Effect of plant densities and fertilizer rates on grain yield of spring maize in inner Terai condition

□S Marahatta*
Agriculture and Forestry University, Rampur, Chitwan
*Corresponding author email: santoshmarahatta@gmail.com

Abstract
To improve the yield of spring season maize in the inner terai of Nepal, the effect of increasing fertilizer levels for increasing planting densities on growth, yield attributes, and yield of open-pollinated maize variety were analyzed through the field experimentation in 2019. The treatments included factorial combinations of three planting densities, (a) 55556/ha, (b) 66667/ha, and (c) 83333/ha; and four fertilizers levels (research-based recommendation i.e., 120:60:40 N:P_2O_5:K_2O kg/ha, 144:72:48 N:P_2O_5:K_2O kg/ha, 180:90:60 N:P_2O_5:K_2O kg/ha, and site-specific nutrient management (SSNM) based nutrient expert model recommendation i.e., 140:40:40 N:P_2O_5:K_2O kg/ha) arranged in a split-plot design with three replications. Data on growth, yield attributes, and yield were analyzed by using R Studio. Growth was higher under the highest planting density and higher fertilizer levels applied treatments. The higher ($p<0.05$) heat use efficiency was recorded under the highest planting density and the higher levels of fertilizer application. The final plant population was 5.33% lower in the plant density of 55556/ha, 8.8 and 15.7% lower respectively for plant densities of 66667/ha and 83333/ha. Both the barrenness and sterility percentage were higher ($p<0.05$) for the highest planting densities and the lowest for the lowest plant density. Higher ($p<0.05$) number of kernels per cobs were recorded in the lowest plant density and the highest amount of fertilizer application. For the lowest and the highest plant densities, the leaf area index increased the grain yield whereas longer grain filling duration and less amount of barrenness and sterility increased ($p<0.05$) the grain yield for all plant densities. The final number of plant populations was the most important parameter to increase ($p<0.05$) the yield under lower plant density whereas the number of kernels per row or cob was the most important attribute to increase ($p<0.05$) the yield of maize under higher plant density. Due to a higher ($p<0.05$) number of final plant populations and comparable yield attributes, the grain yield of the highest planting density was significantly ($p<0.05$) higher. From the significant ($p<0.05$) quadratic response of plant density on the grain yield, a density of 102,950 /ha was estimated as optimum. The increased in amount of fertilizers (144:72:48 N:P_2O_5:K_2O kg/ha, 180:90:60 N:P_2O_5:K_2O kg/ha) gave higher grain yield. The plant densities of 66667/ha and 83333/ha 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 the more profits from open-pollinated spring maize under the central inner Terai.

Keywords: Fertilizer levels, nutrient expert, plant densities, spring maize

Introduction
Maize (*Zea mays* L.) is the second most important crop of Nepal after rice in terms of both area cultivation and production. The national average yield of maize (2.35 t/ha) (MOF, 2017) is far below than the attainable yield of >8.0 t/ha (Devkota *et al*., 2016). Current maize production of 1.3 million tons is not sufficient to meet the national demand thus yields of maize must be increased by 57% (CBS, 2014; KC *et al*., MOF, 2017; TrendEconomy, 2020). The feed demand is increasing at 11% per annum, demands a huge amount of maize. As the possibility of expanding the area in the future is very limited, the required extra production has to come through an increase in productivity. Poor crop management practices, low soil fertility, extreme climatic conductions, etc are the main causes of low productivity (Raza *et al*., 2019). The crop environment was manipulated through agronomic management such as seed rate, plant population, and fertilizer, which influence the growth and ultimately the grain yield (Lomte and Khuspe, 1987). The haphazard and inefficient use of inputs not only reduced the yield and profitability but also caused the wastage of time and effort which leads to weak agricultural economic growth.

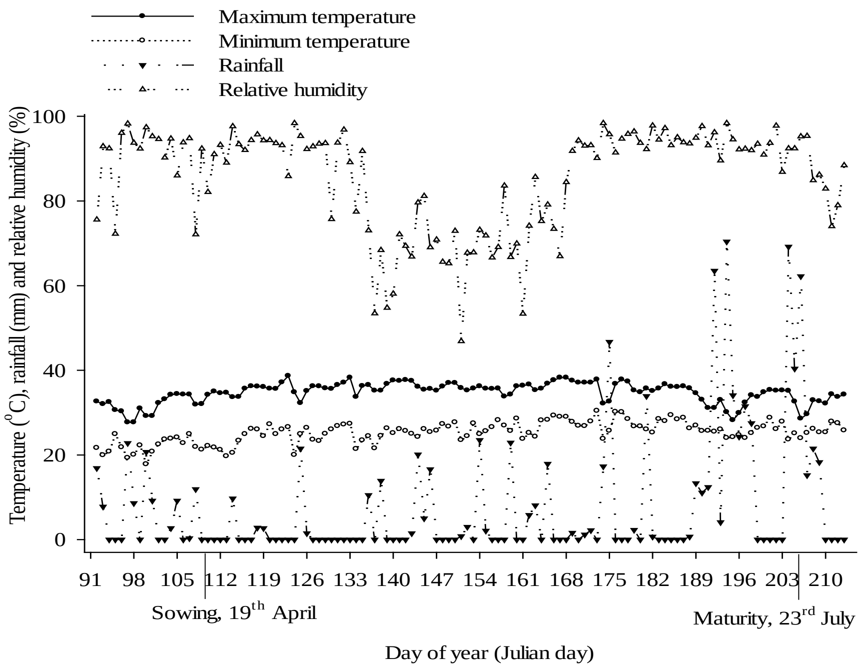
Maize is a unique member of the Poaceae family because of its low tillering capacity, monoecious floral habit, and shorter flowering period, due to which the yield of the maize is greatly influenced by the planting densities (Rehman *et al*., 2011). For the specific agro-ecology, growing season there always exists certain optimum planting densities for each variety which optimizes the use of available resources. Varietal differentiation on plant height, leaf number, individual leaf area, leaf length, vertical leaf angle, and leaf area distribution on the main stem is very common (Edmeades and Lafitte, 1993). Several factors including water and nutrient availability, maturity duration, and row spacing determine the optimum level of their plant population (Haarhoff and Swanepoel, 2018), which is regarded as the major yield contribution factor (Satorre and Maddonni, 2018).

Nitrogen management is the key practice for obtaining the yield potential of maize crop (Sampath *et al*., 2013). Muhammad Arif (2015) reported interaction between nitrogen and plant densities that higher plant densities require maximum dose of nitrogen produced maximum yield. However, increasing the application of nitrogenous fertilizers only negatively affected the nitrogen use efficiency and the environment. For the optimum growth and the better yield, maize crop requires an adequate supply of macro-nutrients particularly nitrogen, phosphorus, and potassium. These elements are important for the formation of chlorophyll, nucleotides, phosphotides, and alkaloids as well as in many enzymes, hormones, and vitamins that optimized the grain yield (Eweetzes *et al*., 2008). It is, therefore, pertinent to explore varying supply of nutrients particularly nitrogen, phosphorus, and potassium needed for optimum growth and high yield. Increasing the planting densities demands the more amount of all these nutrients, rather than a particular one. Even the research-based existing fertilizer recommendations advise using the fixed rates of nitrogen, phosphorus, and potassium. But the need for supplemental nutrients is strongly associated with the crop-growing conditions, crop and soil management, and climate. In this aspect, the site-specific nutrient management (SSNM) based nutrient management tool, nutrient expert (NE) is a suitable option. Therefore, a study was planned to find out the effect of planting density and fertilizer levels of different recommendation dose on the physiological aspects of yield attributes of maize during the hot spring of 2019 in the central inner terai of Nepal.

