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RESEARCH PAPER

Effect of high density planting under paired row arrangement on growth, yield attributes and yield of *kharif* maize (*Zea mays* L.)

Ayush Ashesh[1] · Harpreet Singh[2]

Abstract A field experiment was conducted at Punjab Agriculture University, Regional Research Station, Gurdaspur, Punjab in *kharif* season of 2022. The study focus on optimum plant population and arrangement of hybrid maize for higher productivity. The study comprise of twelve treatments in which nine were paired row treatments of varying intra-row and inter-row spacing, the rest three was of same population and conventional spacing having different methods of sowing of 60 x 20 cm. All paired row treatments were sown flat and other conventional spacing was in flat, ridge or flat followed ridge. Significantly, higher yield (73.9 q ha^{-1}) was obtained in case of paired row at closer spacing of 20 cm intra paired row distance and 60 cm of inter paired row distance. The yield was comparable with treatment having inter and intra paired row spacing of 20 cm - 80 cm, 30 cm - 60 cm and 40 cm - 60 cm respectively. The plant population in the range of 90,909 to 1,25,000 provided higher yield, significantly higher than of 83,333 plant population ha^{-1}. Among treatments comprise of similar spacing of 60 x 20 cm or plant population of 83,333 plants ha^{-1}, paired row at narrow spacing yielded significantly higher than the conventional spacing with flat and ridge sown. Paired row at broad spacing was comparable with treatment comprise of flat sown followed by ridge. The yield attributes likes of cob length, cob girth and number of grains per cob is significantly higher in case of paired row at maximum spacing of 40 cm intra and 100 cm of inter row spacing. The recommended spacing for Punjab region is 60 x 20 cm.

Keyword: High density maize · Paired row · High yield · Twin row

✉ Harpreet Singh: harsun2021@pau.edu

[1]Department of Agronomy, Punjab Agricultural University, Ludhiana, Punjab, India

[2]Department of Agronomist, Punjab Agricultural University, Reginal Research Station, Gurdaspur, India

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Introduction

Maize is a staple food for millions of people, particularly in developing countries and is also used for animal feed, biofuel production and industrial purposes. It is a highly versatile crop, as it can be grown in a wide range of climatic conditions and soil types. In India, maize is the fourth most cultivated crop in terms of area and production, with 10.10 million hectares and 34.61 million tonnes respectively. However, the average yield in India is 3430 kg ha^{-1}, which is significantly lower than the global average (Anonymous, 2022a). In the state of Punjab, during the year 2020-21, maize was grown on an area of 107.8 thousand hectares and produced 395.1 thousand tonnes of maize (Anonymous, 2022b). The productivity of maize crop plants depends on its genetic makeup and how they respond to the environment in which they are grown. However, various abiotic and biotic factors often limit crop plants from reaching their full yield potential. To overcome these limitations and increase yields, effective management through agronomic practices that suit the local environment is crucial.

Modern maize (*Zea mays* L.) hybrids are commonly considered to be highly influenced by population density, as maximum grain yields per unit area are typically attained in dense populations (Li *et al*., 2015). Rather than improvements in individual plant yield, the increased optimum plant population drives the enhanced productivity of modern maize hybrids. This emphasis on high plant density has become a widespread practice to boost grain yield in maize cultivation. Theoretically, this setup is expected to reduce competition between individual plants, alleviate stress from crowding, and ultimately enhance yields. However, there is still uncertainty regarding the practical feasibility of twin rows in increasing plant densities and boosting grain yields (Robles *et al*., 2012). The high population intercepts more photo synthetically active radiation. Higher plant populations can lead to reduced grain yield due to prolonged pollen-to-silking intervals and subsequent barrenness. However, there is a trade-off as increased plant density also heightens the risk of lodging, which can result in significant yield losses. (Gao *et al.,* 2010 and Sher *et al.,* 2017). Density also decides the growth and development of crop, 40 per cent to 60 per cent decrease in leaf area in later growth phases and around a 40 per cent increase in LAI is observed at a higher plant population (Hay and Porter 2006). Stanger and Lauer (2007) found that increased plant density decreases rind strength.

