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Performance of Maize (*Zea mays* L.) in Response to Application of Prilled and Nano Urea under Rainfed Conditions of Northwest India

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ABSTRACT: Cultivation of maize under drylands faces major concerns such as water scarcity and low nutrient use efficiency which threatens sustainable crop production. A field study was conducted during *kharif* season of 2022 and 2023 to evaluate the effects of prilled and nano urea on productivity, economics and soil fertility of rainfed maize (*Zea mays* L.). The experiment was conducted in a randomized block design with seven treatments in different combinations of soil applied prilled urea and foliar applied nano-urea replicated thrice. The pooled results revealed that soil application of 100% recommended NPK and two sprays of nano-urea (T_5) resulted in 21.5, 43.1, 45.1, 44.2, 27.1 and 55.8% higher plant height, cob length, cob girth, grains per cob, test weight and rainwater use efficiency (RWUE), respectively as compared to control. The same treatment also produced higher grain and straw yield, net returns and B:C ratio as compared to control. Pearson's correlation showed that the yield attributes were positively and significantly correlated with grain and straw yield. Application of prilled urea with or without foliar application of nano-urea significantly resulted in higher content of soil organic carbon (SOC) and available N, P and K as compared to control. The treatments 100% recommended NPK (T_3) and 100% recommended NPK and one spray of nano-urea (T_7) were statistically similar (T_5) suggesting that spraying nano-urea could have supplemental effect on maize productivity under rainfed conditions.

Keywords: crop productivity, economics, maize, nano-urea, prilled urea, soil fertility

Introduction

Maize (*Zea mays* L.) occupies third position after rice and wheat in cereal production. In India, maize is grown on 9.86 Mha contributing 31.54 million tonnes produce besides employing approximately 15 million farmers (Bamboriya *et al.,* 2023). Maize is regarded as the premier cereal crop and is the main source of energy not only for humans but also for livestock. In dry lands, the two primary determinants that significantly affect crop performance are nutrients and water. By and large, plants more likely reach their genetic yield potential when soils supply essential nutrients in appropriate manner (Khokhar *et al.,* 2021). Cultivation of maize under drylands faces major concerns such as water scarcity and low nutrient use efficiency which threaten sustainable crop production. Nitrogen is the most yield limiting nutrient in maize cultivation. With an ever-increasing population and fragmented land holdings, the need to use more synthetic fertilizers particularly nitrogen is prerequisite to cater the food requirements of the world population (Upadhyay *et al.,* 2023). Nevertheless, the nutrient use efficiency of nitrogenous fertilizers such as urea is around 30-40%. The unused nitrogen is discharged into the ecosystem though different means thus pollutes the soil, air and water (Duan *et al.,* 2016).

As of today, research into nanoscale or nanostructured materials as fertilizer carriers or controlled-release suggests an increase in nutrient use efficiency while minimizing the negative impact on the environment (Kashyap *et al.,* 2023). Nitrogen use efficiency can be enhanced with the effective use of nano urea owing to its greater penetration ability and translocation throughout the plant parts. In addition to this, nano-fertilizers inhibit the unlikable loss of nutrients through efficient uptake by crops thereby avoiding the interaction of nutrients with soil, air, water and microbes (Meena *et al.,* 2021). Nano-fertilizers boost crop growth and yield when used at the recommended doses. However, if the concentration is greater than the ideal range, they may exert opposite effect on the crop growth. Under rainfed conditions, there is not much information on these aspects. The experiment evaluated the premise that the foliar spray of nano-urea in conjunction with suboptimal or optimal nitrogen fertilizer application improves productivity and profitability of maize.

