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RESEARCH PAPER

Influence of plant population on nutrient dynamics, growth and quality of *kharif* maize (*Zea mays* L.) under diverse paired row planting arrangements

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Abstract A field experiment was carried out during *kharif* season of 2022 at the Regional Research Station of Punjab Agricultural University, located in Gurdaspur, Punjab. The study aimed to determine the optimal plant population and row arrangement for hybrid maize, focusing on its growth and quality, and the nutrient status of both soil and plants. The study comprised of twelve treatments including nine paired row treatments (sown on flat beds) of varying intra-row and inter-row spacing, and three different sowing methods treatments. The result revealed that close spaced paired row panted maize at 20-30 cm intra and 60-80 cm inter row spacing improved plant height, photosynthetically active radiation, and leaf area index. Various planting methods and population densities did not affect the crop reproductive cycle. Highest available soil N content (187.7 kg/ha) was recorded in sparsely planted plot (40 cm intra paired row distance, 100 intra paired row distance having least population of 71,428 plants/ha. Maize planting at 20-30 cm intra paired row distance and 60-80 cm inter paired row distance (90,909-1,25,000 plants/ha) improved maize yield by 15-25 per cent over conventional planting at 60 × 20 cm. These densely sown treatments also recorded increased plant uptake of N, P and K. Higher yield obtained from the paired row planted maize with deteriorating.

Keyword: High density maize • Nutrient uptake • Paired row • Photosynthetically active radiation • Twin row

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Introduction

Maize serves as a staple food for millions, especially in developing countries, and is widely utilized for animal feed, biofuels production, and various industrial purposes. In India, maize ranks as the fourth most cultivated crop, covering an area of 10.10 million hectares and yielding 34.61 million tonnes (Anonymous, 2022a). Despite its extensive cultivation, the country's average yield of 3430 kg/ha falls significantly below the global average. In Punjab, during the 2020-21 seasons, maize was grown on 107.8 thousand hectares, producing 395.1 thousand tonnes (Anonymous, 2022b). Maize productivity is influenced by the crop's genetic characteristics and its interaction with the growing environment. To address these challenges and enhance productivity, it is essential to adopt agronomic practices tailored to the specific conditions of the local environment. High-density maize planting promotes better plant growth and nutrient uptake by enhancing light interception, improving root competition, and increasing nutrient use efficiency. The dense canopy reduces weed growth, conserves soil moisture, and creates a favorable microclimate for nutrient availability. When managed with suitable hybrids, proper fertilization, and adequate water, high-density planting leads to improved biomass production and higher yields. The following studies reported here proves the fact that high density planting of maize can positively effects the growth and quality of *kharif* maize. The critical resources for plant development are light and nitrogen. The quality of maize grains depends upon its nutrient concentration. High requirement of nutrients is required in case of maize due to its tall stature and high amount of dry matter accumulation. Increasing plant per unit area will lead to higher dose of nutrient for higher biomass. Under higher population, it was observed that there is an improvement in the uptake of nutrients by plants i.e. nitrogen, phosphorus, copper and iron which further linked directly and increases biomass by 81 per cent of the plant (Peng *et al.,* 2019). Ciampitti *et al.* (2013) from Indiana observed the relation between plant density and nitrogen rates affects the uptake of phosphorus (P), potassium (K) and sulfur (S) in maize. They reported that the uptake of P, K and S at silking stage is 47, 100 and 58 per cent respectively. Population density and nitrogen rate is responsible for absolute quantities of P, K and S as crop grows. At nitrogen level of 0 to 375 kg ha^{-1} and number of plants 6 to 11 per m^2, the average accumulation of 232 kg N ha^{-1} in biomass was observed at yield level of 12,000 kg ha^{-1} with net harvest index of 64 per cent. Also lower level of N content gram $plant^{-1}$ at pre-silking, maturity and post-silking stage were observed in case of high density at 90,000 plant ha^{-1} as compared to low density at 60,000 plants ha^{-1} (Setiyono *et al.,* 2010). Both plant density and nitrogen rate determined the above ground N content to Leaf area index (LAI). The ratio decreases with increase in density and lower nitrogen level. Higher uptake was observed before silking in case of higher plant population. The aboveground portion mass accumulation was higher in case of higher plant population and higher N level between R1 and R6 stage (Ciampitti and Vyn, 2011). From this discussion it was observed that increasing population do effect the nutrient dynamics in soil as well as in plant. More uptake and nutrient content due higher biomass accumulation observed in different studies. This is possible due to efficient plant biological cycles. The most important principle of agronomy is harvesting as much as possible of solar energy (Reddy and Reddy, 2019). Light provides the energy source for plant growth through photosynthesis. Light and nutrient consider primary base of growth. In a study it was observed 75 per cent of leaf nitrogen is involved in the photosynthetic process, according to Evans (1989). Maize leaves provide energy for growth and development. During last 75 years the increase in density do not increase the per plant leaf area but it contributes towards increase in yield and leaf per unit area (Lambert *et al.,* 2014). Twin row planting is having greater leaf area index (6.3) at anthesis than conventional geometry (Bruns *et al.,* 2012). Better leaf structure is there in case of narrow row corn which efficiently utilizes the different resources needed for essential processes (Sharratt and McWilliams, 2005). There is a 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). A study conducted by Gozubenli *et al.* (2004) found a similar tasseling period of 54.4 days across different planting densities which proves increasing plant population do not affects the reproductive cycle of crop. Although, increase in population increases the plant height decreasing the girth strength and thickness (Stanger and Lauer, 2007) these findings suggests problem of lodging due to weakened ability of plant to withstand high speed wind and leads to lodging in some cases. The quality of maize grain depends also upon its population; Randhawa (2012) also observed the higher grain starch and protein content under 60 x 35 cm as compared with 60 x 15 cm. The above discussion leads the research to find optimum plant population for proper growth and efficient utilization of nutrients.

