EFFECT OF NITROGEN LEVELS ON SPRING MAIZE IN RELATION TO MULCHING MATERIALS IN CENTRAL INNER TARAI OF NEPAL

S. Marahatta*
Agriculture and Forestry University, Chitwan, Nepal
*smarahatta@afu.edu.np

ABSTRACT

The effect of different mulching materials and varying nitrogen fertilizer levels on growth, yield attributes, and yield of open-pollinated maize variety aiming at yield improvement was studied in inner Terai of Nepal through a field experimentation in 2019. The treatments included were the combinations of three mulching materials, (a) plastic mulch, (b) straw mulch, and (c) no mulching; and four nitrogen levels (0, 50, 100, and 150 kg ha^{-1}) arranged in a split-plot design with four replications. Data on growth, yield attributes, and yield were taken and analyzed by using R Studio. The higher ($p<0.05$) heat use efficiency was recorded under plastic mulch and the higher levels of nitrogen application. The number of kernels per cob and thousand kernel weight were higher ($p<0.05$) in mulch treatments and higher nitrogen levels. Both the barrenness and sterility percentage were higher ($p<0.05$) for the 0 kg N ha^{-1} and reduced ($p<0.05$) by the nitrogen application of ≥100 kg ha^{-1}. Increased tasseling-silking interval increased ($p<0.05$) the sterility and grain filling duration and increased ($p<0.05$) the grain yield. Due to the better yield attributes, the grain yield of mulch applied treatments and application of ≥100 kg N ha^{-1} were higher ($p<0.05$) than the no mulch and ≤50 kg N ha^{-1}, respectively. The yield was hampered more by barrenness than by sterility. The effect of nitrogen levels on grain yield followed the quadratic relationship; 104 kg and 129-130 kg Nha^{-1}, respectively for no mulch and mulching treatments which are estimated as economic levels of nitrogen fertilizers for open-pollinated spring maize under the central inner Terai environment.

Keywords: *spring maize, plastic mulch, straw mulch, nitrogen levels*

INTRODUCTION

Maize (*Zea mays* L.) is the second most important crop of Nepal after rice in terms of both the area of cultivation and production. The national average yield of maize (2.35 t ha^{-1}) (MOF, 2017) is far below than the attainable yield of >8.0 t ha^{-1} (Devkota et al., 2016). Current maize production of 1.3 million tons is not sufficient to meet the national demand and thus, yield of maize must be increased by 57% (CBS, 2014; KC et al., MOF, 2017; Trend Economy, 2020). As the possibility of expanding the area under maize 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 conditions, etc. are responsible for the lower yield (Raza et al., 2019). It has been reported that agronomic practices like mulching and proper fertilizer management increases yield attributes and ultimately the grain yield (Inamullah et al., 2011). Mulching plays an important role in improving soil fertility and agricultural productivity, and similarly, Nitrogen has a vital role to play and a huge amount of nitrogen fertilizer is being used to increase crop productivity (Qin et al., 2015).

The use of mulch in the field provides many benefits to the soil by (a) reducing evaporation, improving infiltration, and increased water use efficiency; (b) improving thermal regime; (c) adjusting the microbial biomass; (d) maintaining the soil organic carbon balance; (e) enhancing nutrient cycling; (f) promoting soil enzyme activities; (g); enhancing soil aggregate stability (d) suppressing weed infestation and; and thus increasing grain yield (Wang et al., 2019; Zhou et al., 2009; Smets et al., 2008).

It is assumed that for every 100 kg of maize yield, 1.8 kg N in the grain and 1.0 kg in the above-ground parts of the plant are required, which must be supplied by soil and/or fertilizer (Sampath et al., 2013). Thus, the appropriate nitrogen fertilization can markedly increase the crop yield. However, improper application of nitrogenous fertilizers has negative affect on the nitrogen use efficiency and the environment. Effective nitrogen management strategies should consider the appropriate dose of nitrogen with suitable mulching materials; crop management practices; and climatic conditions. The available information on the combined effects of mulch and plant nutrients, particularly nitrogen, on maize under the hot spring condition of inner Terai region is not conclusive. Thus, the present work was, therefore, undertaken to find out the usefulness of straw and plastic mulch and optimum requirements of nitrogen for better yield and 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 conducted in seed production block of National Maize Research Block (NMRP) at Rampur, Chitwan located in the central Terai region of Nepal (27°40′ N latitude, 84°19′ E longitude, and 228 masl) during spring season 2019. The experimental field had sandy loam soil with a slightly lower 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 Directorate of Soil Management, Ministry of Agriculture Development, Government of Nepal, Kathmandu, Nepal (Table 1).