Materials and Methods

A field experiment was conducted at experimental farm of Regional Research Station, Punjab Agricultural University, Ballowal Saunkhri for two consecutive years (*kharif* 2022 and 2023) under rainfed conditions. The study area is located at 76°27′42″ E and 31°6′24″ N, 335 m above mean sea level in SBS Nagar district of Punjab. The soil texture of the experimental field was sandy loam with 72.5, 17.8 and 9.7% sand, silt and clay, respectively. At the start of the experiment, the soil had alkaline reaction (pH, 7.8) with no salinity problems (EC, 0.21 dS/m). Soil was medium in soil organic carbon (4.8 g/kg) and low in available N (125 kg/ha), high in Olsen P (27 kg/ha), and medium in available K (235 kg/ha). The concentrations of DTPA extractable Zn, Fe, Mn and Cu were 0.96, 4.49, 9.37 and

0.66 mg/kg, respectively. The total rainfall during the maize growing season was 326.1 mm and 615.6 mm in 2022 and 2023, respectively.

The field experiment was conducted in a randomized block design with three replications. A total of 7 treatments were evaluated: T_1: Control (no fertilizer); T_2: 75% recommended N + 100% recommended PK; T_3: 100% recommended NPK; T_4: 75% recommended N + 100% recommended PK and two sprays of nano-urea; T_5: 100% recommended NPK and two sprays of nano-urea; T_6: 75% recommended N + 100% recommended PK and one spray of nano-urea; T_7: 100% recommended NPK and one spray of nano-urea. Maize variety, PMH-13 was sown in the first fortnight of July 2022 and 2023 with a spacing of 60 cm × 20 cm by using a seed rate of 20 kg seeds/ha. The sowing was done by dibbling method by placing seeds 3-5 cm deep. The size of individual plots was 14.4 m^2 (4 m×3.6 m) with a buffer zone of 0.5 m between the plots. The recommended dose of nitrogen for rainfed maize is 80 kg N/ha. The N (in the form of prilled urea) was applied according to the treatments through urea. The half of N was applied as basal while the second half dose was top dressed uniformly at knee high stage as per the treatments. Single superphosphate (250 kg/ha) and potassium chloride (37.5 kg/ha) were used as sources of phosphorous and potassium, respectively. The entire doses of phosphorous and potassium were applied as basal before the sowing of maize crop. The nano-urea (4% N) liquid formulation (w/v) with 20–50 nm particles developed by IFFCO was sprayed at the rate of 4 ml per litre of water according to the treatments. The first foliar spray of nano-urea was applied three weeks after germination of crop and the second two-weeks after the first spray. The spray was done by hand operated knapsack sprayer with flat fan nozzles to ensure that maximum foliage is covered. All other cultural operations were followed as per the package of practices of Punjab Agricultural University. Water use efficiency (kg/ha-mm) was calculated by dividing the grain yield (kg/ha) with total rainfall (mm) received during the crop season. Cost of cultivation, net monetary returns and benefit: cost ratio were calculated on the basis of prevailing market price of inputs and outputs.

Soil samples at a depth of 0–15 cm were collected from all plots after harvesting of the crop. The samples were air-dried and passed through a 2-mm sieve. The pH of the processed soil samples was determined with glass electrode using soil suspension of 1:2 (soil: water) and electrical conductivity (EC) in the supernatant. Soil organic carbon content was determined by wet-oxidation method, available N by alkaline permanganate method, available P by extracting the soil with 0.5 M $NaHCO_3$ and available potassium by leaching the soil samples with neutral 1 N ammonium acetate and analyzing the extract by flame photometer.

The analysis of variance technique (ANOVA) in randomized block design was employed to analyze the data statistically by using SAS software, version 9.4. The significant mean differences of various parameters under different treatments were compared by least significant difference at 0.05 probability level.

