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Effect of Plant Density and Fertilizer Management Practices on Yield of Spring Maize

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ABSTRACT

The grain yield of maize is lowered by an insufficient plant population and an unbalanced fertilizer application. An experiment was carried out in the spring to address these problems. The treatments were set up in a split-plot design with three replications and included factorial combinations of three planting densities and four fertilizer levels: 120:60:40 kg N, P_2O_5, K_2O ha^{-1}, 120% RBR, 150% RBR, and site-specific nutrient management (SSNM), 140:40:40 kg N, P_2O_5, K_2O ha^{-1}. Both the barrenness and sterility percentages were higher ($p<0.05$) for the highest planting densities and the lowest for the lowest plant densities. A higher ($p<0.05$) number of kernels per cob was recorded at the lowest plant density and the highest amount of fertilizer application. For the lowest and highest plant densities, the leaf area index increased the grain yield, whereas longer grain filling duration and less barrenness and sterility increased ($p<0.05$) the grain yield for all plant densities. The number of kernels per row or cob was the most crucial factor in increasing the yield of maize under a higher plant density, whereas the final plant population was the most crucial factor in increasing the yield under a lower plant density. Due to a higher number of final plant populations and comparable yield traits, the grain yield of the planting density with the highest grain production was significantly higher. The increased amount of fertilizer (144:72:48 N:P_2O_5:K_2O kg ha^{-1}, 180:90:60 N:P_2O_5:K_2O kg ha^{-1}) gave a higher grain yield. The plant densities of 66667 ha^{-1} and 83333 ha^{-1} were better, whereas the present recommended dose of N: P_2O_5:K_2O should be increased or need-based SSNM must be adopted to obtain more profits from spring maize.

Keywords: Fertilizer, Management, Plant density, Spring Maize, Yield

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INTRODUCTION

Maize (*Zea mays* L.) is the world's widely grown cereal. It is usually used for human food, feed and fodder for livestock and fuel and raw materials (Adhikari 2008). The production and acreage of maize in Nepal are 3 million mt and 1 million ha, respectively, making it the country's second-most important cereal crop (FAOSTAT 2022). In Nepal, the maize sub-sector accounts for 24.97% of total cereal production and occupies 27% of the land utilized for food crops. It provides 3.15% of the country's GDP and 9.5% of its agricultural GDP (MoALD 2022).The productivity of maize in Nepal is lower as compared to its neighboring countries such as India, Bangladesh, China. The low productivity of maize is due to inappropriate management of plant density and fertilizer management.

The primary method for raising yield is plant density optimization. According to Yang et al. (2017) and Raza et al. (2019) high plant density exposes the plant to shading, which hinders it from fully absorbing light and reduces leaf development, leaf area index, leaf photosynthesis, and premature total biomass production and grain yield. According to Ciampitti and Vyn (2012) and Timlin et al. (2014), too much plant density hinders plant growth by preventing it from receiving enough sunshine and absorbing carbohydrates. The increase in the grain yield of maize under high density is due to the improvement in a light interception during the critical period for grain set, while the number of seeds per plant and plant growth rate is adversely affected by nitrogen deficiency and shading under the high density (Andrade et al 2002).

According to Stefano et al. (2004), inorganic fertilizers have a significant impact on plant growth, development, and production. Improved cell activity, increased cell enlargement and multiplication, and lush growth are the results of having enough growth nutrients from inorganic fertilizers available (Fashina et al 2002). Fertilizer treatment promotes vegetative growth, which increases the formation of dry matter (Obi et al 2005). Grain yield in maize increases with an increase in plant density, rate, and split application for nitrogen (Mariga et al 2000, Scharf et al 2002).

Studies on fertilizer levels for varying plant density for spring maize are not enough. This research investigate the effects of varying level of plant density and fertilizer levels on phenology, morphology, yield and economics of spring maize.

MATERIALS AND METHODS

Experimental site

This field experiment was carried out at National Maize Research Program (NMRP) farm, Rampur, Chitwan from April to July 2019 during spring season. The experimental site is situated at 228 meters above sea level with 27°40' North latitude and 84°19' East longitude.

The detail physio- chemical properties of the experimental soils are presented in Table 1. The pH of soil was 6.1. The available phosphorous was found to be very high. In contrast, the available potassium and total nitrogen was found to be of medium and soil organic matter was low in status.