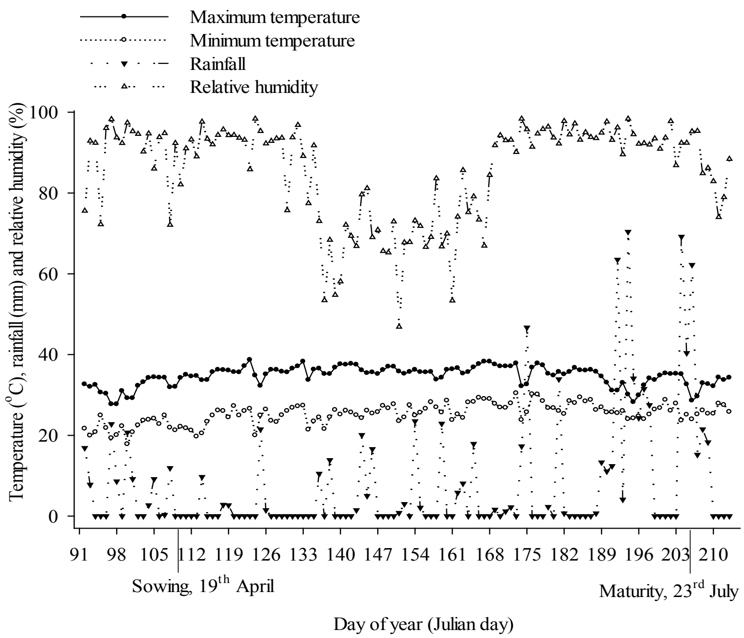
Table 1. Initial physical and chemical soil properties of the experimental fields at Rampur, Chitwan, Nepal, 2019

S.N.	Properties	Content	Rating	Methods (Estefan et al., 2014)
1.	Physical properties			
	Sand (%)	62.90	Sandy loam	Hydrometer.
	Silt (%)	28.80		
	Clay (%)	8.30		
2.	Chemical properties			
	Soil pH	6.10	Acidic	Beckman Glass Electrode pH meter
	Soil-organic matter (%)	2.02	low	Walkey and Black
	Total nitrogen (%)	0.10	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

The experimental site lies in the subtropical humid climate belt of Nepal 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 reproductive- ripening phases.

Experimental design and treatments

The experiment was conducted by using split-plot design, comprising two factors-three mulching materials (silver-black plastic of 45-micron thickness, rice straw at 3 t ha^{-1}, no mulch) in main plots, and four nitrogen levels (0, 50, 100, and 150 kg ha^{-1}) in subplots, with four replications. The experimental plots were 16.4 m^2 (4.8 m × 3.5 m) each in size.



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)

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

Source: NMRP, 2019

Crop management

The field was plowed two times and planking and leveling were done to bring the soil under good tilth. Maize seeds were sown on 19th of April with a handheld maize planter with 2 seeds per hill maintaining a spacing of 60 cm × 25 cm. The full dose of phosphorus (26.2 kg P ha^{-1}) and potassium (33.2 kg K ha^{-1}) was applied for all plots while N dose varied as per the treatment. In N applied treatments, 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 as 45 DAS). Atrazine, a pre-emergence herbicide, was applied @ 1.5 kg a.i. ha^{-1} followed by one hand weeding at 20 days after sowing (DAS). Thinning was done at 13 DAS maintaining one plant per hill. Irrigation was applied when the crop showed the symptoms of temporary wilting.

Sampling and measurements

Cobs were harvested manually from the net plot area of 8.4 m^2 (4 rows). The total number of barren plants were counted in each net plot, and it was converted to the number of barren plants ha^{-1}. Dehusking of cobs was done separately for each plot on the threshing floor. After shelling of grains, seeds were carefully separated, dried and weighed, and moisture percent was recorded. After removing the cobs, the cut stalks were sun-dried for few days and weighed. 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 plot 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^{-1} for statistical analysis.