Materials and Methods

Site description

The experiment was carried out in National Maize Research Programme (NMRP) at Rampur, Chitwan located in the central Terai region of Nepal ($27^{o}40'$ N latitude, $84^{o}19'$ E longitude, and 228 masl) during spring season 2019. The experimental field had sandy loam soil with a slightly acidic pH. The total soil N and available potassium were medium; while organic carbon was low and available phosphorus was very high according to the standard rating of the Directorate of Soil Management, Ministry of Agriculture Development, Government of Nepal, Kathmandu, Nepal. 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 (fertilization to maturity).



Average maximum temperature = 35.42°C (range: 28.20-38.65°C)

Average minimum temperature = 25.83°C (range: 19.70-30.40°C)

Average mean temperature = 30.63°C (range: 26.20-34.10°C)

Average relative humidity = 84.89% (range: 46.84-98.37%)

Total rainfall = 657.90 mm (range: 0-70.40 mm)

Fig. 1: Minimum and maximum daily temperature (°C), daily rainfall (mm) and daily relative humidity during the experimental period at Rampur, Chitwan, Nepal, 2019 (Source: NMRP, 2019)

Experimental design and treatments

The experiment was carried out by using a split-plot design, comprising two factors- plant densities (55556/ha, 66667/ha, and 83333/ha) as main plots, and four fertilizers levels (120:60:40 $N:P_2O_5:K_2O$ kg/ha as the research-based recommendation, 144:72:48 $N:P_2O_5:K_2O$ kg/ha, 180:90:60 $N:P_2O_5:K_2O$ kg/ha, and SSNM based nutrient expert dose 140:40:40 $N:P_2O_5:K_2O$ kg/ha) in subplots, and each treatment arranged with four replication. 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.

Crop management

The field was ploughed two times and planking and leveling were done to bring the soil under good tilth. Maize seeds were sown on 19th April with a handheld maize planter with 2 seeds per hill, and maintaining a spacing of 60 cm × 25 cm. Atrazine, a pre-emergence herbicide, was applied @ 1.5 kg a.i./ha followed by one hand weeding at 20 days after sowing (DAS). Thinning was conducted at 13 DAS and one plant per hill was maintained. Irrigation was applied when the crop showed the symptoms of temporary wilting. The full dose of phosphorus and potassium were applied for all plots. The half dose of N was applied as basal, and the remaining N was applied at two equal splits (first split at 32 DAS and second split at 45 DAS).

Sampling and measurements

Leaf area and above-ground biomass were measured from the destructive sampling of four randomly selected plants from each plot. Dry matter was determined by drying the samples at a temperature of 70°C in a hot oven for 72 hours and weighed and expressed in kg/ha. The leaf area was recorded from the automatic leaf area meter, and the leaf area index was calculated by dividing the leaf area by ground area.

Cobs were harvested manually from the net plot area of 8.4 m^2 (4 rows). The total numbers of barren plants were counted in each net plot, and it was converted to the number of barren plants/ha. Dehusking of cobs was done separately for each plot on the threshing floor. After shelling of grains, seeds were carefully separated and dried and weighed and moisture percent recorded. After removing the cobs, the cut stalks were sun-dried for a few days and weighed, dry weight was also recorded by drying a subsample of stover. The final plant population at harvest, the number of kernels per cob, and thousand-grain weight were recorded. For determining the numbers of grains per cob and sterility percentage, ten cobs were selected randomly, grains separated from the cob, and grains counted. After threshing, seeds were cleaned and weighed. A sample of 250 grains was weighed from each replication to derive a thousand-kernel weight. Total biomass (dry matter basis) and grain yield (adjusted to a moisture content of 13%), recorded on the plot basis and were converted to kg /ha for statistical analysis.

$$\text{Barrenness percentage} = \frac{\text{Number of barren plants in net plot area } (8.4\ m^2)}{\text{Total number of plants in the net plot area } (8.4\ m^2)} \times 100$$

$$\text{Sterility percentage} = \frac{\text{Total unfilled length of cob (cm)}}{\text{The total length of the cob (cm)}} \times 100$$

Days to tasseling, silking, and physiological maturity stages were recorded from the second row of each plot. A particular stage was supposed to be completed while 75% of the observed plants show the characteristics of that phase and numbers of days were counted from the day of sowing. Tasseling-silking interval of maize was determined by the differencing between tasseling and silking days. The calculation of the heat summation unit mostly called the growing degree days (GDD) and their further mathematical derivations like pheno-thermal index (PTI) and heat use efficiencies (HUE) for 75% attainment of the tasseling, silking and physiological maturity were calculated according to the following formulae (Thavaprakaash *et al*., 2007):

$$\text{Growing degree days (GDD)} = \frac{\text{Maximum temperature} - \text{Minimum temperature}}{2} - \text{Base temperature } (10^0C)$$

$$\text{Pheno-thermal index (PTI)} = \frac{\text{GDD}}{\text{Growth days (number of days)}}$$

$$\text{Heat use efficiency (HUE)} = \frac{\text{Grain yield } (\text{kg /ha})}{\text{GDD}}$$

Statistical analysis

The data were subjected to analysis of variance, and Duncan's multiple range test at α level 0.05 (DMRT) for mean separations (Gomez and Gomez, 1984). Correlation and regression analysis was done for selected parameters. Dependent variables were subjected to analysis of variance using the R Studio for strip-split plot design. SPSS v.16 was used for the regression analysis, and Sigma Plot v. 7 was used for the graphical representation.

Results and Discussions

The influence of the mulching materials and nitrogen levels on the growth, yield attributes, and their relation to the grain yield are presented and discussed as follows.

