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OPTIMIZATION OF PLANT SPACING FOR YIELD IMPROVEMENT IN HYBRID MAIZE USING DSSAT

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ABSTRACT

The goal of the study was to simulate how plant spacing might affect maize yield in the semi-arid region of Punjab, Pakistan. At the University of Agriculture, Faisalabad's Agronomy field, the field experiment was carried out. To determine reasons for the changes in grain yield linked to cultivar and plant spacing, various crop growth parameters were recorded. In the case of LAI, plant spacing had a non-significant impact. The maximum mean value of LAI and crop growth was 4.28 and 27.86 g m^{-2} d^{-1} at plant spacing S2 (20 cm) with hybrid H1 (DK-6714), respectively. The minimum mean value for the crop growth rate was recorded (18.86 g m^{-2} d^{-1}) plant spacing S1 (10 cm) with hybrid H1 (DK-6789). In the case of dry matter production, both plant spacing and hybrid had a significant impact. Maximum mean dry matter production (19.47 t ha^{-1}) was recorded in plant spacing S2 (20 cm) with hybrid H1 (DK-6714). Minimum mean dry matter production was recorded (16.30 t ha^{-1}) in plant spacing S1 (10 cm) with hybrid H1 (DK-6714). For the harvest index, plant spacing had a significant impact while hybrid had a non-significant impact. The maximum mean value (47.61) was recorded in the second plant spacing S2 (20 cm) with hybrid H1 (DK-6714). Results indicated that observed and simulated values were closely related, and the CERES-Maize model was accurately calibrated and performed very well.

Keywords: Agriculture, Agronomy, Plant Spacing, Maize Yield

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1. INTRODUCTION

Maize is a high-yielding and important cereal crop of the world. It is cultivated as the fourth most important crop in Pakistan on an area of 1,229 thousand hectares. Maize share is 2.4% in value addition and 0.5% to gross domestic product (GDP) (Ali et al. 2020). Maize is ranked third all over the globe after wheat and rice according to the area and production of cereal crops (Liaqat et al. 2018). The world population is increasing day by day which caused food reduction worldwide. It has great yield potential and is grown as a staple food in many countries of the world; however, the yield of maize has not exceeded 70% of its genetic yield potential (Lobell et al. 2009). It is recognized as being crucial to the production of cattle in addition to serving as some people's primary food (Ali et al. 2020). It is also employed in the production of corn sugar, oil, protein, cornflakes, and corn syrup, among other products (Liaqat et al. 2018).

The elevation of the human growth rate created food and energy crises in the world (ur Rahman et al. 2018; Mubeen et al. 2020; Huang et al. 2020). The number of people living in Pakistan is growing at a startling rate of 2.6% every single year (Mubeen et al. 2020). As a consequence of this, there is a requirement for improved research and planning in order to raise the quantity of food that is produced and enhance its value in order to satisfy the requirements of an ever-increasing population. Corn is a C4 plant, which means it makes better use of its inputs and produces a larger quantity of food grains per unit of land (Durand et al. 2018). The optimum temperature for maize germination ranges between 25 to 28^0C (Corbeels et al. 2018) and a temperature between 30 to 35^oC is optimum for

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maize growth and at productive stages high temperature of 38^0C directly affect the seed setting and pollination resulting reduced in yield of grain of maize crop (Amnuaylojaroen et al. 2021). High temperatures increase plant development, reducing the growth period length that is necessary for the growth and development of plants and grain. Simply switching between different types of maize varieties could prevent yield reductions brought on by terminal heat stress (Adnan et al. 2017).

In Pakistan, a diverse range of maize genotypes, including single- and double-cross hybrids, composites, and synthetics are now being grown. There is a wide range of variation in the ways in which all of these genotypes respond to the various agricultural management strategies, notably those involving water and nutrients. This differential response can be attributed, in large part, to variances in relative maturity (Huang et al. 2020), plant structure, grain filling duration, intra-specific competition in maize plants (Abbas et al. 2017) plant growth rate (Adnan et al. 2017) and flocking stress tolerance (Liaqat et al. 2018) of different maize hybrids. Plant density has a great effect on grain yield. Research shows that maize crop density level i.e., 90000 plants ha^{-1} significantly increased grain yield (Huang et al. 2020). Yilmaz et al. (2008) detected significant impacts of plant densities, planting designs, and maize hybrids on yield mechanisms of maize. The density of the plant population can also change the leaf azimuthal distribution (Abbas et al. 2017).

The use of crop modeling as a tool for assisting crop development, scientific research, and the analysis of strategy has become increasingly important (Adnan 2017; Corbeels et al. 2018; Amnuaylojaroen et al. 2021). Over the course of the past few decades, crop modeling has evolved into a cutting-edge research tool and become an essential component of decision support systems related to agriculture (Durand et al. 2018). Crop models provide a way to calculate potential causes of changes in yield over time at a specific location (Huang et al. 2020). Modeling methods have also been shown to be helpful in the decision-making process. The cropping systems model (CSM), a piece of computer software, is a crucial research tool for analyzing how complex and final management decisions affect crop output. Each strategy has advantages and disadvantages and can be used to simulate crop yield effects on treatment choices and fundamental environmental variables (Durand et al. 2018). These models are frequently employed to change agricultural inputs to enhance crop input utilization (Ahmed et al. 2018; Durand 2018; Mubeen et al. 2020). In contrast to process-based models, the output that these models forecast is limited to the data set. The crop models have been examined for a variety of soil types, for various climatic situations, with a number of production options, and for several maize genotypes (Attia et al., 2021). The current experiment aims to: (i) assess the impact of crop spacing on plant growth and yield in a semi-arid environment, and (ii) assess the effectiveness of the CERES-MAIZE model to simulate maize growth and development under varied plant spacings.