Strategy of maximizing plant density has gained widespread acceptance and adoption in modern maize cultivation as it continues to prove effective in augmenting overall crop yields. Higher plant density as a key factor in achieving improved grain yields per unit area, shift towards increased plant population per acreage is instrumental in boosting overall maize production, and it stands out as a critical factor contributing to enhanced grain yields. The emphasis here is on optimizing the number of maize plants within a given space rather than relying solely on improving the individual grain yield plant^{-1} (Sher *et al.,* 2017). Testa *et al*. (2016) suggest that hybrid varieties are better suited for experiments aimed at identifying the ideal plant population for maize cultivation despite a reduction in the individual plant yield potential in terms of ear weight and thousand kernels weight by 18% and 6%, respectively, due to high planting density, there was a notable increase in final grain yield observed in 90% of the production systems, high planting density of up to 10.5 plants m^{-2} resulted in a substantial boost in crop yield. However, this effect was most pronounced when coupled with narrow inter-row spacing. The paired row system increases cob yield by 16.8% over 45 x 20 cm and 14.2% over 60 x 15 cm spacing. This improvement in yield is due to overall improvements in all growth and yield attributing characters (Bharud *et al.,* 2014). The narrow paired row performed better than the paired row and other treatments for grain yield at population of 1,21,000 plant ha^{-1} (Liang *et al.,* 2020). This suggests that at same plant population grain yield effected by crop geometry. The population range of 4.7–8.3 plants m^{-2} is independent for grain yield and dry matter, range of 8.3–10.75 plants m^{-2} is affected for grain yield and dry matter (Li *et al*., 2015).

Materials methods

The experiment was conducted during *kharif* 2022 at Regional Research Station (RRS), Punjab Agricultural University, Gurdaspur, Punjab, is situated at 32º 27′ N latitude, 75º 24′ E longitude and at an altitude of 241 meter from mean height of sea level. The RRS, Gurdaspur is placed in Agro climatic zone-I and Agro-ecological sub region 9.1 under Sub-mountain (Shiwalik hills) of lower Himalaya. The maximum and minimum and temperature ranges from 25.7 to 43.7 ºC. The total precipitation (mm) during the experiment is 627 mm. The experiment was conducted in Randomized Complete Block Design (RCBD) with three replications. The experiment consisted of twelve treatments. The twelve treatments is a mix of number of paired row, flat sown, ridge sows and flat followed ridge. The paired row treatments are T1(20 cm - Intra paired row distance, 60 cm - Inter paired row distance), T2(20 cm - Intra paired row distance, 80 cm - Inter paired row distance), T3(20 cm - Intra paired row distance, 100 cm - Inter paired row distance), T4(30 cm - Intra paired row distance, 60 cm - Inter paired row distance), T5(30 cm - Intra paired row distance, 80 cm - Inter paired row distance), T6(30 cm - Intra paired row distance, 100 cm - Inter paired row distance), T7(40 cm - Intra paired row distance, 60 cm - Inter paired row distance), T8(40 cm - Intra paired row distance, 80 cm - Inter paired row distance) and T9(40 cm - Intra paired row distance, 100 cm - Inter paired row distance). Other than this there is T10(flat sown followed by ridge), T11 (flat sown) and T12 (ridge sown) at 60 x 20 cm. The date of sowing was 25th June 2022, sowing was done manually with two seeds per spot with the help of rope to make the distance accurate. The variety used was PMH - 13 and seed rate varies according to treatment. Application of N, P and K was given using Urea, Di-ammonium phosphate and Muriate of potash on the basis of soil test value and organic carbon. The fertilizer applied at the rate of 80, 40 and 20 kg ha^{-1} respectively according to soil condition for sandy loam to clayey loam soils for maize under Punjab condition. First irrigation was given three weeks after sowing of crop. Weed control was done using herbicide Atrazine 50 WP) was sprayed @ 2.0 kg ha^{-1} with a knapsack sprayer using 500 litres of water followed by Tembotrione 420 SC @ 260 ml ha^{-1}. Hand hoeing was done at 35 days after sowing (DAS) for effective control of sedges. For plant protection, the crop was sprayed with 75 ml (C*hlorantraniliprole* 18.5 SC) using 150 liters of water ha^{-1} with a knap-sack sprayer against maize borer. Girth of plant was measured at base above the first circular node. Height was recorded, five plants were tagged and height were measured. Measuring was done from each plant from ground to base of fully opened leaf whorl during vegetative stages and base of tassel after tasseling. The Leaf area index was recorded using Sun Scan Canopy Analyser (Sun scan 1) by placing it perpendicular to row five times in a plot to the average value. The experimental plots were harvested manually when 75 per cent of cobs turned yellowish brown and grains became hard. After ten days of harvesting, cobs were separated from plants and dried for another seven days. The cobs were threshed with maize dehusker cum thresher.