Plant densities and fertilizers levels influence plant growth

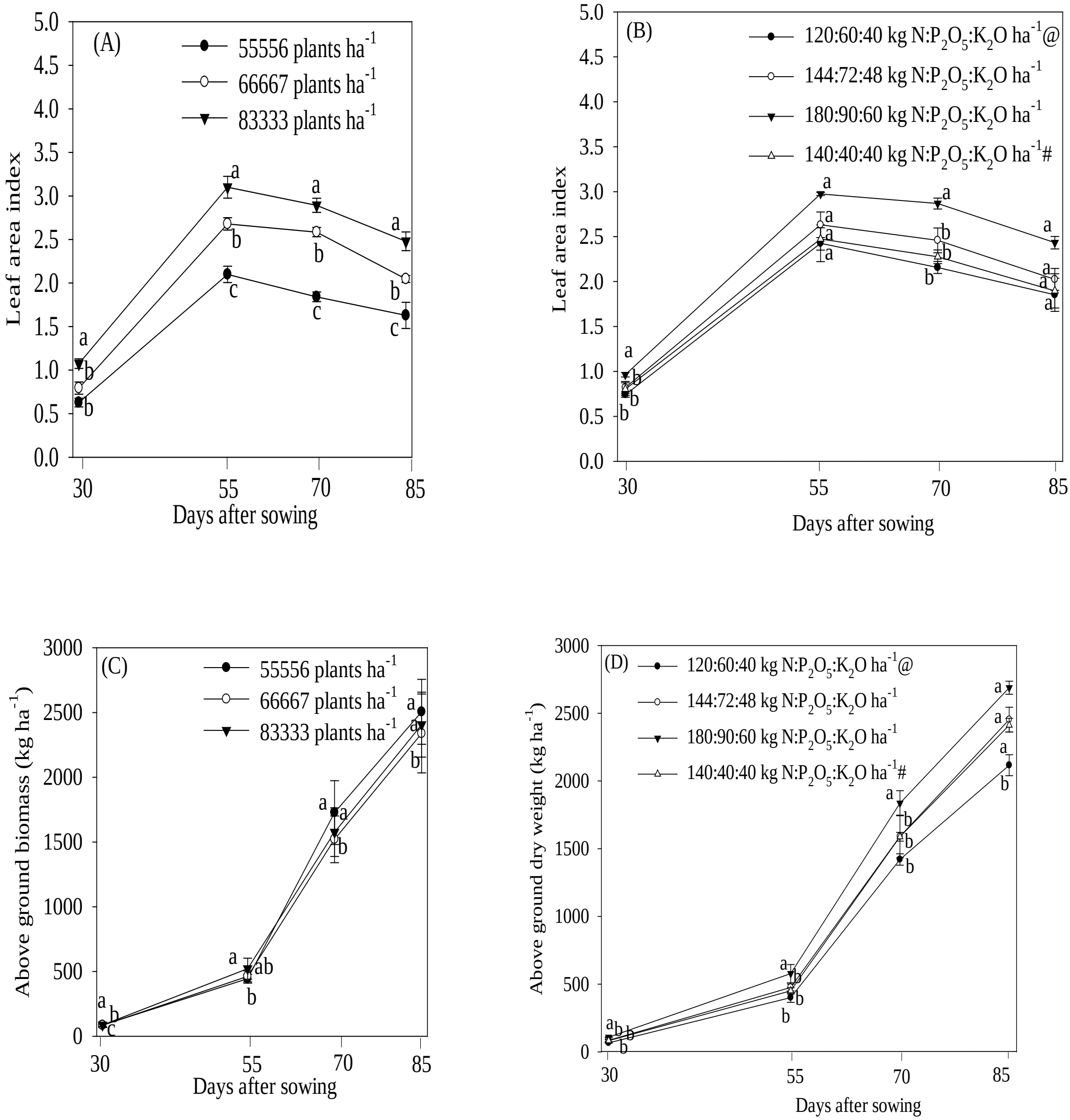
The leaf area index (LAI) was increasing up to 70 DAS and decreased thereafter due to the senescence of lower leaves (Figure 2). LAI was significantly ($p<0.05$) influenced by the plant densities at all dates of observations but fertilizer levels influenced the LAI only at 30, and 70 DAS (Table 1). The significantly ($p<0.05$) higher LAI was recorded on the plant density of 83333/ha as compared to the lower plant densities (66667/ha and 55556/ha). Except at 30 DAS, the LAI was significantly ($p<0.05$) higher for plant density of 66667/ha than the LAI of 55556/ha planting density, but at 30 DAS both were statistically at par ($p>0.05$) for LAI. At 30 and 70 DAS, the highest LAI was recorded on the highest level of fertilizer application (180:90:60 $N:P_2O_5:K_2O$ kg/ha), which was significantly ($p<0.05$) higher than the LAI recorded for other fertilizers levels. All these fertilizer levels were statistically similar ($p>0.05$) for the LAI.

Table 1. Mean square from analysis of variance (ANOVA) for the effects of plant densities and fertilizers levels on evaluated traits of spring maize at Rampur, Chitwan, Nepal, 2019

Source of variation	Replication	Densities (D)	Error(a)	Fertilizer levels (F)	D x F	Error(b)
GDD for Tasseling	5169.33	3258.09	1642.88	5764.34	563.95	4922.32
GDD for silking	323.40	8361.35**	2706.09	768.34	8077.84	6040.18
GDD for PM	7370.73	1519.48	4047.91	932.08**	754.07	1589.29
HUE	1.11	0.03**	0.08	0.01**	0.001	0.001
PTI for tasselling	0.387	0.203**	0.129	0.304	0.137	0.596
PTI for silking	0.001	0.006**	0.003	0.001	0.007	0.005
PTI for PM	0.005	0.001	0.003	0.001**	0.001	0.001
LAI at 30	0.30	0.17*	0.10	0.03*	0.04	0.02
LAI at 55	0.83	0.72**	0.51	0.43	0.46	0.32
LAI at 70	2.98	0.23**	0.60	0.11**	0.13	0.17
LAI at 85	0.74	0.45*	0.37	0.28	0.43	0.25
Dry weight at 30	8095	2451**	1676	468**	128	180
Dry weight at 55	76695	14153*	24725	2498**	13494	12765
Dry weight at 70	1266470	166233**	38912	34938**	82126	79419
Dry weight at 85	2074403	185603**	184615	297162**	112958	99579
Final plant population	308744856	86111111**	62139918	38317330	742226 79	3327617 7
Bareness percentage	23.15	1.34**	7.72	5.77	14.57	11.54
No. of cobs/plant	0.0017	0.0037	0.0020	0.0007	0.0118	0.0055
No. of kernels/cob	254.54	990.17*	1238.35	612.10**	1382.52	596.46
Sterility percentage	1.05	0.40*	4.06	1.29	2.11	3.84
Grain yield	8527610	301634**	667741	29824**	15311	24300
Stover yield	3281026	462474*	3632432	697327**	513512	1372265
Harvest index	115.48	6.27	22.13	9.51	2.10	12.24
Thousand kernel weight	199.58	709.62	361.58	430.79	664.76	596.29
Net return	7111.08	213.30**	608.49	67.32**	16.27	33.73
B:C ratio	1.54	0.03*	0.14	0.02*	0.001	0.01

Note: **, significant differences at 0.05 level of significance; **, significant differences at 0.01 level of significance*

The total dry weight was significantly ($p<0.05$) influenced by both plant densities and the fertilizer levels at all dates of observations (Table 1). The highest total dry weight was recorded for 83333/ ha at all dates of observations which was significantly ($p<0.05$) higher than the total dry weight of the planting density of 55556/ha but statistically similar ($p>0.05$) with the total dry weight of planting density 55556/ha. At 30, 55, and 70 DAS, the highest total dry weight was recorded on the highest level of fertilizer application (180:90:60 $N:P_2O_5:K_2O$ kg/ha), which was significantly ($p<0.05$) higher than the total dry weight recorded for other fertilizers levels. All these fertilizer levels were statistically similar ($p>0.05$) for the total dry weight. Whereas at 85 DAS, all the fertilizer levels were statistically similar ($p>0.05$) with each other except the 120:60:40 $N:P_2O_5:K_2O$ kg/ha which had the minimum total dry weight.