2. MATERIALS AND METHODS

2.1. Site and Layout of the Experiment

The trial was directed at the Agronomy field, University of Agriculture, Faisalabad during the autumn season, 2018. A Split plot experiment was designed with two types of Maize hybrids, H_1: (DK-6714) and H_2: (DK-6789) as a main plot with three replications and plant spacing $S_{1:}$ (10cm), $S_{2:}$ (20cm) and $S_{3:}$ (30cm) as a sub-plot with three replications. The total area was 728m^2. The row-to-row distance was maintained at 75 x 75cm. The following treatments were studied during the experiment.

The net size of the experimental unit was 3 m x 6 m. The sowing was done in the first week of August 2018. Sowing was done manually on ridges by maintaining a line-to-line distance of 75 cm with a rate of 25 kg ha^{-1}, while remaining agronomic and management practices were normal and even. To keep the crop free from insect pests and disease crop protection measures were used (Table 1).

Table 1: Attributes of the experimental site

Location	Latitude N^0	Longitude E^0	Altitude (m)	Soil series USDA classification	Climatic zone
Faisalabad	31^0 26'	73^0 04'	184	Lyallpur (Fine loamy, mixed, hyperthermic, Typic Calciargids/ Typic Haplocambids)	Dry Semi-Arid

2.2. Soil Sampling and Its Analysis

A soil auger was used to gather a composite soil sample from the trial area to a depth of 30cm prior to the seeding of the crop. The sample underwent analysis to determine its physicochemical qualities (Table 2).

2.3. Weather Data

The Agro-meteorology cell, a division of the Department of Agronomy at the University of Agriculture, Faisalabad, provided the meteorological information for the crop's growth phase in 2018. The weather information included the mean temperature in degrees Celsius, the amount of precipitation, the number of hours of sunshine, and the relative humidity as a percentage.

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Table 2: Soil analysis of the experimental site

Parameters	Values		Status
	0-15cm	15-30cm	
pH	8.2	8.4	Alkaline
EC (dSm^{-1})	4.4	4.6	Saline
N (%)	0.061	0.058	Medium
P_2O_5 (ppm)	18.5	14.7	High
K_2O (ppm)	280	240	High
Organic Matter	1.26	1.19	Medium
Sand (%)	20	19	
Silt (%)	17	16	
Clay (%)	63	65	

LAI=Leaf Area Index; LAD=Leaf Area Duration; CGR=Crop Growth Rate; NAR=Net Assimilation Rate; PH=Plant Height; NG/C=No. of Grains per Cob; TGW=Thousand Grain Weight; TDM=Total Dry Matter; GY=Grain Yield; HI=Harvest Index.

2.4. Crop Husbandry

The land was prepped by plowing it twice, and then planking it with a tractor-drawn cultivator to create the standard seed bed. On August 3, 2018, autumn maize hybrids (DK-6714 and DK-6789) were broadcast on ridges using the dibbling method. In the experiment, 25 kg ha^{-1} of the suggested seed rate was applied. The crop was planted on ridges with plant-to-plant distances of 10, 20, and 30cm, respectively, and row-to-row distances of 75x 75cm. Fertilizer was sprayed at rates of 250, 100, and 100 kg ha-1 for N, P2O5, and K2O, respectively. All of the phosphate, potash, and a third of the nitrogen were applied at the time of sowing. Two applications of the remaining 2/3 of the nitrogen were made: one at the tasseling stage and the other 15 days following sowing.

2.5. Methods Adopted for Check out The Growth and Development of Crop

Destructive samples of three plants were taken from all plots at 15-day intervals. Each plant part (stem and leaves) was weighed (fresh weight) and after oven drying (dry weight) with the help of weighing balance in the laboratory. A sample of every fragment was placed in an oven and allowed to dry at 70°C for 48 hours. Following drying, the total dry weight was determined and converted to m^{-2}. These growth-related metrics were noted. The ratio of total leaf area to land area was used to calculate the leaf area index. For a sample, it was determined by using Leaf Area meter (Eq. 1).

$$\text{Leaf Area Index} = \frac{\text{Leaf Area}}{\text{Land Area}}$$

2.5.1. Crop Growth Rate (g m^{-2} d^{-1}): CGR (g m^{-2} d^{-1}) was calculated by using Hunt (1978) formula as shown in equation 2. Eq. 2

$$\text{Crop growth rate} = \{W2 - W1\}/\{T2 - T1\}$$

Where W_1 and W_2 are the total weight (Dry) harvested at time T_1 and T_2, respectively.

2.5.2. Leaf Area Duration (days): LAD was calculated by Hunt (1978) method.

$$\mathbf{LAD} = \frac{\{(\mathbf{LAI1} + \mathbf{LAI2}) \times (\mathbf{T2} - \mathbf{T1})\}}{\mathbf{2}}$$

Where LAI_1 and LAI_2 are, respectively, the area of leaf indices at time T_1 and T_2.

2.5.3. Net Assimilation Rate (g m^{-2} d^{-1}): The average of NAR was calculated by using Hunt (1978) formula.

$$\text{NAR} = \frac{TDM}{LAD}$$

Where TDM and LAD are the total dry matter and leaf area duration respectively at final harvest.