Table 1. Physico-chemical characteristics of the soil (0-15 cm) of the experimental site, NMRP, Rampur, Chitwan (2019)

Properties	Average Content	Rating	Methods
Physical properties			
Sand (%)	62.9		
Silt (%)	28.8	Sandy loam	Hydrometer.
Clay (%)	8.3		
Chemical properties			
Soil pH	6.1	Acidic	Beckman Glass Electrode pH meter
Soil-organic matter (%)	2.02	Low	Walkey and Black
Total nitrogen (%)	0.1	Medium	Micro Kjeldhal Distillation
Available phosphorus (kg ha^{-1})	107.63	Very high	Modified Olsen’s method
Available potassium (kg ha^{-1})	179.42	Medium	Ammonium acetate method

Climatic data

The experimental site lies in the subtropical humid climate belt of Nepal. The area has a sub-humid type of weather condition with cool winter, hot summer, and a distinct rainy season with an annual rainfall of about 2000 mm. The weather data during the cropping season was recorded from the metrological station of the National Maize Research Program (NMRP), Rampur, Chitwan (Figure 1). Comparatively higher rainfall was recorded during the ripening phase.

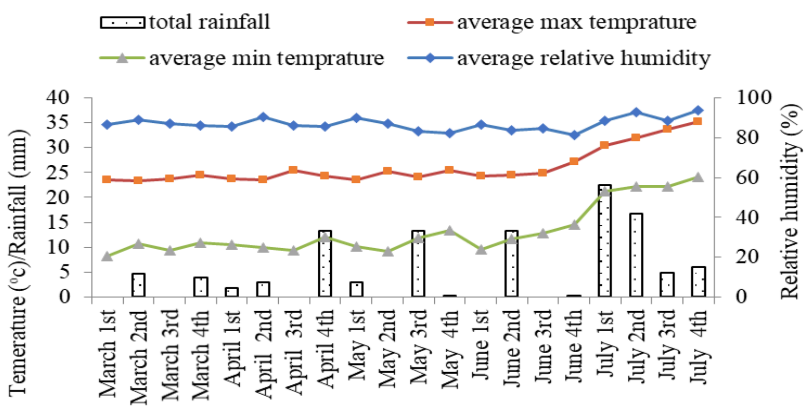

Figure 1. Weekly weather conditions during the course of experimentation

Experimental design, treatments and cultural practices

The gross experimental plot area of 957 m^2 was laid out in split plot design consisting of 12 treatments with three replications. Three population densities (55,555, 66,666 and 83,333 plants per ha^{-1}) as main plot factor and four levels of nitrogen as shown in Table 2 below were used as sub- plot factors .NE as the Nutrient expert recommended dose. The fertilizer dose was determined using Nutrient Expert software prepared by the International Plant Nutrition Institute (IPNI). The experimental plots were 16.4 m^2 (4.8 m × 3.5 m) in size.

Arun-2 (80-100 days) the recommended variety for terai region and lower valley of mid-hills was used in the experiment. The plot size used in experimental plot was 6 m × 3 m. The source of plant material is National Maize Research Program, Rampur, Chitwan, Nepal.

The distance between two replications was 1 m and each plot by 0.5m. Thus, altogether there were 10 rows in each plot of which 1st and 10th rows were treated as the border rows. The central five rows (4, 5, 6, 7 and 8^{th}) were used as net plot rows for harvesting, 3^{rd} and 9^{th} rows were used as guard rows and remaining 2^{nd} and 3^{rd} rows were used for taking samples using destructive method.

Table 2. Treatment combinations

Treatments	Main plot Spacing (cm × cm)	Sub plot fertilizer (kg ha^{-1})	Plant density (plants ha^{-1})
T_1	60×30	120:60:40	55,555
T_2	60×30	120% RBR (144:72:48)	55,555
T_3	60×30	150% RBR (190:80:60)	55,555
T_4	60×30	140:40:40	55,555
T_5	60×25	120:60:40	66,,666
T_6	60×25	144:72:48	66,666
T_7	60×25	190:80:60	66,666
T_8	60×25	140:40:40	66,666
T_9	60×20	120:60:40	83,333
T_{10}	60×20	144:72:48	83,333
T_{11}	60×20	190:80:60	83,333
T_{12}	60×20	140:40:40	83,333

Data collection

Phenological observation:, tasseling, silking, and physiological maturity stages were recorded from two net plot rows of each plot.

Biometrical observation: Plant height, Leaf area index, Dry matter accumulation were recorded.