Note: *Treatments means followed by a common letter (s) are not significantly different among each other based on DMRT at 0.05 level of significance.*

Fig. 2: Leaf area index and above-ground biomass of spring maize as influenced by the plant densities and fertilizers levels at Rampur, Chitwan, Nepal, 2019

The improved growth parameters (LAI and dry weight) on the highest levels of the fertilizers is due to better utilization of all nutrients when applied in a balanced way. Nitrogen has a positive effect on cell division and elongation resulting in increased leaf length and rapid leaf development (Walch-Liu *et al*., 2000). Increase leaf area index under the higher fertilizer levels due to the delays leaf senescence, sustaining leaf photosynthesis, and maintenance of leaf area duration (Liu *et al*., 2017). Under the reduced supply of phosphorus, LAI reduced greatly due to a reduction in the hydraulic conductance of roots, and leaf growth hampered because of a reduction in the turgor pressure of cells in the elongating zone (Xu *et al*., 2017). Beadle and Long (1985) suggested that increasing light interception by optimizing LAI should increase photosynthesis and therefore biomass production. The improved growth parameters could be due to better enzymatic activation, increase protein synthesis, improve nitrogen uptake, and utilization under higher levels of potassium (Asif and Anwar, 2007).

Plant densities and fertilizers levels influence different heat summation unit

The growing degree day for 80% attainment of the tasseling was not influenced (p>0.05) by both the planting densities and the fertilizers levels whereas the GDD for silking was significantly (p<0.05) influenced by the plant densities and GDD for physiological maturity was significantly (p<0.05) influenced by the fertilizer levels. The highest planting densities and the highest fertilizer levels require more amount of GDD for the attainment of 80% phenological stages. The heat used efficiency (HUE) was significantly (p<0.05) influenced by both the planting densities and the fertilizer levels. The HUE for the highest planting density (83333/ha) was significantly (p<0.05) higher than the HUE of the lower plant densities. The lowest levels of fertilizers, i.e., research-based recommendation resulted significantly (p<0.05) lower HUE than the other fertilizer levels. Pheno-thermal index (PHI) for 80% tasseling and silking was significantly (p<0.05) influenced by the planting densities. The planting density of 66667 /ha had significantly (p<0.05) higher PHI for tasseling whereas the planting density of 83333/ha has significantly (p<0.05) higher PHI for silking. The PHI for 80% physiological maturity was influenced significantly (p<0.05) by the fertilizer levels where the highest dose of fertilizers had significantly (p<0.05) higher PHI of physiological maturity than the other fertilizer levels.

Table 2. Growing degree day, heat use efficiency, and pheno-thermal index of spring maize as influenced by the plant densities and fertilizers levels at Rampur, Chitwan, Nepal, 2019

Treatments	Growing degree day (^oC)			HUE (kg/ha day /^oC)	Pheno-thermal index (day ^oC/day)		
	Tasseling	Silking	Physiological maturity		Tasseling	Silking	Physiological maturity
Plant densities							
55556/ha	1625.51	1704.03^b	2652.07	1.30^c	27.47^b	27.71^b	28.65
66667/ha	1662.15	1726.22^b	2670.31	1.54^b	27.97^a	27.73^b	28.66
83333/ha	1664.90	1797.20^a	2672.86	1.71^a	27.52^b	27.79^a	28.66
SEm (±)	11.70	15.02	18.37	0.08	0.10	0.02	0.02
LSD (P<0.05)	ns	58.95	ns	0.32	0.41	0.06	ns
CV(a), %	2.46	2.99	2.39	18.64	1.30	0.20	0.19
Fertilizer levels							
120:60:40 $N:P_2O_5:K_2O$ kg/ha@	1656.15	1757.97	2651.18^b	1.28^b	27.65	27.76	28.64^b
144:72:48 $N:P_2O_5:K_2O$ kg/ha	1647.29	1722.17	2647.62^b	1.59^a	27.66	27.73	28.64^b
180:90:60 $N:P_2O_5:K_2O$ kg/ha	1643.40	1761.39	2713.76^a	1.69^a	27.44	27.76	28.70^a
140:40:40 $N:P_2O_5:K_2O$ kg/ha#	1656.58	1728.39	2647.76^b	1.51^a	27.87	27.73	28.64^b
SEm (±)	23.39	25.91	13.29	0.02	0.26	0.02	0.01
LSD (P<0.05)	ns	ns	39.48	0.06	ns	ns	0.03
CV(b), %	4.25	4.46	1.50	4.10	2.79	0.25	0.12
Grand mean	1650.86	1742.48	2665.08	1.52	27.66	27.74	28.66

Note: *ns, non-significant; @, research-based recommendation; #, nutrient expert dose. 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.*

Influence of plant densities and fertilizers levels on yield attributes

The average final plant population was 61111/ha, ranged from 52222 to 70278/ha (Table 3). The final plant population was significantly ($p<0.05$) influenced by the panting density. The final plant population was 5.3% lower in the planting density of 55556/ha, 8.8% lower in the planting density of 66667/ha and 15.7% lower in the 83333/ha panting density. The highest number of final plant populations (70278/ha) was recorded at the highest level of planting density, followed by a planting density of 66667/ha (60833/ha) and the lowest (52593/ha) in the lowest planting density. The final plant density was not influenced ($p>0.05$) by the fertilizer levels. The average barrenness was 13.70% and ranged from 11.78 to 16.10% among the different treatments. The barrenness percentage was significantly ($p<0.05$) influenced by the planting densities but not ($p>0.05$) by the fertilizer levels. Among the different planting densities, significantly higher barrenness (16.1%) was recorded on the plant density of 83333/ha which was significantly higher than the barrenness on the planting density of 66667/ha and 55556/ha. Both planting density and fertilizer management practices did not influence ($p>0.05$) the number of cobs per plant.

The decrease in per plant biomass reduces in photosynthetic rate per plant which increased plant barrenness as plant population increased (Ciampitti and Vyn, 2011; Edmeades and Daynard, 1979; Maddonni and Otegui, 2004). Delay in the cob differentiation and the growth of the primordia of cob than the tasseling are associated with more barrenness under plant densities (Jacobs and Pearson, 1991). Besides the competition for the assimilates, hormonal (auxin) alternation on the cob development before flowering is also associated with higher plant density for the barrenness (Wilson and Allison, 1978). At the 6-7 leaf stage shoot apex is differentiated into the tassel (Ritchie *et al.*, 1992). After the tassel initiation, it produces a large amount of auxin which stimulated the growth in terms of plant height and dry matter production. Due to high densities, intercepted solar radiation per plant is less (Gardner *et al.*, 1985). Under the low density, the light of high intensity inactivates by oxidation (Salisbury and Ross, 1992) but under the higher densities greater concentration of bioactive auxin is present. Therefore, a high plant population may promote auxin apical dominance over the cobs, contributing to barrenness (Sangoi and Salvador, 1998). Uner higher plating density, the delay in the initiation of the cobs and fewer primordia developed into normally functional florets at the time of flowering, the sterility increased and the number of kernels per cobs decreased. Tollenaar and Daynard (1978) reported abortion of spikelets, lack of pollination and fertilization or abortion of young kernels are also associated with increasing the sterility under dense population. Whereas Jacobs and Pearson (1991) observed that the reduction in kernel number per ear under dense population due to a reduction in the number of spikelets differentiated per ear. The fertilization percentage of the differentiated spikelets determined the number of kernels per cob. Constraints on the growth factors under dense planting delay the specific developmental stages and reduce both spikelet number and silk extrusion, contributing to lessen the number of fertilized spikelets due to non-synchronization of pollen shed and silking of individual spikelets (Jacobs and Pearson, 1991). Therefore, high plant densities may promote limitations in carbon and nitrogen supply to the ear, favoring abortion after fertilization resulting in higher sterility (Luís Sangoi, 2001).