***2.5.4. Plant Height (cm) at Maturity*:** Ten plants were selected in a random manner from each plot at ground level. Using a measuring tape, the participants' heights were measured, and subsequently, the average height was calculated.

***2.5.5. Cob Diameter (cm)*:** With the aid of a vernier calliper, ten cobs from all plots were measured for cob diameter, after which the mean was determined.

2.5.6. Cob Length (cm): With the aid of a measuring tape, ten cobs from every plot were measured to determine the average cob length.

***2.5.7.* Number of Grain Rows Per Cob:** The number of grain rows on each plot's 10 cobs was tallied, and subsequently, the mean value was computed.

2.5.8. Number of Grains Per Cob: Each plot's number of grains per cob was calculated, and the average was then calculated.

2.5.9. Thousand Grain Weight (g): 1000 grains were sampled from each plot, dried in the oven, and weighed by an electronic balance.

2.5.10. Grain Yield (t ha^{-1}): It was calculated using t ha^{-1} after being recorded on a sub-plot basis.

***2.5.11. Total dry Matter (t ha^{-1})*:** The entire plot was harvested, weighed, and converted to t ha^{-1} for biological yield.

$$TDM=LAD\times NAR$$

***2.5.12. Harvest Index (%)*:** The harvest index (HI), which is represented as a percentage, was measured as the ratio of grain yield to biological yield.

$$\text{Harvest Index } (\%) = \frac{\text{Grain Yield}}{\text{Biological Yield}} \times 100$$

***2.5.13. Grain Pith Ratio (GPR)*:** Grain-to-pith weight after cob shelling was used to calculate the grain to pith ratio.

$$\text{GPR} = \frac{\text{Grain Weight}}{\text{Pith weight}}$$

***2.5.14. Cob Sheath Ratio (CSR)*:** Ten cobs were weighed with and without sheaths, and the ratio of cob weight to sheath weight following cob shelling was determined.

$$\text{CSR} = \frac{\text{Cob Weight}}{\text{Sheath Weight}}$$

2.6. Selection Criteria of Plants for Crop Development

To record the various developmental phases, such as emergence (a), tasselling (b), and silking (c), as stated above, three plants were randomly chosen from each plot. (a) After the crop was sown, it was checked daily to count the number of germinations in each plot from a chosen region until a consistent and uniform plant count was attained. From each plant spacing, the mean days to emergence were calculated. (b) Three randomly chosen plants from each plot were tagged, along with the date of tasselling. The average number of days from planting to 50% of tasseling was computed. (c) The alike-tagged plants were kept under observation in all plots, and mean days to silking were calculated starting from the date of the planting.

2.7. Harvesting of the Maize Plants and Yield Calculations

An area (3 x 1.5m) from every plot was harvested, and ten plants were selected as a subsample to determine the various yield components. To calculate the crop of every plot and translate it into t ha^{-1}, all of the plants were mechanically thrashed. The information was gathered in accordance with protocol, which involved randomly selecting ten plants from every plot at ground level and determining their height with a measuring tape. Ten corn cobs were measured for diameter using a Vernier caliper from each patch. With the aid of a measuring tape, the length of 10 cobs was measured from every plot. The number of grain rows made up of 10 corn cobs from every plot was tallied, followed by the quantity of grains in each row. 1000 grains were sampled from each plot, dried in the oven, and weighed using an electronic balance. The grain yield was calculated using t ha^{-1} after being recorded on a sub-plot basis. The entire plot was reaped, weighed, and converted to t ha^{-1} for biological yield. The harvest index (HI), is represented as a percentage and computed as a ratio of grain yield to biological yield (Eq. 3).
H.I = (Grain yield / Biological yield) x 100

Ratio from grain weight to pith weight following cob shelling was used to calculate the grain-pith ratio.
GPR = Grain yield / Pith yield

Cob sheath ratio (CSR), which is the ratio of cob to sheath weight following cob shelling, was calculated after ten cobs were weighed with and without sheaths. For the calibration and assessment of the simulated and observed data, the CERES-Maize model was employed.

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2.8. Genetic Coefficients Adjustment through Model Calibration

The CERES-Maize model was standardized with data gained from field experiments. The treatment with the best result was used for calibration (Hoogenboom et al. 1994).

2.8.1. Model Calibration: The CERES-Maize model needs a set of six eco-physiological genetic coefficients to simulate crop development, growth, and economic production. The cultivar coefficients data file DSSAT (CERES-Maize) provides 6 factors for simulating growth, yield, and phenology; three are connected to development (P1, P2, and P5) two are associated with yield (G2 and G3) and PHINT is used to calculate thermal time. This information was not accessible. Genetic coefficients of both hybrids were predicted by repeated relations up to the nearby match between simulated and collected data about development, growth, and grain yield. Hybrid H2 is -6789) had a maximum value of 345 (˚C days) for P1 which showed that there was maximum duration against Hybrid H1 (DK-6714). The similarity was recorded in P2 values that were 0.7 (days) for both cultivars. P5 values ranged from 848 to 850 for both hybrids. In the case of G2 the value ranged from 758 to 800 for both hybrids. Hybrid H2 (DK-6789) had a minimum value for G3 -i.e., 7.28 mg day^{-1} whereas hybrid H1 (DK- 6714) had a maximum value that was 7.80 mg day^{-1}. Hybrid H2 (DK-6789) had a PHINT (Phylochron interval) value of 37.7°C day; whereas hybrid H1 (DK-6714) had a 38.80°C day PHINT value. The model accomplished best in the simulation of growth, development, grain yield, and total dry matter in the time of calibration for both cultivars. During the calibration procedure for maize cultivars, calibration outcomes presented that the model executed good results in the simulation of the growth, development, yield, and total dry matter. According to model calibration, it is observed that the CERES-Maize model is a good implement for the assessment of different plant spacing effects on crop production. We can lessen the effect of forthcoming threats on food security and crop production on the base of the model.