Yield attributing characters: It included number of harvested plants, number of barren plants, no of cobs per plant, cob length, number of grain rows per cob, grains per row, grains per ear, thousand kernels weight, grain moisture content (%), grain yield, stover yield, and harvest index,

Statistical analysis

The data obtained for different characteristics with respect to growth, yield contributing characteristics and yield were statistically analyzed to find out the statistical significance. The means for all the treatments were calculated and the analysis of variance for all the characters was performed by the "ANOVA" test. The significance of the difference among the means was evaluated by Duncan's Multiple Range Test (DMRT) according to Gomez and Gomez (1984) using R studio 4.0 for interpretation of the result at a 5% level of probability.

RESULTS AND DISCUSSION

The results obtained from the experiment were analyzed and presented with the help of tables and figures below.

Phenological stages of spring maize

Tasseling, silking and physiological maturity stage

The average days to 80% completion of tasseling, silking and physiological maturity were 60, 63 and 93 days respectively. All these phenological stages were neither influenced by the plant density nor by the fertilizer levels (Table 3). But these phonological stages were comparatively delayed in higher plant density, and physiological maturity was slightly delayed at 150% research based recommendation.

Table 3. Days to tasseling, silking, physiological maturity, tasseling and silking interval (TSI) and grain filling duration (GFD) of spring maize as affected by plant density and fertilizer levels

Treatments	Phenological stages			TSI (days)	GFD (days)
	Tasseling	Silking	Physiological maturity		
Plant density (nos. of plants ha^{-1})					
55,556	59	62	93	2.3	31
66,667	59	62	93	2.8	31
83,333	61	65	93	4.2	29
SEm (±)	0.44	0.86	0.49	0.59	1.19
LSD (0.05)	ns	ns	ns	ns	ns
CV%	2.53	4.72	1.84	65.17	13.63
Fertilizer levels (N, P_2O_5,K_2O kg ha^{-1})					
RBR (120:60:40)	60	63	93	3.4	29b
120% RBR	60	62	92	2.6	30b
150% RBR	60	63	95	3.6	31a
NE dose (140:40:40)	59	62	92	2.9	30b
SEm (±)	0.67	0.61	0.34	0.42	0.69
LSD (0.05)	ns	ns	ns	ns	2.06
CV%	3.35	2.92	1.11	40.45	6.89
Grand mean	60	63	93	3.11	30.19

RBR = research based recommendation, NE dose = nutrient expert dose, TSI= tasseling silking interval, GFP= grain filling period (days), ns = non-significant. Treatments means followed by common letter(s) within column are not significantly different among each other based on DMRT at 0.05 level of significance.

Tasseling silking interval grain filling duration

The average tasseling silking period was 3.11 days, which was not influenced by the planting density and fertilizers levels as well. But the slightly longer duration of tasseling silking was recorded for the higher plant density and the higher levels of fertilizers (120% RBR). The average grain filling period was 30.19 days which was significantly influenced by the different fertilizer levels but not affected by the planting density. Comparatively shorter duration of grain filling was recorded for higher planting density. The grain filling duration was significantly higher (31 days) for 180:90:60 kg N, P_2O_5, K_2O ha^{-1} as compared to other levels of fertilizers. The grain filling duration of all the remaining fertilizer levels were statistically similar (Table 3).

Biometrical observations

Plant height

The plant height of maize was increased 30-55 DAS up to 70 DAS (Table 4). The rate of increments of plant height was higher between on 30 to 55 DAS as compare to 55 to 80 DAS. The plant height was not influenced by planting density at all dates of observations but it was significantly influence by fertilizer levels at 30 and 70 DAS.

At 30 DAS, the tallest plants were recorded at the highest level of the fertilizers (180:90:60 kg N, P_2O_5, K_2O ha^{-1}) which was significantly higher than other lower levels of fertilizers. These lower levels of fertilizers were statistically at par with respect to plant height at 30 DAS. Similarly at 80 DAS, the plant height was again highest at 150% research-based recommendation, which was significantly higher than recommended dose and Nutrient expert dose but statically similar with 120% research-based recommendation.

