determining the degree of competition among the plants resulting growth and yield variation of maize [9]. The grain yield per plant reduced due to decreasing availability of light and other growth resources in crowed plant population [10,11]. Plant population changes crop canopy, growth behavior and developmental events and grain production of maize. At low densities, many modern maize varieties do not produce more than one effective cob/ear per plant. Whereas, the use of high population densities increased interplant competition for light, water and nutrients,



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which might be detrimental producing lower grain yield per plant [12]. Maize is an important food crop ranking the third most important cereal crop of Bangladesh after rice and wheat. In Bangladesh, grain yield of maize is very low as compared to other maize growing countries [13]. There is a number of biotic and abiotic factors those affect maize yield considerably. However, it is more affected by variations in plant density than other member of the grass family [14]. Maize differed greatly in its various responses to plant density [11]. Higher population enhances interplant competition for space, light, water, nutrients and other growth resources those affects final yield formation resulting less ears per plant and kernels per ear [15]. Maize yield model may serve to find out appropriate solution for decision making about the optimum plant population. Simple yield models have been developed to predict yield of wheat, maize and pea [16]. At present, model may be used to predict yield and to estimate optimum plant population of crop. Recommended plant spacing for maize is 60 cm × 20 cm (corresponding to 83333 plants/ha) in Bangladesh [3,17]. But the farmers of the country usually use closer spacing for maize cultivation to get higher grain yield. Biomass production of crops is closely related to plant population. Therefore, it is imperative to adjust optimum plant population accordingly to achieve maximum grain yield. Recently, scientist attempted to qualify the optimum plant population/ears/cobs of cereal crops through functional modeling [18]. The traditional growth analysis model expresses crop growth over time with some assumptions and limitations [19,20]. However, these limitations are overcomed with the help of functional models which smoothen the crop growth curve [21,22]. Therefore, this trial was executed to adjust the optimum plant population of maize through assessing functional yield model.

## Materials and methods

The experiment was conducted at the Research field of Bangladesh Agricultural Research Institute, Gazipur, during two consecutive season of 2019-2020 and 2020-2021. Five plants spacing, viz; $T_1$= 66666 plants/ha (75 cm × 20 cm spacing: 6.67 plants/m²), $T_2$= 83333 plants/ha (60cm × 20cm spacing:8.33 plants/m²), $T_3$=100000 plants/ha (50cm × 20cm spacing:10 plants/m²), $T_4$=125000 plants/ha (40cm × 20cm spacing:12.5 plants/m²) and $T_5$=166666 plants/ha (30cm × 20cm spacing:16.67 plants/m²) were used in the experiment. The experiment was laid out in a randomized complete block design with three replications. The unit plot size was 4.5m × 5m. Seeds (variety: BARI Hybrid Maize-9) were sown on 8 November 2019 and 4 November 2020. Fertilizers were applied at the rate of 275-75-120-60-5-2 kg/ha of N-P-K-S-Zn-B [23] as urea, Triple Super Phosphate (TSP), Muriate of Potash (MoP), gypsum, zinc sulphate and boric acid. One third of urea, whole amount of TSP, MoP, gypsum, zinc sulphate and boric acid were applied as basal dose. Remaining 2/3 Urea was top dressed at 35 and 55 days after sowing (DAS) followed by irrigation. Three irrigations were given when it was necessary to maintain adequate soil moisture. Plants were sampled at different DAS (Days After Sowing) for leaf area and dry matter accumulation. Leaf area was measured by an automatic area meter (LI 3100 C, LI-COR, USA). For dry matter, plant samples were dried in an oven at 80°C for 72 hours. Optimum plant population of maize was estimated through the following functional model like $Y= a+ bx- cx^2$.

where optimum plant population for maximum grain yield would be= $-b/2c$. The model was developed with computer based X-cell programme (2016). The values of grain yield from two-year experimentation were plotted against the plant population per m² (treatment wise) in X-cell programme. A quadratic equation (functional relation or equation) was obtained by regression analysis with the highest value of $R^2$ (well fitted) using those experimental data. Then the predicted yield was calculated using that functional model. The consistency was assessed by using correlation and regression of predicted and experimental values. The crop was harvested on 6-8 April in 2020 and 2021. The data on yield components were collected from 5 randomly selected plants prior to harvest from each plot. At harvest, the yield data was recorded plot wise and analyzed statistically. Model analysis was done using the data of 2019-2020 and 2020-2021.