2.9. Statistical Analysis

Fisher's analysis of variance and least-significant difference (LSD) test at 5% probability level were used to analyze data and compare the mean of treatments (Steel 1997).

3. RESULTS AND DISCUSSION

According to the ANOVA (Table 3), the effect of hybrids on LAI was non-significant. Plant spacing impact was statistically significant on leaf area index of maize crop and collaboration among the plant spacing and hybrid was also non-significant. LAI gradually increased and after reaching maximum value, it reduced after 65 days of sowing in all treatments of plant spacing and hybrids. It was observed that the hybrid H1 showed best and (DK-6714) was noted as highly significant as compared to the hybrid H2 (DK-6789). Maximum mean value recorded (4.28) in case of hybrid H1 (DK-6714) at 2nd plant spacing S2 (20 cm) and minimum mean value (3.13) recorded in case of hybrid H1 (DK- 6714) (Table 1). Results showed that the interaction of plant spacing, and hybrids were non-significant. The maximum average value was recorded in H1 (DK-6714) with 2nd plant spacing S2 (20cm) (Table 4).

Photosynthetic capability after pollination is largely reliant on leaf area duration, which is a value of the leaf area index at anthesis and leaf endurance. ANOVA Table 3 showed that the interaction of plant spacing was highly significant. It is evident from the Table that the effect of leaf area duration was statistically significant on maize hybrids. Interaction among plant spacing and hybrids was non-significant. The mean value for leaf area duration was recorded maximum (309 days) in hybrid H1 (DK-6714) at 2nd plant spacing S2 (20cm). A minimum value (281.5 days) was recorded in the second hybrid H2 (DK-6789) at 1st plant spacing S1 (10cm) (Table 4). According to Mubeen et al. (2020) leaf area duration improved at the highest plant.

Table 3: Effect of Hybrids and Plant Spacing on maximum leaf area index at 65 days after sowing

SOV	df	LAI	LAD	NAR	PH	1000GW	GY($t\ ha^{-1}$)	TDM	HI	GPR
Rep	2	0.1719	4.34	4.3438	4.59	0.1719	4.0981	4.3438	44.519	0.1162
H	1	0.084NS	220.50*	0.583NS	2604.3*	0.084NS	3.645NS	1.960NS	54.909*	1.046NS
Error I	2	0.2096	0.75	0.7455	140.26	0.2096	0.5224	0.7456	1.510	0.0467
PS	2	2.004**	1137.50**	4.581*	4539.13**	2.004**	17.520**	15.151**	218.046**	1.571*
H×PS	2	0.080NS	1.50NS	0.000NS	65.79NS	0.080NS	0.3150NS	0.142NS	6.989NS	0.117NS
Error II	8	0.0918	1.11	1.1051	261.97	0.0918	1.0757	1.1052	10.649	0.0765
Total	17									

Analysis of Variance. SOV: Source of variation, DF: degree of freedom, SS: Sum of Square, MS: Mean Square.

LAI	(Leaf Area Index)	LAD	(Leaf Area Duration)	NAR	(Net Assimilation Rate)
PH	(Plant Height)	TDM	(Total Dry Matter)	HI	(Harvest Index)
GPR	(Grain Pith Ratio)				

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Table 4: Effect of Plant Spacing and Maize Hybrids on Leaf Area Index, Leaf Area Duration, Crop Growth Rate, Net Assimilation Rate, pH, Number of Grains/Cob, Thousand Grain Weight, Total Dry Matter, Grain Yield and Harvest Index

Parameters	LAI Plant Spacing	LAD (days)	CGR (g m^{-2} d^{-1})	NAR (g m^{-2} d^{-1})	PH (cm)	NG/C	TGW (g)	TDM (t ha^{-1})	GY (t ha^{-1})	HI
Plant Spacing										
S1 (10cm)	3.13C	281.50C	18.86C	5.42B	166.50C	444.87C	366.83C	16.30C	5.85C	35.60C
S2 (20cm)	4.28A	309.00A	27.86A	7.16A	221.49A	621.50A	443.67A	19.47A	9.25A	47.61A
S3 (30cm)	3.75B	294.00B	22.45B	6.47AB	195.43B	531.80B	405.67B	17.76B	7.25B	40.67B
Hybrids										
H1 (DK-6714)	3.79	298.33A	23.85	6.53	206.50A	561.09A	426.89A	18.17	7.90	43.04A
H2 (DK-6789)	3.65	291.33B	22.25	6.17	182.45B	504.36B	383.89B	17.51	7.00	39.55B

LAI	(Leaf Area Index)	LAD	(Leaf Area Duration)	CGR	(Crop Growth Rate)
NAR	(Net Assimilation Rate)	PH	(Plant Height)	NG/C	(No. of Grains per Cob)
TGW	(Thousand Grain Weight)	TDM	(Total Dry Matter)	GY	(Grain Yield)
HI	(Harvest Index)				

Similar approaches were reported by (Gholinezhad et al. 2009). They concluded that the density of the plant population changes the leaf azimuthal distribution and also the architecture of canopy modification affected the interception of light (Almeida et al. 2000). The promotive effect of N on LAI of maize is stated by (Bangarwa et al. 1988; D'Andrea et al. 2006). LAI typically rose until 55 DAS when tasseling began, after which point LAI fell until the final harvest. After pollination, leaf area duration, which is a value of the leaf area index at anthesis and leaf endurance, has a significant impact on a plant's ability to photosynthesize. The interplay of plant spacing was quite significant, as depicted in Fig. 1. The Table makes it evident that the influence of leaf area duration on maize hybrids was statistically significant. Plant spacing and hybrids did not interact in a significant way. At second plant spacing S2 (20cm), hybrid H1 (DK-6714) had a maximum mean LAD value of 309 days. A minimum value (281.5 days) was recorded in the second hybrid H2 (DK-6789) at 1st plant spacing S1 (10cm). According to Thornton and Zimmermann (2007), leaf area duration improved at the highest plant.