Results and Discussion

Crop growth and yield attributes

Significantly higher plant height was recorded with 100% recommended NPK and two sprays of nano-urea (T_5) as compared to control (T_1), T_2 and T_6 but was statistically similar with other treatments (Table 1). Significantly higher cob length was recorded with application of 100% recommended NPK and two sprays of nano-urea (T_5) as compared to control but was statistically similar with other treatments. Significantly higher cob girth was recorded in T_5 as compared to control, T_2, T_4 and T_6 but was statistically similar with other treatments. Grains per cob exhibited significant variation among the treatments. Significantly higher number of grains per cob were recorded in T_5 than all other treatments but was at par with T_3 and T_7. The pooled data revealed that 1000-grain weight varied from 201.30 grams in control to 255.91 grams in T_5 (Table 1) and all the treatments performed better as compared to control. Significantly higher 1000-grain weight was observed in T_5 as compared to control, T_2, T_4 and T_6 but was statistically similar with other treatments. The suboptimal dose of N either alone or combined with nano-urea resulted in reduced growth and yield attributing characters which suggests that in low nitrogen status soils lower nitrogen application as compared to the recommended dose negatively impact crop growth and development. The increase in plant height with soil applied urea and foliar applied nano-urea can be attributed to the fact that nitrogen promotes plant growth, increases the number and length of the internodes which results in progressive increase in plant height (Khokhar *et al.,* 2021). Moreover, nanoparticles enhance plant growth by modifying leaf organization and regulating the development of vascular bundles in leaves thereby resulting in increased vegetative growth (Yuan *et al.,* 2018). Lack of nitrogen reduces the dry matter production which in turn diminishes the number of grains per cob by preventing translocation of photosynthates. Amanullah *et al.* (2009) also opined that additional urea spraying in maize increased the number of grains per cob. The increased 1000-grain weight in T_5 suggests that N applied through prilled and nano-urea increased the translocation of carbohydrates from source to sink which likely affected the catalytic and enzymatic processes.

Table 1: Effect of prilled urea and nano-urea application on growth and yield attributes of rainfed maize (pooled data of two years)

Treatment	Plant height (cm)	Cob length (cm)	Cob girth (cm)	Number of grains per cob	1000-grain wt. (g)	Water use efficiency (kg/ha/mm)
T_1	147.15^{c}	10.77^{b}	9.96^{c}	277^{d}	201.30^{c}	3.11^{c}
T_2	159.92^{b}	14.02^{a}	12.21^{b}	326^{c}	214.97^{bc}	4.01^{b}
T_3	169.91^{ab}	15.17^{a}	13.37^{ab}	378^{ab}	243.42^{a}	4.68^{a}
T_4	166.16^{ab}	14.95^{a}	12.62^{b}	353^{bc}	228.05^{b}	4.18^{b}
T_5	178.83^{a}	15.41^{a}	14.45^{a}	399^{a}	255.91^{a}	4.84^{a}
T_6	161.87^{b}	14.81^{a}	12.40^{b}	347^{c}	223.32^{b}	4.14^{b}
T_7	172.57^{b}	15.32^{a}	13.62^{ab}	392^{a}	245.08^{a}	4.75^{a}

Different letters in columns represent significant difference at $\alpha \leq 0.05$ level of probability; T_1: Control (no fertilizer); T_2: 75% recommended N + 100% recommended PK; T_3: 100% recommended NPK; T_4: 75% recommended N + 100% recommended PK and two sprays of nano-urea; T_5: 100% recommended NPK and two sprays of nano-urea; T_6: 75% recommended N + 100% recommended PK and one spray of nano-urea; T_7: 100% recommended NPK and one spray of nano-urea.

Crop yield

Significantly higher grain yield was recorded in T_5 as compared to all other treatments but was statistically similar with T_3 and T_7 (Fig. 1). Moreover, all the treatments exhibited significantly higher grain yield than control. However, the treatment T_5 recorded 20.4, 15.7 and 16.8% higher grain yield as compared to T_2, T_4 and T_6, respectively. Significantly higher straw yield was recorded in T_5 as compared to all other treatments but was statistically at par with T_3 and T_7. The treatment T_5 recorded 19.1, 13.9 and 15.6% higher straw yield as compared to T_2, T_4 and T_6, respectively. Kumar *et al.* (2021) evinced that foliar nutrition is usually profitable when roots are unable to absorb adequate amount of nutrients from the soil due to greater fixation of nutrients, leaching losses and moisture deficit. With the application of nano-urea, there was numerical yield advantage. Although nano-fertilizers have a greater use efficiency, nano-urea only contains 4% nitrogen that is insufficient to replace 25% of the recommended dose of nitrogen for maize which is equivalent to 20 kg N/ha. However, in treatments T_3, T_5 and T_7 the balanced nutrient application supplemented by foliar nano-urea might have enhanced the absorption and translocation of nitrogen at faster rate which resulted in higher rate of photosynthesis and more amount of dry matter accumulation thereby increasing the yield. Moreover, the supply of N impacts senescence and it prolongs greenness of the plants besides extending the grain filling duration. Reddy *et al.* (2024) also did not observe any significant impact of conjoint application of urea and nano-urea with zinc fertilization on growth and productivity of spring wheat.