Table 4. Plant height (cm) of spring maize as influenced by plant density and fertilizer level

Treatments	Plant height (cm)		
	30 DAS	**55 DAS**	**70 DAS**
Plant density (nos. of plants ha^{-1})			
55,556	60.45	201.81	228.42
66,667	63.83	213.81	241.80
83,333	66.75	218.81	241.41
SEm(±)	1.58	6.05	4.06
LSD (0.05)	ns	ns	ns
CV%	8.62	9.91	5.93
Fertilizer levels (N, P_2O_5,K_2O kg ha^{-1})			
RBR (120:60:40)	63.36^{b}	202.26	231.92^{b}
120% RBR	62.09^{b}	211.62	237.22^{ab}
150% RBR	68.16^{a}	217.53	246.48^{a}
NE dose (140:40:40)	61.11^{b}	214.48	233.23^{b}
SEm(±)	1.39	5.99	3.45
LSD (0.05)	4.13	ns	10.24
CV(, %	6.55	8.50	4.36
Grand mean	63.68	211.48	237.21

Leaf area index

The leaf area index (LAI) was increasing up to 55 DAS and decreased there after due to senescence of lower leaves (Table 5).

Table 5. Leaf area index of spring maize as influenced by plant density and fertilizer levels

Treatments	Leaf area index			
	30 DAS	**55 DAS**	**70 DAS**	**85 DAS**
Plant density (nos. of plants ha^{-1})				
55,556	0.63^{b}	2.10^{c}	1.84^{c}	1.63^{c}
66,667	0.79^{b}	2.68^{b}	2.59^{b}	2.05^{b}
83,333	1.07^{a}	3.10^{a}	2.89^{a}	2.48^{a}
SEm(±)	0.07	0.10	0.06	0.10
LSD (0.05)	0.27	0.41	0.25	0.39
CV%	28.88	13.63	8.94	16.56
Fertilizer levels (N, P_2O_5, K_2O kg ha^{-1})				
RBR (120:60:40)	0.74^{b}	2.43	2.16^{b}	1.85
120% RBR	0.82^{b}	2.63	2.46^{b}	2.02
150% RBR	0.96^{a}	2.98	2.87^{a}	2.43
NE dose (140:40:40)	0.80^{b}	2.47	2.28^{b}	1.90
SEm(±)	0.05	0.19	0.10	0.16
LSD (0.05)	0.13	ns	0.30	ns
CV%	16.27	22.18	12.26	23.59
Grand mean	0.83	2.63	2.44	2.05

The average LAI at 30 DAS was 0.83. Among the plant density, significantly higher LAI (1.07) was recorded for 83,333 plants ha^{-1} over two other treatments which were statistically similar to each other. In fertilizer levels, the highest LAI (0.96) was recorded for 150% RBR (180:90:60 kg N, P_2O_5, K_2O ha^{-1}) and other fertilizer levels were statistically similar with each other. The average LAI at 55 DAS was 2.63.

Among the plant density, significantly higher LAI (3.10) was recorded for 83,333 plants ha^{-1} and significantly lower (2.68) for planting density 66,667 plants ha^{-1} and (2.10) 55,556 plants ha^{-1}. The planting density of 55,556 ha^{-1} has significantly lower LAI than the 66,667 plants ha^{-1}. Among the fertilizer levels, LAI at 55 DAS of maize was not significantly influenced but comparatively higher LAI was obtained with the fertilizer application of 50% more than research based recommendation. At 70 DAS, the average LAI was 2.44, at this date of observation LAI was significantly influenced both by the planting density and the fertilizer levels. Among the plant density, significantly more LAI (2.89) was observed for 83333 plants ha^{-1} and followed by 66667 plants ha^{-1} (2.05) and the lowest was observed at the plant density of 55556 plants a^{-1} (1.84). In the fertilizer levels the higher LAI (2.87) was obtained from the application of 50 % more fertilizer than the research based recommendation and all the remaining fertilizer levels was statistically similar to each other The average LAI at 85 DAS was 2.05, which was significantly influenced by the plant density but not by the fertilizer levels. Among the plant density, the highest LAI was recorded from the plant density of 83,333 ha^{-1} (2.48), which was significantly higher than the LAI recorded on the lower plant density. The LAI recorded at the 66,667 plants ha^{-1} (2.05) which was significantly higher than LAI for 55,556 plants ha^{-1} (1.63). Comparatively higher LAI was recorded under the highest level of fertilizer. Increased leaf area index under the higher fertilizer levels was attributed to delayed leaf senescence, sustained leaf photosynthesis, and maintenance of leaf area duration (Liu et al 2017).