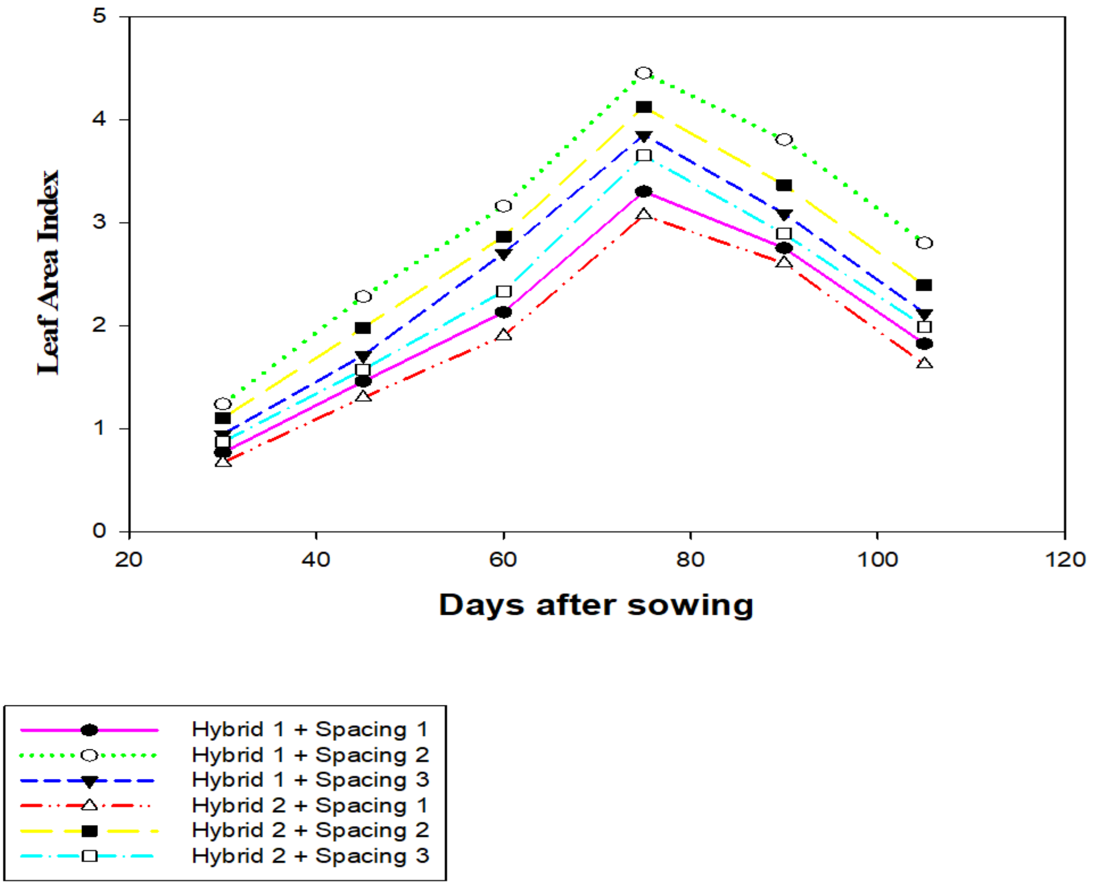

Fig. 1: Effects of hybrids and plant spacing on leaf area index.

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3.1. Effect of Hybrids and Plant Spacing on Net Assimilation Rate (g m-2 d-1)

The quantity that connects plant efficiency to plant mass is known as the net assimilation rate. The typical NAR of a crop is net photosynthetic output per LAD unit (Hunt 1978). NAR was considerably impacted by various plant spacings, as shown in ANOVA Table 3. Hybrids had no discernible impact on the net assimilation rate. The interaction between hybrid and plant spacing failed to reach statistical significance. The treatment of S2 with 20 cm plant spacing resulted in the highest mean net assimilation rate (7.16g m^{-2} d^{-1}). 5.42g m^{-2} d^{-1} was the lowest mean net assimilation rate observed in the S1 (10cm) plant spacing treatment (Table 4).

3.2. Effect of Hybrids and Plant Spacing on Plant Height at Maturity

According to ANOVA Table 3 hybrid showed significant results for plant height. In the case of plant spacing, the results were also highly significant for plant height. Analysis of variance showed that interaction effects for plant height vs. hybrid were observed as non-significant. Hybrids and plant spacing were not affected by each other on plant height at the stage of maturity.