Table 3. Yield attributes as influenced by the different population densities and fertilizer levels on the spring maize at Rampur, Chitwan, Nepal, 2019

Treatments	Final plant population	Barrenness (%)	Number of cob/plant	Number of kernels /cob	Sterility (%)	1000 kernel weight(g)
Plant densities						
55556/ha	52222^{c}	11.77^{b}	1.11	308.60^{a}	5.86^{b}	264.58
66667/ha	60833^{b}	13.36^{b}	1.08	292.89^{b}	7.66^{a}	253.04
83333/ha	70278^{a}	16.08^{a}	1.06	279.79^{b}	8.04^{a}	241.33
SEm (±)	2276	0.80	0.01	10.16	0.58	5.49
LSD (P<0.05)	8934	3.15	ns	39.88	2.28	Ns
CV(a), %	12.90	20.23	4.16	11.98	28.05	7.52

Treatments	Final plant population	Barrenness (%)	Number of cob/plant	Number of kernels /cob	Sterility (%)	1000 kernel weight(g)
Fertilizer levels						
120:60:40 $N:P_2O_5:K_2O$ kg/ha@	60617	14.80	1.05	274.63[b]	7.74	251.45
144:72:48 $N:P_2O_5:K_2O$ kg/ha	61481	13.86	1.11	293.71[b]	7.15	255.91
180:90:60 $N:P_2O_5:K_2O$ kg/ha	61235	12.19	1.10	320.87[a]	6.75	249.13
140:40:40 $N:P_2O_5:K_2O$ kg/ha#	61111	14.11	1.08	285.84[b]	7.10	255.45
SEm (±)	1923	1.13	0.02	8.14	0.65	8.14
LSD (P<0.05)	ns	ns	ns	24.19	ns	ns
CV(b), %	9.44	24.73	6.82	8.31	27.28	9.65
Grand mean	61111	13.74	1.09	293.76	7.18	252.98

Note: *ns, non-significant; @, research-based recommendation; #, nutrient expert dose. 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.*

The number of kernels per cob was significantly ($p<0.05$) influenced both by the plant densities and fertilizer levels (Table 3). The highest number of kernels per cob (308.6) was recorded from the cob of the lowest planting density, which was significantly higher than the number of kernels per cob of higher planting. The planting density of 66667 and 83333/ha were also similar to each other in terms of the number of kernels per cob at a 0.05 level of significance. In the case of fertilizer levels, the highest number of kernels per cob was recorded from the fertilizer levels of 180:90:60 $N:P_2O_5:K_2O$ kg/ha (319.5), which was significantly ($p<0.05$) higher than the number of kernels per cob from the other fertilizer levels. The lower doses of fertilizers were statistically at par ($p>0.05$) with each other for the number of kernels per cob. The sterility percentage was significantly ($p<0.05$) influenced only by the planting densities, where the significantly ($p<0.05$) lower sterility percentage was recorded for the lowest planting density. Thousand kernel weight was not influenced ($p>0.05$) both by the plating density and the fertilizer levels.

Influence of plant densities and fertilizers levels on yield and profitability

The mean grain yield of the experiment was 4043 kg/ha and ranged from 3991 kg/ha to 4587 kg/ ha. The grain yield was significantly ($p<0.05$) influenced by plant densities as well as fertilizer levels (Table 4). The grain yield was significantly ($p<0.05$) higher (4558 kg/ha) at higher plant density and decreased with lower plant density. The grain yield at 66,666/ha was significantly ($p<0.05$) lower than grain yield at 83333 plants per ha and significantly ($p<0.05$) higher than grain yield (3454 kg/ha) at 55556 plants/ha. The relationship between the plating density and grain yield was quadratic and significant at a 0.01 level of significance (Figure 3B). The highest level of yield was obtained by the planting density of 102,950/ha. Increasing the maize population and inhibiting individual growth redundancy are the recent tactics of achieving high maize grain yields (Argenta *et al*., 2001 cited in Yu *et al*., 2019). Maize is more sensitive to variations in plant density than other members of the grass family mainly due to lack of tillering, just opposite of other members of the grass family, cannot compensate for low leaf area and very few numbers of reproductive units by branching (Gardner *et al*., 1985). Sarlangue *et al*. (2007) reported the maize grain yield was significantly influenced by the planting densities. Only under the proper plant density, highest yield can be managed (Monneveux *et al*., 2005). Monneveux *et al*. (2005) also reported that the yield increment under the high plant densities for those genotypes which have lower vigor and lower intra-plant competition. In the present study, the high yield was obtained with the plant density of

83333/ha (Table 4), which is much more than the planting densities recommended per ha by the National Maize Research Program. The tolerance with this level of high plant density was due to the less vigorous growth open-pollinated (OP) variety Arun 2 and shorter plant height (data not sown). However, the number of kernels decreased and the barrenness and sterility percentage increased, which was in agreement with the previous study (Andrade *et al.*, 2002). Due to the higher interplant competition for the resources results in a lower number of kernels per ear (Boomsma *et al.*, 2009; Tollenaar *et al.*, 2006); grain yield increments are attributable to the increased number of cob (Grassini *et al.*, 2011; Ittersum and Cassman, 2013) due to the high number of plants per unit area (Dawadi and Sah, 2012). Thus, for grain yield, the positive effects of high planting densities surpassed the negative effects of interplant competition. Hashemi *et al.* (2005) and Dawadi and Sah (2012) reported the negative relationship between yields attributes with increasing plant density. Increased plant density increased grain yield quadratically (Novacek *et al.*, 2013; Mitchell *et al.*, 2014; Stanger and Lauer, 2006). Some researchers indicated responses other than quadratic (Hammer *et al.*, 2009; Robles *et al.*, 2012).

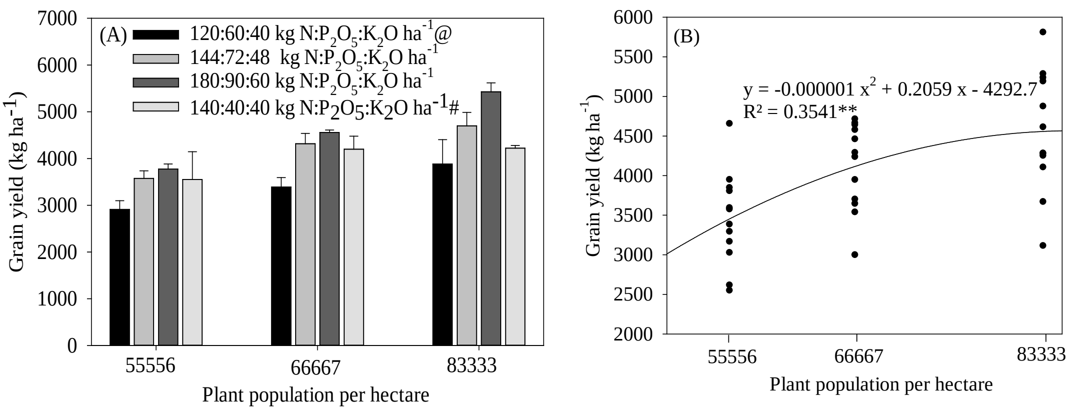


Fig. 3: (A) Grain yield (kg/ha) as influenced by the different population densities and fertilizer levels, (B) the quadratic regression of pant densities on the grain yield of the spring maize at Rampur, Chitwan, Nepal, 2019

The grain yield of maize was the highest (4587.4 kg/ha) at the fertilizer level of 180:90:60 N:P_2O_5:K_2O kg/ha, and this treatment was statistically similar (p>0.05) with grain yield (4197.5 kg/ha) at 144:72:48 N:P_2O_5:K_2O kg/ha but significantly (p<0.05) higher than grain yields (3396.7 kg/ha) at fertilizer levels of 120:60:40 N:P_2O_5:K_2O kg/ha and 140:40:40 N:P_2O_5:K_2O kg/ha (3991.0 kg/ha). The grain yields at 144:72:48 N, P_2O_5, K_2O kg/ha and at 140:40:40 N:P_2O_5:K_2O kg/ha were also statistically similar (p>0.05).