## Results and discussion

### Leaf Area Index (LAI)

The variation in LAI was greatly influenced by plant population (Figure 1). LAI increased up to 85 DAS and then it decreased slightly in all the treatments. LAI showed the highest value (5.03) at 85 DAS in the dense population ($T_5$: 166666 plants/ha) followed by $T_4$ (125000 plants/ha) while the lowest in $T_1$. Higher plant population increased LAI due to more number leaves per unit area. The results indicated that LAI (4.33 at 85 DAS and 4.14 at 110 DAS) were found suitable for maximum grain yield in $T_3$ (Figure 1). Higher LAI in $T_5$ failed to produce maximum grain yield because of mutual shading and inter plant competition in dense plant population of maize [3]. The Leaf Area Index (LAI) of the crop at a particular growth stage indicated its photosynthetic potential or the level of its dry matter accumulation and it was influenced by plant population [24]. The highest physiological growth indices were achieved under high plant density, because of the increased photosynthesis by development of more leaf area [25].

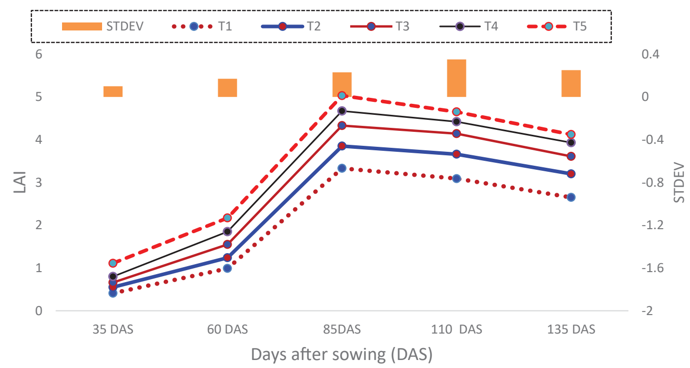


**Figure 1:** Leaf area index (LAI) of maize as influenced by plant population (On the basis of mean value of 2019-2020 and 2020-2021; bar above the lines indicate standard deviation: STDEV).



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## Dry matter accumulation

Dry matter accumulation was highly influenced by plant population (Figure 2). Total Dry Matter (TDM) is merely invisible at 35 DAS and afterwards it gradually increased, and reached at peak at 135 DAS. The highest TDM was recorded in T5 followed by T4 whereas the lowest in T1 at 60 DAS and subsequent sampling DAS. TDM increased with the increasing plant population due to more plants per unit area. The maximum TDM (8137.17g/m²) was recorded in T5 (166666 plants/ha) followed by T4 treatment and the lowest (3289 g/m2) was found in T1 treatment at 135 DAS. Generally, more TDM accumulation produced more yield [7]. Higher TDM in T5 failed to produce higher grain yield because of inter plant competition resulting lower grains/cob and 1000-grain weight (Figure 2, Tables 1,2). The results are in agreement with the other findings [12]. However, the TDM value with 5343 g/m² at 135 DAS was found optimum for the highest grain yield of maize in T3 (Figure 2 and Table 2). Although, previous research findings indicated that high maize density produced higher total dry weight, when crop growth rate increased than low maize density throughout crop growth season [26].