Plant height is a crucial morphological characteristic that depends on a variety of factors, including a plant's genetic makeup, the nutrient status of the soil, the vigor of the seed, and the ecological settings in which it is grown. It is a function of both environmental conditions and genetic makeup. Data regarding plant height shown in Table 3, exhibited that plant spacing showed a highly significant influence on plant height. The hybrids also significantly influenced plant height. Collaborative effects of plant spacing and cultivars were noted to be statistically non-significant on the plant height of maize crop at maturity. Regarding different plant spacing, significantly higher plant height (221.49cm) was obtained when plant spacing was 20cm (S2) with hybrid H_1 (DK- 6714). A significantly lower plant height (166.50cm) was obtained where plant spacing was (10cm) and it was followed by treatment S1 which was (10cm) plant to plant spacing in hybrid H_2 (DK-6789) (Table 4).

In order to maintain consistent production of maize under a variety of environmental conditions, genotypes that are resilient to abiotic and biotic stressors are anticipated to have improved yield stability (Haroon et al. 2022). Yang et al. (2015) concluded that increasing plant density can help increase maize yield. To reach the maximum plant height, densities greater than 60,000 plants ha1 were necessary, which in turn enhanced the leaf area index, dry matter accumulation, and grain output.

3.3. Effect of Hybrids and Plant Spacing on Thousand Grain Weight (g)

According to findings in Table 3, plant spacing significantly affected thousand-grain weight. Additionally, hybrids significantly affected the weight of a thousand grains. Effects of interactions between various plant spacings and hybrids on thousand-grain weight were statistically insignificant. Results revealed that hybrid H1 (DK-6714) with second plant spacing of S2 (20cm) achieved the maximum mean thousand-grain weight (443.67g). The minimum mean of thousand-grain weight (366.83g) was recorded in the case of first plant spacing S1 (10cm) with hybrid H2 (DK-6789) (Table 4). The grain test weight is a crucial element in achieving the highest crop yield possible. The thousand-grain weight is a very significant factor that significantly affects the crop's overall grain production and also demonstrates the cultivar's potential (Inamullah et al. 2011) reported similar outcomes for the thousand-grain weight.

3.4. Effect of Hybrids and Plant Spacing on Grain Yield (t ha^{-1})

Interaction among different plant spacing and hybrids had a non-significant impact on grain yield as shown in Table 3. Maximum grain yield for plant spacing (9.25 t ha-^{1}) was recorded in hybrid H1(DK-6714) with 2nd plant spacing which was S2 (20cm). A minimum value of grain yield (5.85 t ha-^{1}) was documented in the case of the first plant spacing which was S1 (10cm) with hybrid H2 (DK-6789) (Table 4).

The growth and expansion of the whole crop, which is prejudiced by a variety of agronomic techniques and conservational conditions that the crop is exposed to during its period of growth and development, together determine grain yield. Therefore, any difference between them has the potential to alter grain yield. Following statistical research, it was found that plant spacing significantly affected grain yield. The final grain yield of maize crops was significantly impacted by hybridization as well. (Maddonni et al. 2006) described that different plant spacing had an adverse effect on grain yield because, at different plant population densities, crops face variations in the availability of resources and thus reduce their weight.

3.5. Effect of Hybrids and Plant Spacing on Total Dry Matter Accumulation (t ha^{-1})

For the assessment of a crop plant's performance, the manufacture of total biomass and its dissemination between the economic and straw yields is a subject of major significance. Ecological factors and soil nutrients that the plant has absorbed have an impact on the total biomass production of the plant on a dry matter accumulation basis. According to ANOVA Table 3, the impact of plant spacing was statistically highly significant on the TDM build-up. Hybrids showed a non-significant impact on total dry matter and communication among different plant

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spacing and hybrids were also non-significant on the total dry matter accretion. The maximum average value of dry matter manufacture was noted (19.47 t ha^{-1}) in a treatment of second plant spacing S2 (20cm) with hybrid H1 (DK-6714) and the minimum average value of total dry matter production was noted (16.30 t ha^{-1}) in treatment of first plant spacing S1 (10cm) with hybrid H2 (DK-6789) (Table 4). Plant growth rates were estimated from dry matter of shoots based on days before and after silking (Fig. 2). The data of grain yield, dry matter, and yield components were collected at crop physiological maturity. The study revealed fluctuation in grain yield with different plant densities and kernel variability between years of development (Echarte et al. 2000). Ali et al. (2015) reported the same result. The treatments of plant spacing, and hybrids mean sharing different capital letters and are statistically significant from each other.