The higher levels of combined application of nitrogen, phosphorus, and potassium significantly increased the growth parameters, yield attributes, and ultimately the grain yield of maize in the present experiment. Balanced nutrition must be achieved to optimize maize productivity. A close association exists between the maize grain yield and whole plant and grain concentration of nitrogen, phosphorus, and potassium (Setiyono *et al.*, 2010). Nitrogen improves the crops growth thereby affects crop yields through its influence on the yield components. Ittersum and Cassman (2013) also reported the higher values of the yield components (kernel per cob, thousand kernels weight, and the number of cobs per unit area). Within the optimum levels of nitrogen, the number of kernels per cobs, and thousand-grain weight increased (Xu *et al.*, 2017). Concerning grain yield, several studies reported the increase in maize grain yield with the application of increasing nitrogen levels (Abebe and Feyisa, 2017; Davies *et al.*, 2020; Galindo *et al.*, 2019; Pasley *et al.*, 2019; Skonieski *et al.*, 2019).

The sterility decreased under higher levels of phosphorus thus increased the number of kernels per cob. The deficiency of phosphorus led to incomplete pollination, which delayed the silking and tasseling time and thereby resulted in the longer sterile tip of the cobs (Pellerin *et al*., 2000). Therefore, the application of appropriate phosphorus levels to maize should reduce the lengths of barren ear tips, increased the number of kernels per cob, and thus increase grain yield. (Xu *et al*., 2017) reported a similar finding that sterile tip length negatively affects the kernel number than grain yield. 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. Potassium also improved growth, yield attributes, and grain yield. Amanullah *et al*. (2016) reported that the highest level of potassium (90 kg/ha) significantly increased the yield components (number of kernels per cob, thousand kernel weight), grain yield, and shelling percentage. Potassium increased the photosynthetic activities (Bukhsh *et al*., 2009), translocation of assimilated from the leaves to the cob (Hussain *et al*., 2007) that maximizes the number of kernels per cob.The stover yield was also significantly ($p<0.05$) influenced both by planting densities and the fertilizer levels. The stover yield was the highest at the planting density of 83333/ha, which was significantly ($p<0.05$) higher than the stover yield obtained by the planting density of 55556/ha and statistically at par ($p>0.05$) with 66667/ha. Regarding the fertilizer levels, a significantly ($p<0.05$) higher sterility percentage was recorded for the highest fertilizer levels which were significantly ($p<0.05$) higher than the stover yield of other fertilizer levels. The harvest index was neither influenced ($p>0.05$) by the planting densities nor by the fertilizer levels.

Table 4. Grain yield (kg/ha), stover yield (kg/ha), harvest index (%), net return (NRs. '000) and B:C ratio as influenced by the different population densities and fertilizer levels of the spring maize at Rampur, Chitwan, Nepal, 2019

Treatments	Grain yield (kg/ha)	Stover yield (kg/ha)	Harvest index(%)	Net return (NRs. '000)	B:C ratio
Plant densities					
55556/ha	3454^{c}	7020^{b}	29.78	50.35^{b}	1.78^{b}
66667/ha	4117^{b}	7745^{ab}	31.47	70.50^{a}	2.08^{a}
83333/ha	4558^{a}	8508^{a}	31.64	82.84^{a}	2.26^{a}
SEm (±)	111	257	1.11	7.12	0.11
LSD (P<0.05)	434	1011	ns	27.96	0.43
CV(a), %	9.47	11.49	12.42	36.33	18.6
Fertilizer levels					
120:60:40 $N:P_2O_5:K_2O$ kg/ha@	3397^{c}	7184^{b}	28.99	49.48^{b}	1.77^{b}
144:72:48 $N:P_2O_5:K_2O$ kg/ha	4198^{ab}	7520^{b}	32.51	72.47^{a}	2.10^{a}
180:90:60 $N:P_2O_5:K_2O$ kg/ha	4587^{a}	8828^{a}	30.83	81.30^{a}	2.20^{a}
140:40:40 $N:P_2O_5:K_2O$ kg/ha#	3991^{b}	7498^{b}	31.52	68.34^{a}	2.09^{a}
SEm (±)	181	317	1.54	1.94	0.03
LSD (P<0.05)	539	942	ns	5.75	0.10
CV(b), %	13.45	12.26	14.93	8.55	4.90
Grand mean	4043	7758	30.96	67.90	2.04

Note: *ns, non-significant; @, research-based recommendation; #, nutrient expert dose. 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.*

The average net return and B:C ratio were NRs. 67.90 thousands/ha and 2.04 respectively, which were significantly ($p<0.05$) influenced by the plant densities and the fertilizer levels. Among the different plant densities significantly ($p<0.05$) higher net return (NRs. 82.83 thousands/ha) was obtained from plant density of 83333/ha followed by 66667/ha (NRs. 70.50 thousands/ha) and 55556/ha (NRs.50.35

thousands/ha) which were significantly ($p<0.05$) different from each other. For fertilizer levels, significantly ($p<0.05$) higher net return (NRs.81.30 thousand ha^{-1}) was obtained at the highest fertilizer levels (180:90:60 $N:P_2O_5:K_2O$ kg/ha) and the net returns at 120:60:40 $N:P_2O_5:K_2O$; 144:72:48 $N:P_2O_5:K_2O$ kg/ha and at 140:40:40 $N:P_2O_5:K_2O$ kg/ha were statistically similar ($p>0.05$). Among the different plant densities significantly ($p<0.05$) higher B:C ratio (2.26) was obtained from plant density of 83333/ha followed by 66667/ha (2.08) and 55556/ha (1.78) which was significantly ($p<0.05$) different among each other. For the fertilizer levels, a significantly ($p<0.05$) higher B:C ratio (2.20) was obtained from the highest fertilizer levels (180:90:60 $N:P_2O_5:K_2O$ kg/ha). The B:C ratio at 120:60:40 $N:P_2O_5:K_2O$, 144:72:48 N: $P_2O_5:K_2O$ kg/ha and at 140:40:40 $N:P_2O_5:K_2O$ kg/ha fertilizer application were statistically similar ($p>0.05$) each other.Table 5 showed the coefficient of determination between the important growth, developmental parameters, and yield attributing traits on the grain yield under various plant densities. The tasseling silking interval was the highly variable characters for all plant densities, 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 66667/ha, 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 DS, barrens and sterility percentage and number of grains per cob or row with the grain yield was significant.