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

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

Days to tasseling, silking, and physiological maturity stages were recorded in the plants 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 was determined by the difference between tasseling and silking days. The calculation of the heat summation unit, mostly called the growing degree days (GDD), and their 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):

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

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

$$\text{Heat use efficiency (HUE)} = \frac{\text{Grain yield}\,\left(\text{kg ha}^{-1}\right)}{\text{GDD}}$$

Statistical analysis

The recorded data were subjected to analysis of variance, and Duncan's multiple range test at α level 0.05 (DMRT) for mean separations (Gomez & Gomez, 1984). Correlation and regression analysis was done for selected parameters. Dependent variables were subjected to analysis of variance using the R Studio for 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 DISCUSSION

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

Mulching materials and nitrogen levels influence different heat summation unit

Growing degree days (GDD) and phenol-thermal index (PTI) for 75% attainment of different phenological stages, and heat use efficiency (HUE) were significantly influenced by the mulching materials and nitrogen levels (Table 2). The lowest GDD requirement for tasseling and silking was recorded under plastic much, which was significantly lower than the GDD requirement under straw mulch and no mulch treatments, whereas the GDD for physiological maturity was not significantly affected by the mulching treatments. The nitrogen levels did not influence the GDD requirement for the tasseling whereas for silking and physiological maturity were significantly lower for 0 kg N ha^{-1}. GDD requirement for silking and physiological maturity was the highest for 150 kg N ha^{-1} which was statistically similar to 50 and 100 kg N ha^{-1} for the GDD requirement of silking, and 100 kg N ha^{-1} for the GDD requirement of physiological maturity.

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

Treatments	Growing degree day (°C)			HUE (kg $ha^{-1}day$ $°C^{-1}$)	Pheno-thermal index (day °C day^{-1})		
	Tasseling	Silking	Physiological maturity		Tasseling	Silking	Physiologi-cal maturity
Mulching materials							
Plastic mulch	992^{b}	1107^{b}	1894	1.76^{a}	20.34^{b}	20.45^{c}	20.64^{b}
Straw mulch	1072^{a}	1166^{a}	1911	1.74^{a}	20.38^{a}	20.49^{b}	20.64^{b}
No mulching	1073^{a}	1186^{a}	1868	1.28^{b}	20.39^{a}	20.53^{a}	20.68^{a}
SEm (±)	10.65	8.80	15.36	0.05	0.01	0.01	0.01
$LSD_{0.05}$	36.86	30.46	ns	0.16	0.02	0.04	0.02
CV,%	2.00	1.50	1.60	6.00	0.1	0.1	0.04
Nitrogen levels (kg ha^{-1})							
0	1065	1207^{a}	1845^{c}	1.10^{c}	20.37	20.56^{a}	20.70^{a}
50	1025	1137^{b}	1881^{bc}	1.57^{b}	20.37	20.47^{b}	20.64^{b}
100	1037	1133^{b}	1915^{ab}	1.85^{a}	20.37	20.47^{b}	20.64^{b}
150	1055	1135^{b}	1922^{a}	1.85^{a}	20.38	20.46^{b}	20.64^{b}
SEm (±)	13.42	13.43	13.09	0.04	0.01	0.02	0.01
$LSD_{0.05}$	ns	38.97	38.00	0.11	ns	0.06	0.01
CV,%	4.40	4.00	2.40	8.10	0.20	0.40	0.10
Grand mean	1046	1153	1891	1.59	20.37	20.49	20.65

Note: HUE, heat use efficiency; SEm, Standard error of mean; LSD, least significant difference; CV, coefficient of variation; ns, not significant. Treatments mean followed by a common letter (s) within the column are not significantly different among each other based on DMRT at 0.05 level of significance.

Maize under plastic and straw mulch were significantly more efficient to show more HUE than the no mulch treatment (Table 2). Similarly, the nitrogen levels of 100 and 150 kg ha^{-1} were significantly more efficient in terms of HUE than lower nitrogen levels. The highest PTI for tasseling, silking and physiological maturity were recorded under no mulch treatment, which was significantly higher than that recorded under plastic mulch but statistically similar with straw mulch for tasseling. PTI for physiological maturity was statistically at par with the plastic and straw mulch treatments. The nitrogen levels did not influence the PTI requirement for the tasseling whereas for silking and physiological maturity it was significantly lower for control plots (0 kg N ha^{-1}).