Material and methods

The experiment was conducted during the *kharif* season of 2022 at the Regional Research Station (RRS) of Punjab Agricultural University, Gurdaspur, Punjab. The station is located at 32º27′ N latitude, 75º24′ E longitude, and an altitude of 241 meters above sea level. RRS Gurdaspur falls under Agro-climatic Zone-I and Agro-ecological Sub-region 9.1, situated in the Sub-mountain region (Shiwalik hills) of the lower Himalayas. During the experimental period, the maximum and minimum temperatures ranged from 25.7°C to 43.7°C, and the total rainfall was 627 mm. The experiment followed a Randomized Complete Block Design (RCBD) with three replications and included twelve treatments. These treatments were a combination of paired row planting at various spacings, flat sowing, ridge planting, and flat sowing followed by ridge planting. The treatments were: T_1(20 cm - intra paired row distance, 60 cm - inter paired row distance), T_2(20 cm - intra paired row distance, 80 cm - inter paired row distance), T_3(20 cm - intra paired row distance, 100 cm - inter paired row distance), T_4(30 cm - intra paired row distance, 60 cm - inter paired row distance), T_5(30 cm - intra paired row distance, 80 cm - inter paired row distance), T_6(30 cm - intra paired row distance, 100 cm - inter paired row distance), T_7 (40 cm - intra paired row distance, 60 cm - inter paired row distance), T_8(40 cm - intra paired row distance, 80 cm - inter paired row distance),T_9 (40 cm -

intra paired row distance, 100 cm - inter paired row distance),T_{10}(flat sowing followed by ridge panting at 60 x 20 cm), T_{11} (flat sowing at 60 x 20 cm) and T_{12} (ridge panting at 60 x 20 cm). The sowing of the maize crop was carried out manually on June 25, 2022, by placing two seeds per spot using a rope to ensure precise spacing. The maize variety PMH-13 was used, and the seed rate was adjusted based on the respective treatments. Fertilizer application included nitrogen (N), phosphorus (P), and potassium (K), supplied through urea, di-ammonium phosphate, and muriate of potash, respectively, based on soil test values and organic carbon content. The N, P and K were applied at rates of 80, 40, and 20 kg/ha, respectively. First irrigation was given three weeks after sowing of crop. Weeds were controlled through pre-emergence application of atrazine (50 WP) @ 2.0 kg/ha followed by post emergence spray of tembotrione (42 SC) @ 260 ml/ha. For plant protection against maize borer, the crop was sprayed with chlorantraniliprole (18.5 SC) @75 ml/ha. Plant height and stem girth were recorded at harvest by tagging five plants per plot. Measurements for pant height were taken from the ground to the base of the tassel. The stem girth was measured at the plant base just above the first circular node. The leaf area index and photosynthetically active radiation (PAR) were assessed at 60 DAS using a Sun Scan Canopy Analyzer (Sun Scan 1). The analyzer was positioned perpendicular to the row and readings were taken five times per plot to calculate the average value. The 50 percent silking and tasseling was observed as number of days taken from sowing to the emergence of tassels and silk to half the population of plot. The protein content (%) in maize grain was analysed for each plot by multiplying its nitrogen content by 6.25. Nitrogen content of grain was estimated by modified Kjeldahl's distillation method. Olsen (1954) method was used to obtain available P in soil. Mervin and Peech (1950) used for estimation of available potassium in soil. In case of plant analysis Plant samples were collected for analysis at the time of harvest of each plot. It was then oven dried and ground further. The powdered samples were used for analysis. For nitrogen, digestion of the 0.5 g of plant sample and grain sample was done using concentrated Sulphuric Acid in the presence of catalytic mixture. It was then filtered and made the volume up to 50 ml. 5 ml of the extract was taken and absorbed on boric acid using and distilled using Kjeldahl's apparatus in the presence of Boric Acid. The alkaline condition maintained using sodium hydroxide. The absorbed product titrated with 0.014 normal (N) sulphuric acid for estimation of nitrogen content in grain and straw. For phosphorus the sample from plant digested using di-acid mixture i.e. concentrated Nitric Acid ($NHNO_3$) and Perchloric Acid ($HClO_4$) in the ratio of 3:1. Phosphorus content was estimated from the extract using Vanado-molybdate phosphoric yellow colour method. The intensity of the yellow color was measured using a spectrophotometer at 470 nm wavelength. In a 25 ml volumetric flask 1 ml of the sample of plant and grain extract obtained using di-acid digester was taken. The final volume made was 25 ml using distilled water and the solution was fed into a flame photometer for the estimation of total potassium (K) in the sample. Total content calculated by multiplying total dry matter with available content.