## Yield and yield component

Number of cobs/m² was recorded the highest (16.64-16.66) in T5 ((30 cm × 20 cm)) while the lowest in T1 (75 cm × 20 cm) (Table 1). Closer plant spacing produced higher number of cobs/m². The maximum number of grains/cob (448-467 in 2019-2020 and 445-478 in 2020-2021) was recorded in T1, T2 and T3 treatments (broader spacing). Similar trend was noticed in the case of 1000-grain weight (328-337 g in 2019-2020 and 279-295 g in 2020-2021) (Table 2). Closer plant spacing reduced number of grains/cob and 1000-grain weight. More inter plant competition retarded number of grains/cob and 1000-grain weight in closer spacing. The results are in agreement with the other findings [27]. The use of high plant densities might reduce the supply of nitrogen, photosynthates and water to the growing ear. It was also reviewed that high stand establishment created competition for light, aeration, nutrients and consequently compelling the plants to undergo less reproductive growth and grain filling [28]. Plant population also showed significant influence on grain yield (Table 2). Grain yield increased with the increase of plant population up

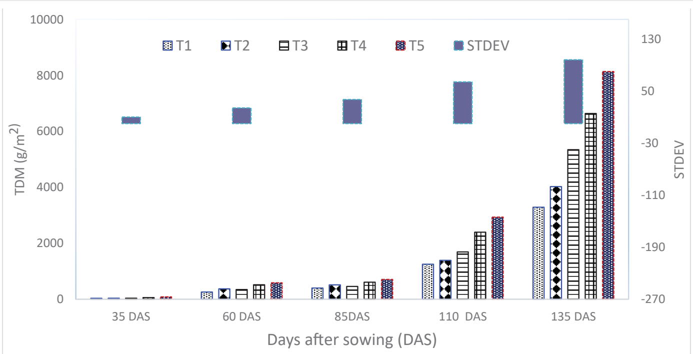


**Figure 2:** Dry matter production in hybrid maize as influenced by plant population (On the basis of mean value of 2019-2020 and 2020-2021, bars above bar graph indicate standard deviation: STDEV).

**Table 1:** Cobs/m² and grains/cob of maize (2019-2020 and 2020-2021).

| Plant population | Cobs/m² (no.) | | Grains/cob (no.) | |
|---|---|---|---|---|
| | 2019-2020 | 2020-2021 | 2019-2020 | 2020-2021 |
| $T_1$ | 6.74 | 6.71 | 467 | 478 |
| $T_2$ | 8.39 | 8.35 | 454 | 461 |
| $T_3$ | 10.05 | 10.03 | 448 | 445 |
| $T_4$ | 11.12 | 11.11 | 424 | 429 |
| $T_5$ | 16.66 | 16.64 | 405 | 398 |
| $LSD_{(0.05)}$ | 2.11 | 2.08 | 32 | 41 |
| CV (%) | 3.53 | 3.21 | 3.85 | 4.71 |

**Table 2:** Weight of 1000-grain and grain yield of maize (2019-2020 and 2020-2021).

| Plant population | 1000-grain weight (g) | | Grain yield (t/ha) | |
|---|---|---|---|---|
| | 2019-2020 | 2020-2021 | 2019-2020 | 2020-2021 |
| $T_1$ | 337 | 295 | 8.03 | 8.85 |
| $T_2$ | 336 | 283 | 9.68 | 9.93 |
| $T_3$ | 328 | 279 | 10.78 | 10.12 |
| $T_4$ | 289 | 231 | 9.98 | 8.64 |
| $T_5$ | 277 | 224 | 5.33 | 5.02 |
| $LSD_{(0.05)}$ | 28 | 37 | 0.94 | 0.75 |
| CV (%) | 4.75 | 8.76 | 5.73 | 4.64 |