The onset of different growth stages in plants is termed as the phenology, which is driven by the genetic as well as meteorological factors (Ma et al., 2012). When the required GDD and PTI are completed, the crop switches to physiological maturity and completes its growing cycle (Xiao et al., 2013). The higher nitrogen levels increased nitrogen uptake, and hence the GDD for the different phonological stages was increased. Maize crop accumulates more heat units to tasseling, silking and physiological maturity with increasing the levels of nitrogen and vice versa (Amanullah et al., 2009). An increase in nitrogen level might have increased the rate of photosynthesis in the plant that resulted in leaf durability and delayed the phenological characteristics in the crop (Gungula et al., 2003).

Mulching materials and nitrogen levels influence yield attributes and yield

Among the various yield associated traits and yield attributes, only the number of kernels per cob and thousand kernel weight was influenced significantly by the mulching materials whereas most of these were influenced significantly by the nitrogen levels (Table 3). Both the kernels per cob and thousand kernel weight were significantly higher under mulch applied plots as compared to no mulch plots. The nitrogen levels did not influence the number of plants per hectare. Both the barrenness and sterility percentage were significantly higher in the control plot and were lowest at 150 kg N ha^{-1} applied blots which was significantly lower than 0 and 50 kg N ha^{-1} for barrenness and 0 kg N ha^{-1} for sterility. The number of kernels per cob was significantly higher in 100 and 150 kg N ha^{-1} treated plots than in the plots with lower nitrogen levels. The thousand kernel weight was significantly higher under nitrogen applied plots than the control plots. The grain yield in plastic mulch and straw mulch treatments were statistically at par with each other but significantly higher than the no mulch treatment while the stover yield did not differ among the treatments with mulching factor. The nitrogen application of 100 and 150 kg N ha^{-1} resulted in a significantly higher grain yield than the lower nitrogen levels. However, the harvest index was statistically similar among the nitrogen received treatments. Grain yield, stover yield, and harvest index were lowest in the control, which was significantly lower than that in the treatments with nitrogen application of ≥50 kg ha^{-1}.

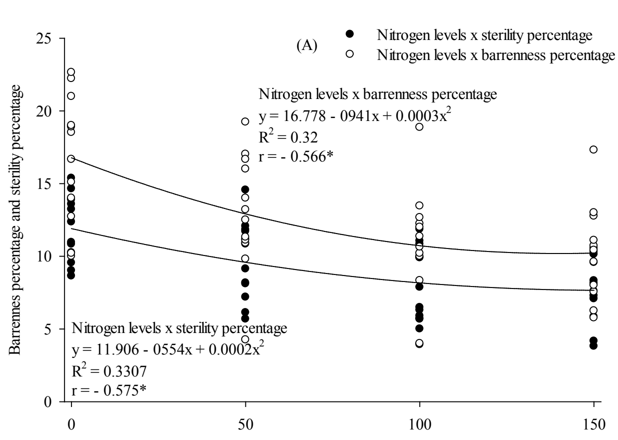
The yield attributing characters, especially the number of kernels per cob and thousand kernel weight was higher in the mulch treatments, which may have resulted in good final grain yield. A similar finding was reported by Meskelu *et al*. (2018). Xu *et al*. (2015) recorded a higher yield (+19%) under the plastic mulch treatment compared to the control treatment. The yield improvement due to plastic mulching was 28% higher in a normal year and 88% higher in the dry year at the Changwu, China (Bu et al., 2013). From the metadata analysis, Qin *et al*. (2015) concluded that the yield advantage under straw mulching on maize was 20%, independent of water input level, while the mean effect of plastic mulching on maize yield was 60% at low water input (<370 mm), and 40% at high water input. Due to the mulching, the water content at least of the topsoil was higher and relatively stable by reducing the evaporation from the soil surface directly (Zhou et al., 2009), and the movement of water from the deeper soil layers to the topsoil by capillary action and vapor transfer (Tian et al., 2003).