Harvesting of the experimental plots was done manually once 75% of the cobs turned yellowish-brown and the grains had hardened. Ten days after harvesting, cobs were separated from the plants and left to dry for an additional seven days. The dried cobs were then processed using a maize dehusker-cum-thresher. Data collected on various parameters were analyzed using the ANOVA technique for RCB Das outlined by Gomez and Gomez (1984). Critical difference (CD) values were computed to facilitate pair wise comparisons of treatment effects.

Results and discussion

Growth

Plant height, leaf area index and photosynthetically active radiation were significantly higher in T_1 (1,25,000 plants/ha) over rest treatments except T_2 and T4 which showed comparable results with T_1 (Table 1). In contrast, stem girth showed an inverse relationship with plant density, as higher plant densities resulted in thinner stems. Maximum stem girth was recorded in T_9, while the minimum was observed in T_1. These results are consistent with the findings of Maddonni *et al.* (2001), who reported a 13 per cent increase in plant height at a population density of 1,00,000 plants/ha. The increased plant height under higher densities is attributed to limited horizontal growth space, leading to greater competition for sunlight. This promotes vertical growth but results in thinner stems due to constrained resources. The days taken to reach tasseling

Table 1. Influence of high density and paired row arrangement on plant growth and phenological parameters of *kharif* maize

Treatments	Plant height (cm)	Stem girth (cm)	Leaf area index	Days taken to 50% tasseling	Days taken to 50% silking	PAR (%)
T_1	231.3	5.8	5.53	50	55	83.6
T_2	215.3	6.2	5.31	49	54	77.3
T_3	211.7	6.4	4.87	49	54	72.6
T4	222.0	5.9	5.27	49	54	79.6
T_5	213.7	6.2	4.83	48	53	75.6
T_6	210.7	6.6	4.43	50	55	71.3
T_7	214.0	6.2	5.10	50	55	76.6
T_8	208.3	6.5	4.27	51	56	69.3
T_9	207.0	6.9	3.83	48	53	63.6
T_{10}	212.7	6.7	4.40	48	53	66.3
T_{11}	209.0	6.8	4.30	49	54	64.6
T_{12}	215.7	6.7	4.30	48	53	64.3
CD (p=0.05)	11.9	0.6	0.28	NS	NS	6.7

and silking stage were not affected by the different paired row arrangements and population density. The above result was found in line with Gozubenli *et al.* (2004).

Available soil nutrient

The effect of paired row planting and plant population on available soil P and K were found non-significant (Table 2). However, significantly highest available N content in soil was recorded in sparsely planted and east populated (71,428 plants/ha) treatment (T_9). Conversely, treatments having higher plant density recorded comparatively lower available soil N. Low soil N in case of closely spaced paired row attributed to the higher biomass accumulation per unit. Higher biomass had taken up the majority of nitrogen from soil for plant growth and development and therefore soil left with lower soil available N.