Table 5: Linear regression results including coefficient of variation, slope, and slope significance for the relationship between grain yield with different biometrical observations, yield attributes, and yield for different plant densities at Rampur, Chitwan, Nepal, 2019

Independent variables	Plant densities								
	55556/ha			66667/ha			83333/ha		
	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)	11.33	0.03	-0.12	13.58	0.22	0.24	14.30	0.04	0.12

Note: * *significant differences at 0.05 level of significance; **, significant differences at 0.01 level of significance*

Conclusions

Better growth, heat use efficiency, yield attributes and yield were obtained from the highest planting density and higher fertilizer dose. Though the barrenness and sterility percentage were higher at the highest planting density of 83333/ha, higher final plant populations, and comparable other yield attributes, resulted in higher grain yield. The increased amount of fertilizers (144:72:48 N:P_2O_5:K_2O kg/ha, 180:90:60 N:P_2O_5:K_2O kg/ha) increased the grain yield. Due to better net return and B:C ratio, plant densities of 66667/ha and 83333/ha were better whereas the research-based recommendation needed to be increased to grow maize under the central inner Terai.

References

Abebe Z and H Feyisa. 2017. Effects of Nitrogen Rates and Time of Application on Yield of Maize: Rainfall Variability Influenced Time of N Application. *International Journal of Agronomy* 1545280. https://doi.org/10.1155/2017/1545280

Akhtar ME; MT Saleem and MD Stauffer. 2003. Potassium in Pakistan agriculture. Pakistan Agricultural Research Council, Islamabad, 80.

Amanullah A; J Iqbal; K Irfanullah and Z Hidayat. 2016. Potassium management for improving growth and grain yield of maize (*Zea mays* L.) under moisture stress condition. *Scientific Reports* 6(1): 34627. https://doi.org/10.1038/srep34627

Andrade FH; L Echarte; R Rizzalli; A Della Maggiora and M Casanovas. 2002. Kernel number prediction in maize under nitrogen or water stress. *Crop Science*, 42(4): 1173-1179.

Asif M and M Anwar. 2007. Phenology, leaf area and yield of spring maize (Cv. Azam) as affected by levels and timings of potassium application. *World Applied Sciences Journal* 2 (4): 299-303

Beadle CL and SP Long. 1985. Photosynthesis-is it limiting to biomass production? *Biomass* 8(2): 119–168.

Boomsma CR; JB Santini; M Tollenaar and TJ Vyn. 2009. Maize morphophysiological responses to intense crowding and low nitrogen availability: An analysis and review. *Agronomy Journal* 101(6): 1426-1452. https://doi.org/10.2134/agronj2009.0082

Bukhsh MA; R Ahmad; M Ishaque and AU Malik. 2009. Response of maize hybrids to varying potassium application in Pakistan. *Pak. J. Agri. Sci.* 46(3): 179–184.

CBS. 2014. National population and housing census 2011 (Population projection 2011-2031) (Vol. 08). Central Bureau of Statistics, Government of Nepal, Kathmandu, Nepal.

Ciampitti IA and TJ Vyn. 2011. A comprehensive study of plant density consequences on nitrogen uptake dynamics of maize plants from vegetative to reproductive stages. *Field Crops Research* 121(1): 2–18. https://doi.org/10.1016/j.fcr.2010.10.009

Dai X; Z Ouyang; Y Li and H Wang. 2013. Variation in yield gap induced by nitrogen, phosphorus and potassium fertilizer in North China Plain. *PloS One* 8(12): e82147.

Davies B; JA Coulter and PH Pagliari. 2020. Timing and rate of nitrogen fertilization influence maize yield and nitrogen use efficiency. Plos One 15(5): e0233674. Retrieved from https://doi.org/10.1371/journal.pone.0233674

Dawadi D and S Sah. 2012. Growth and Yield of hybrid maize (*Zea mays* L.) in relation to planting density and nitrogen levels during winter season in Nepal. Tropical Agricultural Research 23(3): 218-227. https://doi.org/10.4038/tar.v23i3.4659

Devkota KP. 2017. Use of ORYZA3 simulation model for rice productivity assessment in terai districts of Nepal. **In:** Rice Science and Technology in Nepal (M. N. Paudel, D. R. Bhandari, M. P. Khanal, B. K. Joshi, P. Acharya, & K. H. Ghimire Eds.). Pp. 550–556. Crop Development Directorate, Lalitpur, Nepal

Devkota KP; AJ McDonald; L Khadka; A Khadka; G Paudel and M Devkota. 2016. Fertilizers, hybrids, and the sustainable intensification of maize systems in the rainfed mid-hills of Nepal. European Journal of Agronomy 80: 154–167. https://doi.org/10.1016/j.eja.2016.08.003

Edmeades GO and TB Daynard. 1979. The development of plant to plant variability in maize at different planting densities. *Canadian Journal of Plant Science* 59(3): 561–576. https://doi.org/10.4141/cjps79-095

Edmeades GO and HR Lafitte. 1993. Defoliation and Plant Density Effects on Maize Selected for Reduced Plant Height. *Agronomy Journal* 85(4): 850–857.

https://doi.org/10.2134/agronj1993.00021962008500040014x
Ewees MSA; SA Ei Yazal and DM Ei Sowfy. 2008. Improving maize grain yield and its quality grown on a newly reclaimed sandy soil by applying micronutrient, organic manure and biological inoculation. *Research Journal of Agriculture and Biological Sciences* 4(5): 537–544. Retrieved from http://www.aensiweb.com/rjabs/rjabs/2008/537-544.pdf
Galindo FS; MCM Teixeira Filho; S Buzetti; PH Pagliari; JMK Santini; CJ Alves; MM Megda; TAR Nogueira; M Andreotti and O Arf. 2019. Maize yield response to nitrogen rates and sources associated with *Azospirillum brasilense*. *Agronomy Journal* 111(4): 1985–1997. https://doi.org/10.2134/agronj2018.07.0481
Gardner FP; RB Pearce and RL Mitchell. 1985. Physiology of crop plants. Iowa State University Press
Gomez AA and KA Gomez. 1984. Statistical procedures for agricultural research. In Statistical procedures for agricultural research (Second). John Wiley & Sons.
Grassini P; J Thorburn; C Burr and KG Cassman. 2011. High-yield irrigated maize in the Western US Corn Belt: I. On-farm yield, yield potential, and impact of agronomic practices. *Field Crops Research* 120(1): 142–150.
Haarhoff SJ and PA Swanepoel. 2018. Plant population and maize grain yield: a global systematic review of rainfed trials. Crop Science 58(5): 1819–1829. https://doi.org/10.2135/cropsci2018.01.0003
Hammer GL; Z Dong; G McLean; A Doherty; C Messina; J Schussler; C Zinselmeier; S Paszkiewicz and M Cooper. 2009. Can changes in canopy and/or root system architecture explain historical maize yield trends in the U.S. corn belt? *Crop Science* 49(1): 299–312. https://doi.org/10.2135/cropsci2008.03.0152
Hashemi AM; SJ Herbert and DH Putnam. 2005 Yield Response of Corn to Crowding Stress. *Agronomy Journal* 97(3): 839–846. https://doi.org/10.2134/agronj2003.0241
Hussain N; AZ Khan; H Akbar; NG Bangash; ZH Khan and M Idrees. 2007. Response of maize varieties to phosphorus and potassium levels. *Sarhad J Agric.* 23: 881–888. https://doi.org/10.3329/bjar.v36i3.9272
Jacobs BC and CJ Pearson. 1991. Potential yield of maize, determined by rates of growth and development of ears. Field Crops Research 27(3): 281–298. https://doi.org/https://doi.org/10.1016/0378-4290(91)90067-6
KC G; TB Karki; J Shrestha and BB Achhami. 2015. Status and prospects of maize research in Nepal. Journal of Maize Research and Development 1(1): 1–9. https://doi.org/10.3126/jmrd.v1i1.14239
Liu T; R Huang; T Cai; Q Han and S Dong. 2017. Optimum leaf removal increases nitrogen accumulation in kernels of maize grown at high density. Scientific Reports 7(1): 39601. https://doi.org/10.1038/srep39601
Lomte MH and VS Khuspe. 1987. Effects of plant densities, phosphorus levels and Antitranspirant on the yield of summer groundnut. Journal of Maharashtra Agricultural University 12(1):28-30
Maddonni GA and ME Otegui. 2004. Intra-specific competition in maize: early establishment of hierarchies among plants affects final kernel set. *Field Crops Research* 85(1): 1–13. https://doi.org/https://doi.org/10.1016/S0378-4290(03)00104-7
MOF. 2017. Economic survey 2016-2017. Retrieved from http://mof.gov.np/
Monneveux P; PH Zaidi abd C Sanchez. 2005. Population density and low nitrogen affects yield-associated traits in tropical maize. *Crop Science* 45(2): 535–545. https://doi.org/10.2135/cropsci2005.0535
Muhammad Arif SI. 2015. Effect of Nitrogen levels and plant population on yield and yield components of maize. Advances in Crop Science and Technology, 03(02): 3–9. https://doi.org/10.4172/2329-8863.1000170
Novacek MJ; SC Mason; TD Galusha and M Yaseen. 2013. Twin rows minimally impact irrigated maize yield, morphology, and lodging. *Agronomy Journal* 105(1): 268–276. https://doi.org/10.2134/agronj2012.0301
Novacek MJ; SC Mason; TD Galusha and M Yaseen. 2014. Bt transgenes minimally influence maize