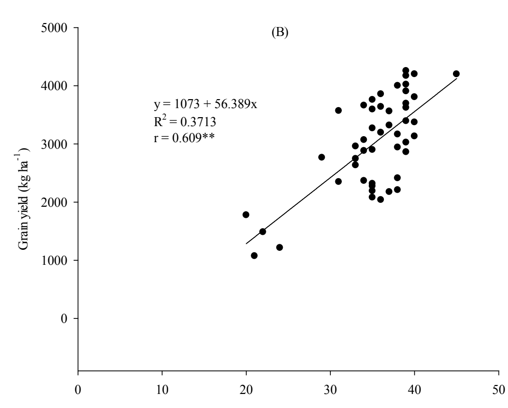
Table 3. Yield attributes, barrenness percentage, sterility percentage, grain yield, stover yield and harvest index of spring maize as influenced by the mulching materials and nitrogen levels at Rampur, Chitwan, Nepal, 2019

Treatments	Plants ha^{-1}	Barren-ness (%)	Kernels cob^{-1}	Sterility (%)	TKW	Grain yield (kg ha^{-1})	Stover yield (kg ha^{-1})	HI (%)
Mulching materials								
Plastic mulch	60714	11.94	276^{a}	9.59	262.3^{a}	3333^{a}	9786	28.08^{a}
Straw mulch	59970	11.67	280^{a}	8.17	264.0^{a}	3329^{a}	10071	27.79^{a}
No mulching	59375	14.38	238^{b}	9.99	240.6^{b}	2406^{b}	9258	23.02^{b}
SEm (±)	1089	1.78	3.94	0.64	5.15	76	268	0.86
$LSD_{0.05}$	ns	ns	13.64	ns	17.81	263	ns	2.98
CV,%	3.6	28.1	3.0	13.7	4.0	5.0	5.5	6.6
Nitrogen levels (kg ha^{-1})								
0	60913	16.75^{a}	224^{c}	11.61^{a}	225.5^{b}	2050^{c}	8166^{c}	22.55^{b}
50	60218	13.00^{b}	264^{b}	9.72^{b}	259.5^{a}	2958^{b}	9070^{b}	27.49^{a}
100	59226	10.64^{bc}	284^{a}	8.04^{b}	270.4^{a}	3539^{a}	10409^{a}	28.31^{a}
150	59722	10.25^{c}	287^{a}	7.62^{b}	267.0^{a}	3542^{a}	11175^{a}	26.83^{a}
SEm (±)	1103	0.88	5.56	0.66	4.92	77	288	0.81
$LSD_{0.05}$	ns	2.55	16.13	1.92	14.26	225	834	2.36
CV,%	6.4	24.0	7.3	24.5	6.7	8.9	10.3	10.7
Grand mean	60020	12.66	265	9.25	255.6	3023	9705	26.30

Note: TKW, thousand kernel weight; HI, harvest index; SEm, Standard error of mean; LSD, least significant difference; CV, coefficient of variation; ns, not significant. Treatments mean followed by a common letter (s) within the column are not significantly different among each other based on DMRT at 0.05 level of significance.

The relationships between the barrenness and sterility with nitrogen levels and grain yield were negative and followed the significant quadratic relationship (Figure 3A and 3D). Due to the higher coefficient of determination, it is concluded barrenness hampers the yield more as compared to sterility. The relationship between the tasseling silking interval and sterility percentage was significant, positive, and linear (Figure 3C). Increasing the grain filling duration significantly increased the grain yield (Figure 3B).





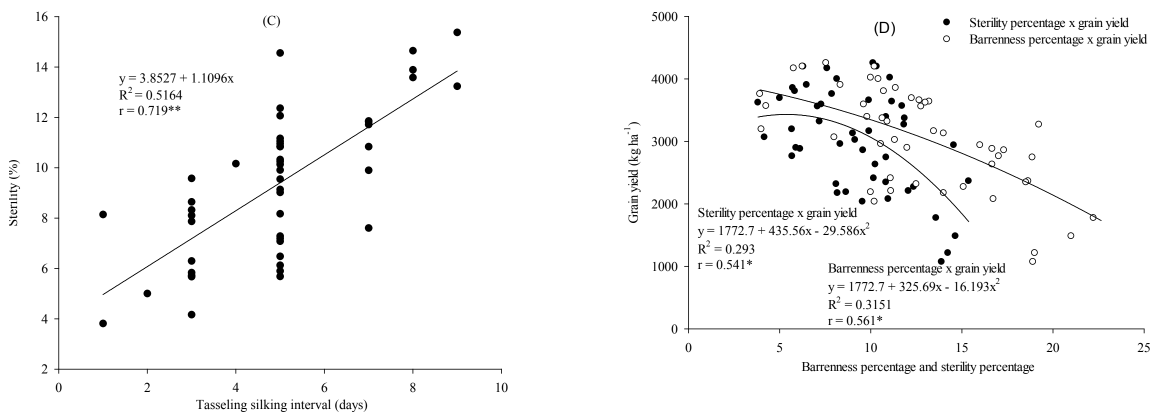


Figure 3. Relationship between (A) nitrogen levels and barrenness percentage and sterility percentage with grain yield, (B) grain filling duration and grain yield, (C) tasseling-silking interval and sterility percentage, and (D) barrenness percentage and sterility percentage with grain yield of spring maize as influenced by the mulching materials and nitrogen levels at Rampur, Chitwan, Nepal, 2019