Plant nutrient content and uptake

The plant N, P and K concentration was constant throughout the treatments (Table 3) indicates that nutrient in soil was not a constraint and equally taken up irrespective of plant population and sowing method. The

Table 2. Influence of high density and paired row arrangement on soil available nitrogen, phosphorus and potassium and their plant uptake in *kharif* maize

Treatment	Available nutrients (kg/ha)			Nutrient uptake (kg/ha)		
	N	P	K	N	P	K
T_1	169.0	29.3	129.3	181.0	61.1	237.8
T_2	179.0	31.7	133.7	173.3	60.5	231.2
T_3	182.3	33.7	139.0	168.9	53.7	208.3
T_4	172.7	30.3	137.0	173.7	58.0	234.1
T_5	183.1	33.2	135.9	172.8	57.9	217.8
T_6	186.7	34.7	138.3	150.9	48.8	197.3
T_7	179.3	30.8	127.4	172.1	60.8	222.2
T_8	187.7	33.0	135.7	164.5	53.8	213.2
T_9	192.7	34.6	128.0	149.5	52.5	192.7
T_{10}	178.3	29.0	129.0	158.6	54.3	212.2
T_{11}	182.7	32.7	135.3	144.3	46.2	202.3
T_{12}	179.7	30.0	131.7	154.2	50.2	204.9
CD (p=0.05)	12.3	NS	NS	12.4	6.5	18.5

Table 3. Influence of high density and paired row arrangement on grain nutrient and protein content and yield of *kharif* maize

Treatment	Nutrient concentration (%)			Protein content	Grain yield
	N	P	K	(%)	(q/ha)
T_1	1.52	0.39	0.45	9.5	73.9
T_2	1.50	0.41	0.44	9.4	70.3
T_3	1.60	0.39	0.46	10.0	66.4
T_4	1.50	0.40	0.45	9.4	70.3
T_5	1.58	0.41	0.44	9.9	69.4
T_6	1.62	0.41	0.46	10.1	58.1
T_7	1.54	0.42	0.45	9.6	71.3
T_8	1.57	0.42	0.43	9.8	67.3
T_9	1.63	0.42	0.45	10.2	57.5
T_{10}	1.57	0.41	0.46	9.8	65.9
T_{11}	1.54	0.38	0.46	9.6	58.4
T_{12}	1.54	0.41	0.46	9.6	60.3
CD (p=0.05)	NS	NS	NS	NS	5.5

uptake of N, P and K was significantly higher in case of T_1 and it was similar with T_2, T_3, T_4, T_5 and T_7 (Table 2). The higher biological yield and grain yield resulted in higher total N, P and K uptake in closer paired row planted crop. The least uptake of all the macro-nutrients was observed in T_{11} and T_6. The lower uptake attributed to lower plant population, sowing method and soil condition. The above observation for total uptake of N, P and K was found in line with Peng *et al.* (2019).

Protein content

The Protein content (per cent) was shown in the Table 3 indicates that there was no effect of paired row on the protein content of maize grain and it was in between 9 to 10 per cent throughout the treatments at both the locations.

Grain yield

A significantly higher grain yield was obtained in T_1 (20 cm intra-paired row distance, 60 cm inter-paired row distance) with a population of 125,000 plants/ha (Table 3). Similarly, treatments T_2 (100,000 plants/ha), T_4 (111,111 plants/ha), T_5 (90,909 plants/ha), and T_7 (100,000 plants/ha) also produced higher yields comparable to T_1. The grain yield advantage for T_1, T_2, T_4, T_5 and T_7 were approximately 25%, 17%, 17%, 15%, 18%, respectively compared to ridge sowing at 60 × 20 cm (T_{12}). The primary factor contributing to the higher yield in these treatments was the increased plant population, which compensated for the lower length, girth, and number of grains per cob. However, as the paired row space increased at the same population, the yield level decreased. Comparatively higher yield in T_{10} (flat sown followed by ridge at 60 × 20 cm) was attributed to greater cob length, increased girth, and a higher number of grains per cob compared to conventional treatments T_{11} (flat sown) and T_{12} (ridge sown) at 60 × 20 cm. These findings align with the study conducted by Robles *et al.* (2012).

Conclusion

The study demonstrated that plant population and paired row spacing significantly influenced maize growth, nutrient uptake, and grain yield. The highest grain yield was obtained in 20 cm intra-paired row distance, 60 cm inter-paired row distance with a population of 1,25,000 plants per hectare, providing a 25 per cent yield advantage over the conventional ridge sowing method (60 cm x 20 cm). The findings highlight that optimizing plant population and spacing can enhance maize yield and nutrient utilization efficiency without negatively impacting soil nutrient status. These results align with previous studies, reinforcing the benefits of paired row planting for improved maize productivity.

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