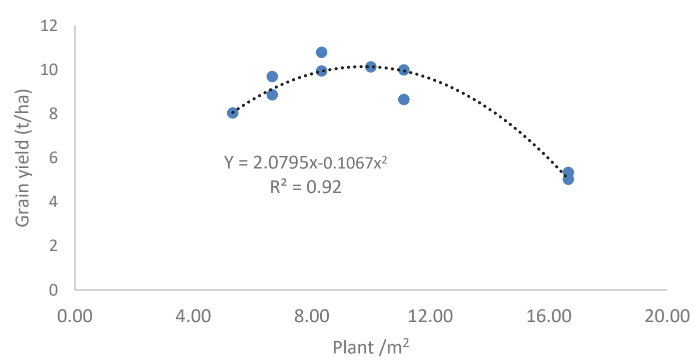


**Figure 3:** Functional relationship between plant population and grain yield of maize.

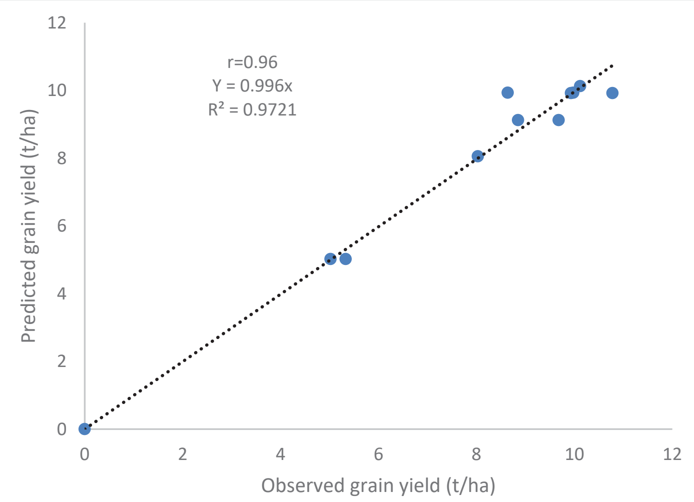


**Figure 4:** Relationship between observed and predicted grain yield of maize (Using the functional model of plant population and grain yield of maize: $Y = 2.0795x-0.1067x^2$, $R^2 = 0.92$).

to a certain level and afterwards it deceased. The highest grain yield (10.12-10.78 t/ha) were recorded in T3 (50 cm × 20 cm spacing) corresponding to 100000 plants/ha. This was happed due to cumulative effect of cobs/m2 with higher grains/cob and



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1000-grain weight (Tables 1,2). The increase in grain weight in T3 might be due to availability of more resources and uptake by the plants [7]. On the contrary, the lowest grain yields (5.02-5.33 t/ha) were recorded in T5 (30 cm × 20 cm) treatment having plant population of 166666plants/ ha. Lower grain weight in higher plant population density was occurred probably due to less availability of photosynthates for grain development on account of high inter-plant competition which resulted in low rate of photosynthesis and high rate of respiration as a result of enhanced mutual shading [28].

### Model analysis

Functional relationship between plant population and grain yield of maize was established as Y = 2.0795x-0.1067x2 ($R^2$ = 0.92) (Figure 3). The result indicated that the effect of plant population on the grain yield of maize could be explained about 92% at by the functional model. The co-efficient indicated that the increase of one plant/m2 would increase the grain yield @ 2.0795 t/ha up to a limit, afterward it would decrease @ 0.1067 t/ha (with the value of $x^2$). The optimum plant population would be 9.74/m² then the predicated grain yield would be 10.12 t/ha as per estimation by the developed model. The results are in agreement with the finding of others [29,30]. The functional model can be used to predict maize grain yield at a specific population. There existed a good consistency between observed and predicted grain yield of maize ($r=0.96$ at $p<0.01$ and $R^2=0.97$; using the developed functional model) (Figure 4). Similar model prediction in wheat, lentil and mungbean was done by others [18,31,32].

## Conclusion

LAI (leaf area index) and TDM (total dry matter) increased with the increase of plant population. The highest grain yield (10.12-10.78 t/ha) was recorded in T3 (100000 plants/ha). Functional relationship between plant population and grain yield of maize was established as Y = 2.0795x-0.1067x2; ($R^2$= 0.92). The optimum plant population of maize would be 9.74 plants/m² (974000 plants/ha) and the predicted grain yield would be 10.13 t/ha using the developed functional model. The model can be used for prediction of grain yield of maize at any specific plant population and validation of other results.

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