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

There was an increasing trend in the yield attributes and decreasing trends on the sterility and barrenness percentage with increasing nitrogen levels. Proper translocation of sugar and starch in the grain by nitrogen fertilization might be the cause of improving the yield attributes under the higher nitrogen levels (Rahman et al., 2016). The higher degree of sterility under lower levels of Nitrogen might be attributed to poor development of sinks and reduced translocation of photosynthates. The number of grains that developed from the fertilized spikelet was higher under adequate nitrogen levels resulting in low sterility. Nitrogen omission and lower nitrogen levels had pronounced nitrogen stress during pre-flowering resulting in lower photosynthesis rate and few ear spikelets (potential grains). Nitrogen stress during the flowering stage, nitrogen stress had resulted in the kernel and ear abortions (Turc & Tardieu, 2018). Under the nitrogen stress conditions, there may be the asynchronous flowering and increased sterility and thus reduced the number of kernels per cob. The nitrogen application of 100-150 kg ha^{-1} significantly increased kernel number by 27-28% over control. In agreement with the results of the present study, higher values of thousand kernel weight have been reported with an increase in nitrogen levels (Dawadi & Sah, 2012). Maize plant and ear barrenness decrease as nitrogen applications increase (Chen et al., 2016). Ma et al. (2006). Similarly, Qian et al. (2016) found that nitrogen fertilization significantly increased the grain yield per plant and the per unit area.

Nitrogen response

The response of nitrogen levels on grain under different mulching treatments in depicted in Figure 4.

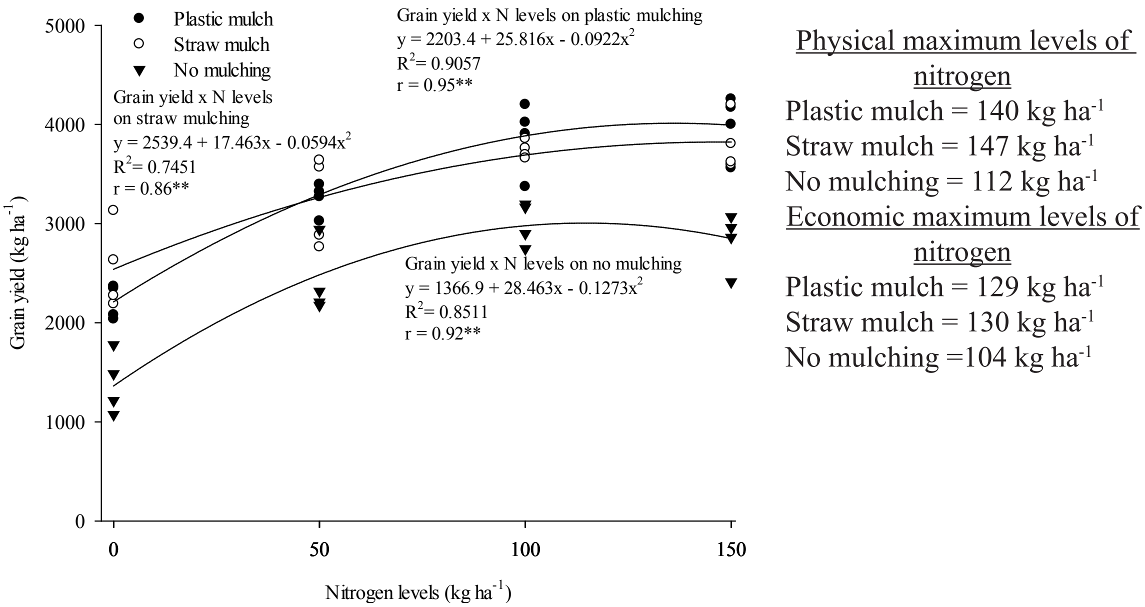


Figure 4. Response of nitrogen on grain yield under different mulching materials of spring maize at Rampur, Chitwan, Nepal, 2019

*Note: **, significant at 0.01 level of significance*

The crop under mulch applied treatments was more responsive to nitrogen levels, which resulted in higher physical and economic maximum levels of nitrogen. Both the physical and economic maximum levels of nitrogen were slightly higher (5.0 and 0.8% respectively) under straw mulching than under the plastic mulching.