Total dry weight

The average total dry weight at 30 DAS was 85.64 g m^{-2}. Among the plant density, the highest total dry weight (113.66 g m^{-2}) was recorded for 83,333 plants ha^{-1} followed by 82.44 g m^{-2} for 66,667 plants ha^{-1} and 60.83 g m^{-2} for 55,556 plants ha^{-1} (Table 6). These all were statistically different among each other. In fertilizer levels, total dry weight was significantly higher (108.82 g m^{-2}) for 150% of RBR than other fertilizers levels. These remaining fertilizer levels were statistically similar but significantly lower than 150% RBR for total dry matter at 30 DAS. The average total dry weight at 55 DAS was recorded significantly higher (570 g m^{-2}) for 83,333 plants ha^{-1}, which was significantly at par with 66,667 plants ha^{-1} (469.85 g m^{-2}) and significantly higher than the 55,556 plants ha^{-1} (388.68 g m^{-2}). In fertilizer levels, total dry weight was 577.82 g m^{-2} for 150% of RBR and all the remaining total dry weight at 55 DAS for other fertilizer levels were similar but significantly lower than 150 % of RBR.

The average total dry weight at 70 DAS was 1608.67 g m^{-2} and significantly influenced among both plant density and fertilizer levels. Among the plant density, the significantly higher total dry weight was recorded for 83,333 plants ha^{-1} (1893.81 g m^{-2}) as compared to at 66,667 plants ha^{-1} (1708.95 g m^{-2}) and statistically at par with the plant density of 55,556 ha^{-1} (1223.25 g m^{-2}). In fertilizer level total dry weight was recorded higher (1835.79 g m^{-2}) for 150% of RBR and all the total dry weight at 70 DAS for other fertilizer levels were similar The average total dry weight was 2417.31 g m^{-2} at 85 DAS which was significantly influenced by plant density and fertilizer levels (Table 6). The total dry weight was highest (2772.18 g m^{-2}) in density of 83,333 plants ha^{-1} followed by for 66,667 plants ha^{-1} (2578.72 g m^{-2}) and 1901.04 g m^{-2} for 55,556 plants ha^{-1}. Regarding the fertilizer levels, all the fertilizers levels were statistically similar with each other expect the research based recommendation in which minimum total dry weight of 2116.18 g m^{-2} was observed.

Table 6. Total dry weight (g m^{-2}) of spring maize as influenced by plant density and fertilizer levels

Treatments	Total dry weight (g m^{2})			
	30 DAS	**55 DAS**	**70 DAS**	**85 DAS**
Plant density (nos. of plants ha^{-1})				
55,556	60.83^{c}	388.68^{b}	1223.25^{b}	1901.04^{b}
66,667	82.44^{b}	469.85^{ab}	1708.95^{a}	2578.72^{a}
83,333	113.66^{a}	570.46^{a}	1893.81^{a}	2772.18^{a}
SEm(±)	4.35	25.69	65.92	66.73
LSD (0.05)	17.07	100.86	258.81	261.98
CV%	17.59	18.68	14.2	9.56
Fertilizer levels (N, P_2O_5,K_2O kg ha^{-1})				
RBR (120:60:40)	66.70^{b}	401.15^{b}	1420.35^{b}	2116.18^{b}
120% RBR	85.15^{b}	475.56^{b}	1590.18^{b}	2452.87^{a}
150% RBR	108.32^{a}	577.82^{a}	1835.79^{a}	2688.18^{a}
NE dose (140:40:40)	82.39^{b}	450.80^{b}	1588.36^{b}	2412.03^{a}
SEm(±)	6.31	32.26	71.86	94.61
LSD (0.05)	18.75	95.86	213.52	281.11
CV%	22.11	20.32	13.4	11.74
Grand mean	85.64	476.33	1608.67	2417.31

Yield attributes

Plant population

The average final plant population was 61,235 ha^{-1}, ranged from 52,593 to 70,278 ha^{-1} (Table 7). The final plant population was 5.33% lower in the planting density of 55,556 ha^{-1}, 8.75% lower in the planting density of 66,667 ha^{-1} and 15.67% lower in the 83,333 plants ha^{-1} planting density. The final plant density was significantly influenced by the planting density. The highest number of final plant population (70,278 plants ha^{-1}) was recorded at the highest level of planting density, followed by planting density of 66,667 (60,833 plants ha^{-1}) and the lowest (52,593 plants ha^{-1}) in the lowest planting density. The final plant density was not influenced by the fertilizers levels.