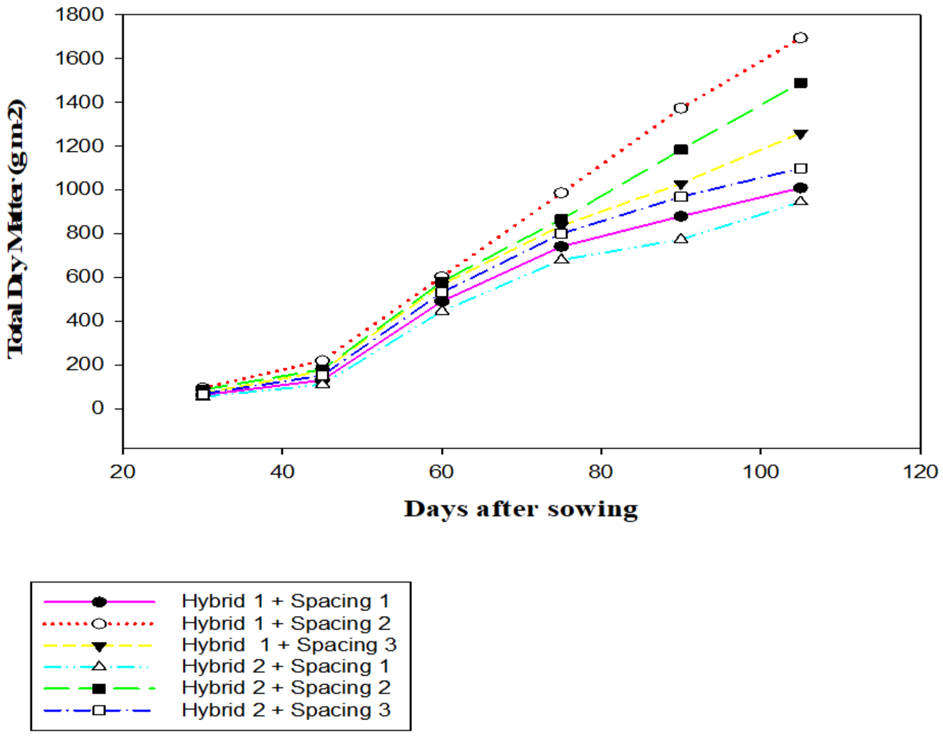

Fig. 2: Effect of hybrids and plant spacing on total dry matter.

3.6. Harvest Index

The data about the harvest index is indicated in Table 3. After statistical analysis, the ANOVA depicted that plant spacing indicated a highly significant impression on the harvest index. The effects of hybrids on the harvest index were also significant. Interaction among plant spacing and hybrids was statistically non-significant on the harvest index. Conferring to average comparison Table 3 the maximum value for harvest index was 47.61% in a treatment of second plant spacing S2 (20cm) with hybrid H1 (DK- 6714). First plant spacing S1 (10cm) with hybrid H2 (DK-6789) produced the lowest harvest index value of 35.60% (Table 4). The harvest index measures the crop plant's physiological productivity in converting photosynthetic products into the plant's economically significant portions. Plant population density was found to have a negative impact on the harvest index by Ali et al. (2015).

3.7. Grain Pith Ratio

The grain pith ratio is (GPR) the ratio from grain weight to the weight of pith. Data regarding grain pith ratio in Table 3, revealed that GPR was significantly affected by different plant spacing treatments. ANOVA also presented that the impact of hybrids was non-significant on GPR and the interaction among plant spacing and hybrids was also statistically non-significant on grain pith ratio. According to the mean comparison, the maximum value for grain pith ratio was 7.89 in a treatment of second plant spacing S2 (20cm) with hybrid H1 (DK-6714). The minimum value for grain pith ratio was 6.24 recorded in the treatment of first plant spacing S1 (10cm) with hybrid H2 (DK-6789). The mean values of GPR were 6.11, 7.63, and 7.22 for S1 (10cm), S2 (20cm), and S3 (30cm) respectively. In the case of hybrids, the mean values of GPR were 7.39 and 6.91 for H1 (DK-6714) and H2 (DK-6789) respectively.

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Cob sheath ratio (CSR): Cob sheath ratio (CSR) is the ratio of cob weight to sheath weight. Data on grain pith ratio showed that different plant spacing treatments had a substantial impact on CSR (Table 3). After statistical analysis, ANOVA depicted that the impact of hybrids was non-significant on the cob sheath ratio and the interaction among plant spacing and hybrids also showed a statistically non-significant impact on the cob sheath ratio. According to the mean comparison, the maximum value for the cob sheath ratio was 15.11 in a treatment of second plant spacing which was S2 (20 cm) with hybrid H1 (DK-6714). The minimum value for cob sheath ratio was (9.53) observed in a treatment S1 (10cm) plant spacing with hybrid H2 (DK-6789).

3.8. Crop Growth Modelling

P1: The period of thermal time from the emergence of the crop plant towards the completion of the maturation phase (expressed in degrees Celsius per day above 8 degrees Celsius) during which the crop plant is not receptive to contrast in photoperiod. P2: Phenology continues for the number of days (expressed in hours) that exceeds the highest photoperiod at which it advances at the fastest rate, which is thought to be 12.5 hours (P5: Thermal period) indicated in C days beyond a base temperature of 8°C from days of cob initiation through physiological maturity. G2: The most grains allowed per plant. G3: The rate at which grains are filled during the linear kernel filling stage and under ideal circumstances (mg d^{-1}). Phylochron interval, or a total of thermal days between sequential leaf tip arrivals (Hoogenboom et al. 1994).

3.9. Performance and the Evaluation of Model

Running a model against independent data collected during the 2018 fall season and against plant spacing S1 (10cm), S2 (20cm), and S3 (30cm) allowed researchers to assess the effectiveness of the model and the genetic performance of maize hybrids. The model simulation's outcomes are explained as follows. A) A description of the contrast between predicted and actual biological yield values. The model accurately predicted the data, with an RMSE of 892kg/ha to 1523kg/ha (Tables 5 and 6). The model simulated less biological yield at 1st plant spacing with an error of 3% while the maximum simulated value was observed at 3rd plant spacing. The CERES-Maize model reasonably simulates biological yield during the autumn season (Khaliq 2008). The response of the model was worthy for grain yield in different plant spacing for both of the hybrids. The RMSE (2025.21) value for hybrid DK-6714 was inacceptable range for the yield of grains and the RMSE (2365.81) value for hybrid DK-6789 displayed that hybrids were assessed well (Tables 7 and 8).

Table 9 describes the comparison between the simulated and the observed values for the grain yield. The model simulated well at the Faisalabad location with RMSE ranging from 2025kg ha^{-1} to 2365kg ha^{-1}. Simulation results were best for all plant spacing at Faisalabad condition. The model simulated less economical yield at 1st plant spacing with an error of 42% while the maximum simulated value was observed at 3rd plant spacing. (Khaliq 2008) found similar results that the CERES-Maize model reasonably simulates grain yield during the autumn season.