The recorded data for different parameters like growth stages, yield, and yield attributes were analysed by the ANOVA technique by Gomez and Gomez (1984) for RCBD using Excel workbook. The LSD test was used to reduce the effect of treatments at a 5% level of significance (P=0.05). The critical difference (CD) values for pair-wise comparison among the treatment effects were computed.

Results and discussion

Growth

Plant height was significantly higher in case of T1 (20 cm - Intra paired row distance, 60 cm - Inter paired row distance) at population of 1,25,000 plant ha^{-1} at 60 days after sowing. It was similar with T4 (30 cm - Intra paired row distance, 60 cm - Inter paired row distance. The Leaf area index was also reported highest in-case of T1 (20 cm - Intra paired row distance, 60 cm - Inter paired row distance) and is similar with T2 (20 cm - Intra paired row distance, 80 cm - Inter paired row distance) and T4 (30 cm - Intra paired row distance, 60 cm - Inter paired row distance). The girth of stem followed a reverse pattern where higher density produced thinner stems. At 60 DAS the maximum girth was in treatment T9 (40 cm - Intra paired row distance, 100 cm - Inter paired row distance) and lowest girth was in the treatment T1 (20 cm - Intra paired row distance, 60 cm - Inter paired row distance). These findings align with those of Maddonni *et al.* (2001), who observed a 13 per cent increase in plant height at a population of 1,00,000 plants ha^{-1}. Plants under higher plant population have lower horizontal space to grow and tends to intercepts more sunlight using vertical space having higher height, consequently having thinner stems.

Yield attributes

The number of cobs per plant is not affected by the paired row spacing and other planting methods and it's remains constant throughout the experiment. The cob girth is highest in the treatment T9 (40 cm - Intra paired row distance, 100 cm - Inter paired row distance), where the population is least and crop is having large space and less competition. Cob girth in case of closer row spacing was significantly lower than from the cobs from the plant at higher spacing and also lower than the cobs from the plant sown at conventional spacing of 60 x 20 cm. The reduction in cob girth for T1 (20 cm - Intra paired row distance, 60 cm - Inter paired row distance, P - 1,25,000 plants ha^{-1}) is around 9 per cent with respect to ridge sown at 60 x 20 cm. Cob length is significantly higher in the treatment T9 (40 cm - Intra paired row distance, 100 cm - Inter paired row distance) having population of 71,428 plant ha^{-1}. Higher cob length and cob girth was obtained where each plant is having higher resource use per plant under lower plant population. The higher cob length attributed to larger spacing which was similar to girth of cob. The reduction in length was around 15 per cent forT1 (20 cm - Intra paired row distance, 60 cm - Inter paired row distance) having population 1,25,000 plants ha^{-1}. The result of cob girth was in line with Testa *et al.* (2016).

No significant effect was observed for the variation in cob weight among the different treatments. Cob weight was higher in-case of larger spacing and low in weight in-case of narrow paired row T1 (20 cm - Intra paired row distance, 60 cm - Inter paired row distance). Number of grains per cob significantly higher for the T9 (40 cm

Table 1. Effect of high density and paired row arrangement on plant height (cm), stem girth (cm), Leaf area Index, number of cobs per plant, cob girth (cm) and cob length (cm) of *kharif* maize (*Zea mays* L.)