Barrenness

The average barrenness was 13.27%, and ranged from 11.02 to 15.42% among the different treatments. The barrenness percentage was significantly influenced by the planting density but not by the fertilizer levels. Among the different planting density significantly higher barrenness (15.42%) was recorded on the plant density of 83,333 ha^{-1} which was statistically at par with plant density of 66,667 ha^{-1} (13.36%) but significantly higher than he the planting density of 55,556 ha^{-1} (11.11%). Among the fertilizer levels, higher barrenness (14.71%) was obtained from 120 % of RBR and followed by NE dose (13.55%), research based recommendation (12.50%), and the lowest barrenness was recorded on the fertilizer level of 150% RBR (12.30%) but these values were statistically similar to each other.

Number of cobs per plant

The average number of cobs per plant was 1.09, which varied among the treatments between the 1.05 and 1.11. Both planting density and fertilizer management practices did influence the number of cobs per plant. The number of kernels was decreased and the barrenness and sterility percentage were increased, which was in agreement with the previous study (Andrade et al 2002).

Number of kernels per cob

The average number of kernels per cob was 293.36, which was significantly influenced both by the plant density and fertilizer levels (Table 7). The highest number of kernels per cob (309.79) was recorded from the cob of lowest planting density, which was significantly higher than highest planting density (277.35) but statistically at par with the plating density of 66,667 ha^{-1} (292.94). The planting density of 66,667 and 83,333 plants ha^{-1} are also similar to each other in terms of number of kernels per cob. In the case of fertilizer levels, the highest number of kernels per cob was recorded from the fertilizer levels of 150% of RBR (319.48), which was significantly higher than the number of kernels per cob from the other fertilizer levels. These other lower doses of fertilizers were statistically at par with each other for number of kernels per cob.

Thousand kernel weight

While the thousand kernel weight was not influenced both by the planting density and the fertilizer levels. The average thousand kernel weight was 255.78 g which was comparatively higher in the lower planting density and at higher levels of fertilizer (Table 7).

Cob length, cob diameter, sterility and kernel rows

Cob length, cob diameter, sterility percentage, and number of kernel rows for cob were not influenced both by planting density and fertilizer levels (Table 8). These yield attribute and yield associated traits were comparatively lower in the higher planting density and highest levels of fertilizers i.e., 150% of RBR.

Table 7. Yield attributes of spring maize as influenced by the plant density and fertilizer levels

Treatments	Final plant population per ha^{-1}	Barren-ness (%)	Number of cobs per plant	Number of kernels per cob	Thousand kernel weight (g)
Plant density (nos. of plants ha^{-1})					
55,556	52593^{c}	11.02^{b}	1.11	309.79^{a}	264.58
66,667	60833^{b}	13.36^{ab}	1.08	292.94^{ab}	253.04
83,333	70278^{a}	15.42^{a}	1.06	277.35^{b}	249.72
SEm (±)	682.51	0.95	0.01	6.67	4.16
LSD (0.05)	2679.44	3.74	ns	26.17	ns
CV%	3.86	24.91	3.05	7.87	5.63
Fertilizer levels (N, P_2O_5,K_2O kg ha^{-1})					
RBR (120:60:40)	61111	12.50	1.05	274.63^{b}	251.45
120% RBR	61481	14.71	1.11	289.56^{b}	255.90
150% RBR	61235	12.30	1.10	319.48^{a}	260.31
NE dose (140:40:40)	61111	13.55	1.08	289.76^{b}	255.45
SEm (±)	983.79	1.25	0.02	7.26	5.06
LSD (0.05)	ns	ns	ns	21.56	ns
CV%	4.82	28.20	6.55	7.42	5.93
Grand mean	61235	13.27	1.09	293.36	255.78

Number of kernels per kernel row

The numbers of kernels per row was 25.08 on average and ranged between 23.68 to 27.08, which was significantly influenced by both planting density and fertilizers levels (Table 8). The highest number of kernels per row (25.86) was recorded on planting density of 55,555 ha^{-1}, which was significantly higher than the highest density of 83,333 ha^{-1} (25.13) but statistically at par with 66,667 ha^{-1} (24.24). Among the different fertilizers levels, the highest number of kernels per row was recorded on highest level of fertilizers 150% of RBR which was significantly higher than other fertilizers levels. These remaining lower fertilizers levels resulted the similar number of kernels per kernel row to each other.