Table 5: Genetic coefficients of autumn maize hybrids used for CERES-Maize model

Cultivar	P1 (°C d)	P2 (d)	P5 (°C d)	G2	G5 (mg d^{-1})	PHINT (°C d)
DK-6714	340.0	0.70	850.0	800.0	7.80	38.80
DK-6789	345.0	0.73	848.0	758.0	7.28	37.70

To simulate crop growth rates, biomass yield, and other factors, crop cultivar coefficients are required. There are six genetic coefficients in CERES-maize; P1: Degree days (base 8 ◦C) from emergence to the end of the juvenile phase. P2: Coefficient of photoperiod sensitivity. P5: From silking to physiological maturity in degree days (base 8 ◦C). G3: Number of potential kernels (G2), the rate of potential kernel growth mg/(kernel d) PHINT: Degree days it takes for a leaf tip to emerge (phyllochron interval)(◦C d).

Table 6: Observed and simulated results during model calibration with recorded data at 2nd Plant pacing with hybrid DK-6714

Variable	Unit	^{a}Obs.	^{b}Sim.	^{e}RMSE
Biological yield	kg ha^{-1}	19980	18557	892
Grain Yield	kg ha^{-1}	9900	9719	2025

^{a}Observed ^{b}Simulated ^{c}Root mean square error.

Table 7: Observed and simulated results during model calibration with recorded data at 2nd Plant pacing with hybrid DK-6789.

Variable	Unit	^{a}Obs.	^{b}Sim.	^{c}RMSE
Biological yield	kg ha^{-1}	18970	18975	1523
Grain Yield	kg ha^{-1}	8600	9143	2365

^{a}Observed ^{b}Simulated ^{c}Root mean square error.

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Table 8: Comparison of observed and simulated data for biological yield at different plant spacing

Hybrids	DK-6714			DK-6789		
	Sim	Obs	Error %	Sim	Obs	Error %
S1 (10cm)	17222	16570	3	18184	16030	13
S3 (30cm)	16900	17980	-6	17585	17550	0.01

To determine the factors that contribute to changes in grain yield linked to cultivar and plant spacing, measurements of the crop growth and ecological factors were made. Plant spacing is a key factor for crop production. By increasing plant population density, the availability of resources decreases due to which growth and development of the plant are affected and ultimately grain yield is also decreased due to high plant population density. In the case of Leaf Area Index plant spacing had a non-significant influence on leaf area index. The maximum mean value was recorded (4.28) in the second plant spacing which was S2 (20cm) with hybrid H1 (DK-6714). The minimum average value was documented (3.13) with the first plant spacing S1 (10cm).

Maximum crop growth rate (27.86 g m^{-2} d^{-1}) was noted with second plant spacing which was S2 (20 cm) with hybrid H1 (DK-6714). The minimum mean value of CGR was recorded (18.86 g m^{-2} d^{-1}) with the first plant spacing which was S1 (10cm) with hybrid H1 (DK-6789). In the case of plant height, both plant spacing and hybrid had a significant effect on plant height. The highest average plant height (221.49cm) was reported when hybrid H1 (DK-6714) was planted with a second plant spacing of S2 (20cm). First plant spacing, with S1 (10 cm) with hybrid H2 (DK-6789) and S2 (20cm) with hybrid H1 (DK-6714), had a minimum mean value of plant height of 166.50cm.

In the case of dry matter production, both plant spacing and hybrid had a significant impact on dry matter production. The maximum mean value of dry matter production (19.47 t ha^{-1}) was recorded in second plant spacing S2 (20cm) with hybrid H1 (DK-6714). The minimum mean value of dry matter production was recorded (16.30 t ha^{-1}) in the first plant spacing S1 (10cm) with hybrid H1 (DK-6789).

In the case of the harvest index plant spacing had a significant impact while hybrid had a non-significant impact on the harvest index. The maximum mean value (47.61) was recorded in the second plant spacing S2 (20 cm) with hybrid H1 (DK-6714). The minimum mean value was recorded (35.60) in the first plant spacing S1 (10 cm) with hybrid H2 (DK-6789). The CERES-Maize model was well standardized for all parameters that were provided to a model at the same preliminary conditions. All the above Tables specify that experiential and simulated values were closely associated, and the model performs very well.

Table 9: Comparison of simulated and observed data for grain yield at different plant spacing

Hybrids	DK-6714			DK-6789		
	Sim	Obs	Error %	Sim	Obs	Error %
S1 (10cm)	8645	6050	42	8501	5650	50
S3 (30cm)	8962	7750	15	8501	6750	26

4. Conclusion

Based on results and discussion it had been concluded that grain yield amongst the numerous treatments was correlated to the photosynthetic activity. Treatment like 20cm plant spacing increased growth and yield of maize crop due to maximum light interception and greater LAD. The best (P × P) plant spacing for hybrid (DK-6714) was 20cm. In this plant spacing grain yield was maximum compared to the other plant spacing. The performance of both hybrids DK-6714 and DK-6789 was also well in 2nd plant spacing (20cm). So according to my findings, I recommended plant spacing (20cm) at which yield was less affected by plant density due to the availability of maximum resources for best performance. To assess the impact of plant spacing CERES- Maize model is a very useful tool. It calibrates very well the best of the treatments, and it impartially appraises the remaining treatments for crop growth, development, biomass, and grain yield.

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