	Treatments	Plant height (cm) at 60 DAS	Stem girth (cm) at 60 DAS	Leaf area index at 60 DAS	Number of cobs per plant	Cob girth (cm)	Length of cob (cm)
T1	20 cm - Intra paired row distance, 60 cm - Inter paired row distance (P-1,25,000)	236.3	4.8	5.63	1.01	14.1	13.1
T2	20 cm - Intra paired row distance, 80 cm - Inter paired row distance (P- 1,00,000)	212.3	5.2	5.41	1.01	14.7	14.0
T3	20 cm - Intra paired row distance, 100 cm - Inter paired row distance (P- 83,333)	207.3	5.4	4.97	1.08	15.8	15.7
T4	30 cm - Intra paired row distance, 60 cm - Inter paired row distance (P – 1,11,111)	222.0	4.9	5.37	1.00	14.2	13.6
T5	30 cm - Intra paired row distance, 80 cm - Inter paired row distance (P - 90,909)	210.7	5.2	4.93	1.09	15.3	14.8
T6	30 cm - Intra paired row distance, 100 cm - Inter paired row distance (P-76,923)	206.6	5.5	4.53	1.09	15.8	15.5
T7	40 cm - Intra paired row distance, 60 cm - Inter paired row distance (P-1,00,000)	210.0	5.2	5.00	1.06	14.5	13.9
T8	40 cm - Intra paired row distance, 80 cm - Inter paired row distance (P-83,333)	205.0	5.4	4.37	1.09	16.0	15.7
T9	40 cm - Intra paired row distance, 100cm - Inter paired row distance (P - 71,428)	204.3	5.7	3.93	1.06	16.1	16.1
T10	Flat sown followed by ridge 60 cm x 20 cm (P- 83,333)	206.0	5.6	4.50	1.02	15.7	15.9
T11	Flat sown 60 cm x 20 cm (P - 83,333)	205.6	5.7	4.40	1.03	15.1	15.1
T12	Ridge sown 60 cm x 20 cm (P- 83,333)	207.3	5.7	4.40	1.01	15.5	15.5
	CD (p=0.05)	16.4	0.4	0.28	NS	1.3	1.3

P - Plant population (plant ha^{-1}); DAS – Days after sowing

Table 2. Effect of high density and paired row arrangement on yield attributes and yield of *kharif* maize (*Zea mays* L.)

	Treatments	Cob weight (g)	Number of grains per cob	Test weight (TW)	Grain yield (q ha^{-1})	Stover yield (q ha^{-1})
T1	20 cm - Intra paired row distance, 60 cm - Inter paired row distance (P-1,25,000	137.8	285	261	73.9	134.4
T2	20 cm - Intra paired row distance, 80 cm - Inter paired row distance (P- 1,00,000)	140.2	296	262	70.3	125.9
T3	20 cm - Intra paired row distance, 100 cm - Inter paired row distance (P- 83,333	149.7	325	270	66.4	111.1
T4	30 cm - Intra paired row distance, 60 cm - Inter paired row distance (P – 1,11,111)	139.3	290	260	70.3	129.3
T5	30 cm - Intra paired row distance, 80 cm - Inter paired row distance (P - 90,909)	143.3	313	268	69.4	118.2
T6	30 cm - Intra paired row distance, 100 cm - Inter paired row distance (P-76,923)	147.6	329	274	58.1	103.4
T7	40 cm - Intra paired row distance, 60 cm - Inter paired row distance (P-1,00,000)	142.6	298	263	71.3	121.8
T8	40 cm - Intra paired row distance, 80 cm - Inter paired row distance (P-83,333)	149.6	325	269	67.3	110.2
T9	40 cm - Intra paired row distance, 100cm - Inter paired row distance (P - 71,428)	151.7	332	275	57.5	101.5
T10	Flat sown followed by ridge 60 cm x 20 cm (P- 83,333)	148.3	323	265	65.9	108.1
T11	Flat sown 60 cm x 20 cm (P - 83,333)	142.3	303	260	58.4	104.6
T12	Ridge sown 60 cm x 20 cm (P- 83,333)	145.6	319	267	60.3	106.1
	CD (p=0.05)	NS	18	9.0	5.5	7.7