Table 8: Yield attributes and yield associated traits of spring maize as influenced by plant density and fertilizer levels

Treatments	Cob Diameter (cm)	Cob Length (cm)	Sterility (%)	Number of kernel rows per cob	Number of kernels per kernel row
Plant density (nos. of plants ha^{-1})					
55,556	3.83	14.95	5.77	11.98	25.86^{a}
66,667	3.76	14.33	7.57	11.65	25.13^{ab}
83,333	3.73	14.00	8.04	11.45	24.24^{b}
SEm (±)	0.04	0.24	0.58	0.21	0.23
LSD (0.05)	ns	ns	ns	ns	0.91
CV%	3.34	5.76	28.03	6.29	3.21
Fertilizer levels (N, P_2O_5, K_2O kg ha^{-1})					
RBR (120:60:40)	3.70	14.10	7.74	11.60	23.68^{b}
120% RBR	3.80	14.22	6.92	11.67	24.85^{b}
150% RBR	3.80	14.81	6.75	11.80	27.08^{a}
NE dose (140:40:40)	3.77	14.57	7.10	11.71	24.69^{b}
SEm (±)	0.04	0.26	0.46	0.18	0.56
LSD (0.05)	ns	ns	ns	ns	1.66
CV(, %	2.93	5.43	19.30	4.58	6.69
Grand mean	3.77	14.43	7.13	11.69	25.08

Yield and harvest index

Grain yield

The mean grain yield of the experiment was 4043.14 kg ha^{-1} and ranged from 3991 kg ha^{-1} to 4587.4 kg ha^{-1}. The grain yield was significantly influenced by plant density as well as fertilizer levels (Table 9). The grain yield was significantly higher (4558 kg ha^{-1}) at higher plant density and decrease with decreasing plant density. The grain yield at 66,666 plants ha^{-1} was significantly lower than 83,333 plants $ha^{-1}$and significantly higher (3454 kg ha^{-1}) than 55,556 plants ha^{-1}.The grain yield of maize was the highest (4587.4 kg ha^{-1}) at the fertilizer level of 150 % RBR and this treatment was statistically similar with grain yield at 120% of RBR (4197.5 kg ha^{-}

^{1}) but significantly higher than research based recommendation (3396.7 kg ha^{-1}) and NE dose (3991.0 kg ha^{-1}).The grain yields at 120% RBR and at NE dose were also statistically at par.

Increased plant density increased grain yield quadratically (Novacek et al 2013). A close association exists between the maize grain yield and whole plant and grain concentration of nitrogen, phosphorus, and potassium (Setiyono et al 2010). Concerning grain yield, several studies reported the increase in maize grain yield with the application of increasing nitrogen levels (Abebe and Feyisa 2017, Amin 2011,Davies et al 2020). Dai et al (2013) indicated that contribution to increases in grain yield is more by the phosphorus than nitrogen and potassium fertilizer on the North Plain of China. Amanullah et al (2016) reported that the highest level of potassium (90 kg K ha^{-1}) significantly increased the yield components (number of kernels per cob, thousand kernel weight), grain yield, and shelling percentage.

Table 9: Grain yield (kg ha^{-1}), stover yield (kg ha^{-1}) and harvest index (%) of spring maize as influenced by the plant density and fertilizer levels

Treatments	**Grain yield (kg ha^{-1})**	**Stover yield (kg ha^{-1})**	**Harvest index (%)**
Plant density nos. of plants ha^{-1}			
55556	3454^{c}	7020^{b}	29.78
66667	4117^{b}	7745^{ab}	31.47
83333	4558^{a}	8500^{a}	31.64
SEm (±)	111	257	1.11
LSD (0.05)	434	1011	ns
CV%	9.47	11.49	12.42
Fertilizer levels (N, P_2O_5,K_2O kg ha^{-1})			
RBR (120:60:40)	3396.7^{c}	7183.7^{b}	28.99
120% RBR	4197.5^{ab}	7520.4^{b}	32.51
150% RBR	4587.4^{a}	8827.8^{a}	30.83
NE dose (140:40:40)	3991.0^{b}	7498.1^{b}	31.52
SEm (±)	181.3	316.9	1.54
LSD (0.05)	538.6	941.7	ns
CV%	13.45	12.26	14.93
Grand mean	**4043.14**	**7757.53**	**30.96**

Stover yield

The mean stover yield of the experiment was 7757.53 kg ha^{-1} and ranged from 7183.7 kg ha^{-1} to 8827.8 kg ha^{-1}. The stover yield was significantly influenced by plant density as well as fertilizer levels (Table 9).