Three mathematical equations (including linear with a plateau, quadratic, and exponential) are typically used to express crop yield as the function of nitrogen levels (Zhang et al., 2018). However, the effect of nitrogen application on crop yield could be separated into two stages, the first stage is yield increase and the second stage is yield stabilization or even reduction with an increase in N rate (Wang et al., 2017). The decrease in yield with higher application levels is not adequately captured when a linear relationship with a plateau curve, so a quadratic curve was selected in our study.

CONCLUSION

The study indicated that the variation among the mulch and no mulch treatments and the nitrogen levels, affects the grain yield of maize. Both mulching and higher nitrogen levels result in the better yield parameters, lowers the barrenness and sterility percentage, and hence produce higher grain yield. Mulching lowers the GDD and PTI for the efficient attainment of major phonological stages. Maize under mulching is more responsive to a higher level of nitrogen fertilizer. Thus the nitrogen level of around 104 kg and 129-130 kg ha^{-1} is recommended for no-mulch and mulching, respectively, for open-pollinated spring maize under the central inner Terai condition of Nepal.

REFERENCES

Amanullah, R., Khattak, A., & Khalil, S.K. (2009). Plant density and nitrogen effects on maize phenology and grain yield. *Journal of Plant Nutrition, 32*, 246–260.

Bu, L., Liu, J., Zhu, L., Luo, S., Chen, X., Li, SQ, Hill, R. L., & Zhaoa, Y. (2013). The effects of mulching on maize growth, yield and water use in a semi-arid region. *Agric Water Manage, 123*, 71-78.

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

Chen, K., Camberato, J. J., Tuinstra, M. R., Kumudini, S. V., Tollenaar, M., & Vyn, T. J. (2016). Genetic improvement in density and nitrogen stress tolerance traits over 38 years of commercial maize hybrid release. *Field Crops Research*, *196*, 438-451.

Dawadi, D. R., & Sah, S. K. (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.

Devkota, K. P., McDonald, A. J., Khadka, L., Khadka, A., Paudel, G., & Devkota, M. (2016). Fertilizers, hybrids, and the sustainable intensification of maize systems in the rainfed mid-hills of Nepal. *European Journal of Agronomy*, *80*, 154-167.

Estefan, G., Sommer, R., & Ryan, J. (2013). *Methods of soil, plant, and water analysis : a manual for the West Asia and North* (Third). Retrieved from www.icarda.org

Gomez, A. A, & Gomez, K. A. (1984). *Statistical procedures for agricultural research* (Second). John Wiley & Sons.

Gungula, D. T., Kling, J. G., & Togun, A. O. (2003). CERES-Maize predictions of maize phenology under nitrogen-stressed conditions in Nigeria. *Agronomy Journal, 95*, 892-899.

Inamullah, Shah, N. H., Rehman, N. U., Siddiq, M., & Khan, Z. (2011). Phenology, yields and their correlations in popular local and exotic maize hybrids at various nitrogen levels. *Sarhad J. Agric., 27*(3), 363- 369.

Jacobsohn, R., Greenberger, A., Katan, J., Levi, M., & Alon, H. (1980). Control of Egyptian broomrape (*Orobanche aegyptiaca*) and other weeds by means of solar heating of the soil by polyethylene mulching. *Weed Sci., 28*, 312-316.

KC, G., Karki, T. B., Shrestha, J., & Achhami, B. B. (2015). Status and prospects of maize research in Nepal. *Journal of Maize Research and Development*, *1*(1), 1–9.

Li, F. M., Guo, A. H., & Wei, H. (1999). Effects of clear plastic film mulch on yield of spring wheat. *Field Crops Res 63*, 79-86.

Ma, B.L., Subedi, K.D., & Liu, A. (2006). Variations in grain nitrogen removal associated with management practices in maize production. *Nutr. Cycl. Agroecosyst., 76*(1), 67–80.

Ma, S., Churkina, G., & Trusilova, K. (2012). Investigating the impact of climate change on crop phenological events in Europe with a phenology model. Intl. J. Biometeorol. 56(4): 749-63.