P - Plant population (plant ha^{-1}); DAS – Days after sowing

- Intra paired row distance, 100 cm - Inter paired row distance), having higher cob length and girth. For T1 (20 cm - Intra paired row distance, 60 cm - Inter paired row distance) the number of grains per cob is least. It is less than 10 percent with reference to ridge sown at 60 x 20 cm (T12). Similarly for other close spaced paired rows T4 (30 cm - Intra paired row distance, 60 cm - Inter paired row distance) the reduction is 9 percent, for T5 (40 cm - Intra paired row distance, 60 cm - Inter paired row distance), it was around 6 per cent as compared to ridge sown 60 x 20 cm (T12). The higher yield were confirmed by Li *et al.* (2015) under high density maize. The test weight is significantly higher in case of T9 (40 cm - Intra paired row distance, 100 cm - Inter paired row distance), having higher length girth and number of grain per cob. The higher test weight attributes to lower competition among the plants due to lesser plant per unit area. For rest of the treatments it was not affected by plant population and method of planting.

Yield

Grain yield

The significantly higher grain yield was obtained in case of T1 (20 cm - Intra paired row distance, 60 cm - Inter paired row distance) having population of 1,25,000 plants ha^{-1}. The grain yield advantage is around 25 per cent for T1 (20 cm - Intra paired row distance, 60 cm - Inter paired row distance) treatment as compared to ridge sown 60 x 20 cm (T12). The main attributing factor towards higher yield of T1 (20 cm - Intra paired row distance, 60 cm - Inter paired row distance) was plant population. The population compensate for the lower length, girth and number of grains per cob and gave significantly higher yield. Similarly for T2 (20 cm - Intra paired row distance, 80 cm - Inter paired row distance), T4 (30 cm - Intra paired row distance, 60 cm - Inter paired row distance), T5 (30 cm - Intra paired row distance, 80 cm - Inter paired row distance) and T7 (40 cm - Intra paired row distance, 60 cm - Inter paired row distance) having population on higher side 1,00,000, 1,11,111, 90,909 and 1,00,000 plant ha^{-1} respectively gave more yield and at par with T1 (20 cm - Intra paired row distance, 60 cm - Inter paired row distance) as the paired row space increased at same population, the level of yield decreases. The higher yield in the T10 (flat sown followed ridge at 60 x 20 cm) attributed to higher cob length, more girth and number of grains per cob as compare with conventional T11 (flat sown) and T12 (ridge sown) at 60 x 20 cm. For T2 (20 cm - Intra paired row distance, 80 cm - Inter paired row distance), and T4 (30 cm - Intra paired row distance, 60 cm - Inter paired row distance) the yield advantage is around 17 per cent. For T5 (30 cm - Intra paired row distance, 80 cm - Inter paired row distance) it is of 15 per cent, for T7 (40 cm - Intra paired row distance, 60 cm - Inter paired row distance), it is 18 per cent with respect to T12 (ridge sown at 60 x 20 cm). The above discussion goes with Robles *et al*., (2012).

Stover yield

Stover yield was significantly higher for T1 (20 cm - Intra paired row distance, 60 cm - Inter paired row distance at population 1,25,000 plant ha^{-1}) having higher population and at par with T4 (30 cm - Intra paired row distance, 60 cm - Inter paired row distance), the second highest population of1,11,000 plant ha^{-1}. For the other treatments there was no effect of paired row and plant population on the stover and it was at par with different treatments. The higher stover yield is due to more number of plants per unit area which constitutes higher biomass.

Conclusion

From the experiment it has been concluded that the paired row at closer spacing having higher plant population (1,25,000; 1,11,111; 1,00,000 and 90,909 plant ha^{-1}) is having higher plant height, Leaf area index and yield. It yield was significantly higher than the conventional methods at spacing of 60 x 20 cm having population (83,333 plant ha^{-1}) and other paired rows having lower population (83,333; 76,923 and 71,428 plant ha^{-1}). The most stable character is test weight, which remains similar among different treatments. The most important character towards highest yield is more number of plants ha^{-1} which compensate for lower cob length, girth and number of grains per cob. The experiment concluded that best treatment was (40 cm Intra paired row distance, 60 cm Inter paired row distance) giving 71.3 q ha^{-1} grain yield. The population was 1 lakh plant ha^{-1}, taking lesser quantity of seed than the other paired row treatments.

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