grain yield and lodging across plant populations. *Maydica* 59(1): 90–95.

Pasley HR; JE Cairns; JJ Camberato and TJ Vyn. 2019. Nitrogen fertilizer rate increases plant uptake and soil availability of essential nutrients in continuous maize production in Kenya and Zimbabwe. *Nutrient Cycling in Agroecosystems* 115(3): 373–389. https://doi.org/10.1007/s10705-019-10016-1

Pellerin S; A Mollier and D Plénet. 2000. Phosphorus deficiency affects the rate of emergence and number of maize adventitious nodal roots. *Agronomy Journal* 92(4): 690–697. https://doi.org/10.2134/agronj2000.924690x

Raza A; A Razzaq; SS Mehmood; X Zou; X Zhang; Y Lv and J Xu. 2019. Impact of climate change on crops adaptation and strategies to tackle its outcome: A review. *Plants* 8(2): 34. https://doi.org/10.3390/plants8020034

Rehman A; ME Safdar; MF Saleem; M Yasin; SM Shahzad; M Asif and S Haider. 2011. Effect of planting density on grain yield and yield related parameters of spring hybrid maize (*Zea mays* L.). *Int. J. Agric. Appli. Sci.* 3(1): 30–34.

Ritchie SW; JJ Hanway and GO Benson. 1992. How a corn plant develops. Ames, Iowa: Iowa State University of Science and Technology, Cooperative Extension Service.

Robles M; I Ciampitti and T Vyn. 2012. Responses of maize hybrids to twin-row spatial arrangement at multiple plant densities. *Agronomy Journal* 104: 1747-1756.

Salisbury FB and CW Ross. 1992. Plant physiology. Belmont, Calif.: Wadsworth Pub. Co.

Sampath O; M Madhavi and P Rao. 2013. Evaluation of genotypes and nitrogen levels for yield maximization in rabi maize (*Zea mays* L.). *International Journal of Innovative Research and Development* 2(9):314-318.

Sangoi L and R Salvador. 1998. Effect of maize plant detasseling on grain yield, tolerance to high plant density and drought stress. *Pesq. agropec. bras.*, *Brasi lia* 33(5): 677-684

Sangoi L. 2001. Understanding plant density effects on maize growth and development: an important issue to maximize grain yield. *Cienc. Rural 31*(1): 159-168. https://doi.org/10.1590/s0103-84782001000100027

Sangoi L and R Salvador. 1996. Agronomic performance of male-sterile and fertile maize genotypes at two plant populations. *Cienc. Rural* 26(3): 377–383. Retrieved from http://www.scielo.br/scielo.php?script=sci_arttext&pid=S0103-84781996000300006&nrm=iso

Sarlangue T; FH Andrade; PA Calviño and LC Purcell. 2007. Why do maize hybrids respond differently to variations in plant density? *Agronomy Journal* 99(4): 984-991. https://doi.org/10.2134/agronj2006.0205

Satorre EH and GA Maddonni, ed. 2018. Spatial crop structure in agricultural systems BtT - encyclopedia of sustainability science and technology. https://doi.org/10.1007/978-1-4939-2493-6_223-3

Setiyono TD; DT Walters; KG Cassman; C Witt and A Dobermann. 2010. Estimating maize nutrient uptake requirements. *Field Crops Research* 118(2): 158-168.

Skonieski FR; J Viegas; TN Martin; CA Carlos Mingotti; S Naetzold; TJ Tonin; LR Dotto and GR Meinerz. 2019. Effect of nitrogen topdressing fertilization and inoculation of seeds with azospirillum brasilense on corn yield and agronomic characteristics. *Agronomy* 9(12): 1-11. https://doi.org/10.3390/agronomy9120812

Stanger TF and JG Lauer. 2006. Optimum plant population of Bt and non-Bt corn in Wisconsin. *Agronomy Journal* 98(4): 914-921. https://doi.org/10.2134/agronj2005.0144

Tollenaar M and TB Daynard. 1978. Leaf senescence in short season maize hybirds. *Canadian Journal of Plant Science* 58(3): 869–874. https://doi.org/10.4141/cjps78-126

Tollenaar M; W Deen; L Echarte and W Liu. 2006. Effect of crowding stress on dry matter accumulation and harvest index in maize. *Agronomy Journal* 98(4): 930-937.

TrendEconomy. 2020. Nepal imports and exports-maize (corn). Retrieved from https://trendeconomy.com/

Ittersum MK and KG Cassman. 2013. Yield gap analysis-Rationale, methods and applications-

Introduction to the Special Issue. Elsevier.
Walch-Liu P; G Neumann; F Bangerth and C Engels. 2000. Rapid effects of nitrogen form on leaf morphogenesis in tobacco. *Journal of Experimental Botany* 51(343): 227-237. https://doi.org/10.1093/jexbot/51.343.227
Wilson JH and JCS Allison. 1978. Effect of plant population on ear differentiation and growth in maize. Annals of Applied Biology 90(1): 127-132. https://doi.org/10.1111/j.1744-7348.1978.tb02619.x
Xu C; S Huang; B Tian; J Ren; Q Meng and P Wang. 2017. Manipulating Planting density and nitrogen fertilizer application to improve yield and reduce environmental impact in chinese maize production. *Frontiers in Plant Science,* 8:1234. Retrieved from https://www.frontiersin.org/article/10.3389/fpls.2017.01234
Yu X; Q Zhang; J Gao; Z Wang; Q Borjigin; S Hu; B Zhang and D Ma. 2019. Planting density tolerance of high-yielding maize and the mechanisms underlying yield improvement with subsoiling and increased planting density. *Agronomy* 9(7): 370. https://doi.org/10.3390/agronomy9070370.