Meskelu, E., Tesfaye, H., Debebe, A., & Mohammed, M. (2018). Integrated effect of mulching and furrow methods on maize yield and water productivity at Koka, Ethiopia. *Irrigat Drainage Sys Eng 7*(1), 207.

MOF. (2017). *Economic survey 2016-2017*. Retrieved from http://mof.gov.np/

Qian, C., Yu, Y., Gong, X., Jiang, Y., Zhao, Y., Yang, Z., Hao, Y., Li, L., Song, Z., & Zhang, W. (2016). Response of grain yield to plant density and nitrogen rate in spring maize hybrids released from 1970 to 2010 in Northeast China. *The Crop Journal, 4*(6), 459-467

Qin, W., Hu, C., & Oenem, O. (2015). Soil mulching significantly enhances yields and water and nitrogen use efficiencies of maize and wheat: a meta-analysis. *Scientific Reports, 5*, 16210. Retrieved from https://www.nature.com/

Rahman, M. M., Paul, S. K., & Rahman, M. M. (2016). Effects of spacing and nitrogen levels on yield and yield contributing characters of maize. *J. Bangladesh Agril. Univ. 14*(1), 43-48

Raza, A., Razzaq, A., Mehmood, S. S., Zou, X., Zhang, X., Lv, Y., & Xu, J. (2019). Impact of climate change on crops adaptation and strategies to tackle its outcome: a review. *Plants*, *8*(2), 34.

Sampath, O., Madhavi, M., & Rao, P.C. (2013). Evaluation of genotypes and nitrogen levels for yield maximization in rabi maize (*Zea mays* L.). *Int. J. Innov. Res. Dev. 2*:314-318.

Smets, T., Poesen, J., & Knapen, A. (2008). Spatial scale effects on the effectiveness of organic mulches in reducing soil erosion by water. *Earth Sci. Rev. 89*, 1-12.

Thavaprakaash, N., Jagannathan, R., Velayudham, K., & Gurusamy, L. (2007). Seasonal influence on phenology and accumulated heat units in relation to yield of baby corn. *International Journal of Agricultural Research, 2*, 826-831.

Tian Y, Su, D. R., Li, F. M., & Li, X. L. (2003) Effect of rainwater harvesting with ridge and furrow on yield of potato in semiarid areas. *Field Crops Research 84*, 385–391.

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

Turc, O., & Tardieu, F. (2018). Drought affects abortion of reproductive organs by exacerbating developmentally driven processes via expansive growth and hydraulics. *Journal of Experimental Botany*, *69*(13), 3245–3254.

Wang, H., Zhang, Y., Chen, A., Liu, H., Zhai, L., Lei, B., & Ren, T. (2017). An optimal regional nitrogen application threshold for wheat in the North China Plain considering yield and environmental effects. *Field Crop Research, 207*, 52-61.

Wang, X., Fan, J., Xing, Y., Xu, G., Wang, H., Deng, J., Wang, Y., Zhang, F., Li, P., & Li, Z. (2019). The effects of mulch and nitrogen fertilizer on the soil environment of crop plants. *Advances in Agronomy, 153*, 121-173

Xiao, D., Tao, F., Liu, Y., Shi, W., Wang, M., Liu, F., Zhang, S., & Zhu, Z. (2013). Observed changes in winter wheat phenology in the North China Plain for 1981-2009. *Intl. J. Biometeorol. 57*(2), 275-85.

Xu, J., Li, C., Liu, H., Zhou, P., Tao, Z., Wang, P., Meng, Q., & Zhao, M. (2015). The effects of plastic film mulching on maize growth and water use in dry and rainy years in northeast China. *PLoS ONE, 10*(5), e0125781.

Zhang, Y., Wang, H., Lei, Q., Luo, J., Lindsey, S., Zhang, J., Zhai, L., Wu, S., Zhang, J., Liu, X., Ren, T., & Liu, H. (2018). Optimizing the nitrogen application rate for maize and wheat based on yield and environment on the Northern China Plain. *Science of The Total Environment, 618*, 1173-1183

Zhou, L. M., Li, F. M., Jin, S. L., & Song, Y. J. (2009). How two ridges and the furrow mulched with plastic film affect soil water, soil temperature and yield of maize on the semiarid Loess Plateau of China. *Field Crops Research, 113*, 41–47.