The stover yield was highest (8500 kg ha^{-1}) at plant density of 83333 and decreased with decreasing plant density. The stover yield at 66,666 plants ha^{-1} was statistically similar with the stover yield at 83,333 plants ha^{-1} but significantly higher than stover yield (7020 kg ha^{-1}) at 55,556 plants ha^{-1}. The stover yield of maize was the highest (8827.8 kg ha^{-1}) at the fertilizer level of 150 % RBR which was significantly higher than the stover yield recorded in the other treatments.

Harvest index

The mean harvest index of the of the spring maize was 30.96% and ranged from 28.99 to 32.51%. The harvest index was not significantly influenced by plant density as well as fertilizer levels (Table 9).

Relationship between grain yield with growth and yield component traits

Table 10 showed the coefficient of determination between the important growth, developmental parameters, and yield attributing traits on the grain yield under various plant density. The tasseling silking interval was the highly variable characters for all plant density, the relationship between the final plant population, barrenness, and sterility percentage on the grain yield was significant for the lowest plant density whereas, in the plant density of 66,667 ha^{-1}, grain filling duration and barrenness percentage had the significant association with the grain yield and in the highest plant density the relationship between the LAI at 70 DAS, barrenness and sterility percentage and number of grains per cob or row with the grain yield was significant.

Table 10. Linear regression results including coefficient of variation, slope, and slope significance for the relationship between grain yield with different growth and yield component traits under different plant densities

Independent variables	Plant density								
	55,556 ha^{-1}			66,667 ha^{-1}			83,333 ha^{-1}		
	CV (%)	R^2	Slope	CV (%)	R^2	Slope	CV (%)	R^2	Slope
LAI at 30 DAS	20.90	0.25	2163.11	22.32	0.06	746.13	13.92	0.26	2474.13
LAI at 70 DAS	12.86	0.28	1255.92	12.69	0.19	705.44	19.93	0.57**	958.86
Tasseling silking interval	44.19	0.02	-67.79	56.89	0.15	-115.64	46.82	0.03	-61.23
Grain filling duration	9.00	0.28	106.55	4.81	0.35*	209.40	9.08	0.30	153.35
Final plant population	3.36	0.43*	0.21	4.16	0.02	0.03	4.62	0.08	0.06
Barrenness (%)	19.11	0.61**	-196.43	23.77	0.36*	-99.92	17.62	0.62**	-203.04
No. of cobs per plant	7.14	0.03	1305.02	6.95	0.04	1372.81	4.89	0.00	728.94
Cob diameter (cm)	3.56	0.02	154.88	5.78	0.10	201.42	5.85	0.18	379.08
Cob length (cm)	2.33	0.13	2273.89	3.06	0.01	-488.57	2.86	0.03	1230.47
No. of rows per cob	4.54	0.02	-153.42	4.27	0.12	-361.43	4.21	0.15	581.35
No. of kernels per row	6.76	0.20	144.23	7.01	0.16	117.75	7.98	0.64**	302.19
No. of kernels per cob	6.88	0.13	9.42	9.01	0.02	3.11	10.09	0.64**	20.73
Thousand kernel weight	3.28	0.24	31.97	5.63	0.01	3.70	13.48	0.01	-2.06
Sterility (%)	25.44	0.41*	-241.48	15.66	0.32	-247.77	19.12	0.42*	-307.26
Stover yield (kg ha^{-1})	11.33	0.03	-0.12	13.58	0.22	0.24	14.30	0.04	0.12

* = significant differences at 0.05 level of significance; ** = significant differences at 0.01 level of significance

CONCLUSIONS

The increasing plant density from 55,555 plants ha^{-1} to 83,333 plants ha^{-1} increased the grain yield of OPVs spring maize. Similarly higher levels of fertilizer application increased the grain yield of OPV spring maize in Chitwan. Adequate plant population, and balanced use of fertilizers increase the grain yield of maize.

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AUTHORS' CONTRIBUTION

Binod Kumar Mandal conceived and designed the experiments; performed the experiments; analyzed and interpreted the data; wrote the paper. Pankaj Kumar Yadav assisted in research analyzed and interpreted the data; wrote the final manuscript. Santosh Marahatta: Guidance, analyzed and interpreted the data; wrote the paper and monitoring of experiment, reviewed initial draft of manuscript. Prabina Bhujel assisted in manuscript writing and reviewed final draft of manuscript.

CONFLICTS OF INTEREST

The authors have no any conflict of interest to disclose.

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