Rainwater use efficiency was significantly influenced by different treatments (Table 1). Significantly higher RWUE was recorded in T_5 as compared to control and other treatments but was statistically similar with T_3 and T_7. Soil application of 100% recommended NPK and two sprays of nano-urea (T_5) resulted in 55.8% higher RWUE as compared to control. The treatment T_5 recorded 20.5, 15.8 and 17.0% higher RWUE as compared to T_2, T_4 and T_6, respectively. The ideal chemical fertilizer application promotes the expansion of root system thereby enhancing the water use efficiency by supporting the plants to efficiently utilize water to produce more biomass. Furthermore, greater plant growth results in larger canopy cover which reduces evaporation owing to shading of the soil surface and increases the quantity of water available for transpiration and consequently enhances water use efficiency (Khokhar *et al.,* 2021).

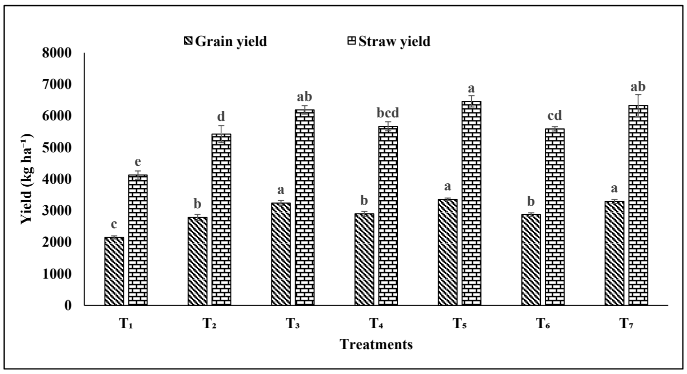

Fig. 1: Effect of prilled and nano-urea on yield of rainfed maize

Economics

The higher cost of inputs for maize cultivation was incurred in 100% recommended NPK and two sprays of nano-urea (T_5) which was due to the variation in prices of inputs and labour employed (Table 2). Maximum gross returns and net returns were recovered from the treatment 100% recommended NPK and two sprays of nano-urea (T_5) which was significantly superior to the control, T_2, T_4 and T_6 with gross returns of ₹. 72960/ha and net returns of ₹. 36011/ha but was statistically similar with T_3 and T_7. The highest benefit cost ratio (2.07) was realized from the treatment 100% recommended NPK and two sprays of nano-urea (T_5) as compared to control T_2, T_4 and T_6 but was statistically similar with T_3 and T_7. Khokhar *et al.* (2021) also reported higher returns and B:C ratio with the application of recommended dose of NPK and foliar spray of urea.

Table 2: Effect of prilled urea and nano-urea application on economics of rainfed maize

Treatment	Cost of cultivation (₹/ha)	Gross returns (₹/ha)	Net returns (₹/ha)	BC ratio
T_1	30895	47116	17804[c]	1.59[c]
T_2	35057	61055	27266[b]	1.82[b]
T_3	36322	73941	37206[a]	2.04[a]
T_4	35496	66295	29954[b]	1.87[b]
T_5	36970	76604	38350[a]	2.07[a]
T_6	35439	65624	29312[b]	1.86[b]
T_7	36626	75165	37365[a]	2.05[a]

T_1: Control (no fertilizer); T_2: 75% recommended N + 100% recommended PK; T_3: 100% recommended NPK; T_4: 75% recommended N + 100% recommended PK and two sprays of nano-urea; T_5: 100% recommended NPK and two sprays of nano-urea; T_6: 75% recommended N + 100% recommended PK and one spray of nano-urea; T_7: 100% recommended NPK and one spray of nano-urea.

Soil fertility

Application of prilled and nano-urea did not exhibit any significant effect on soil pH and electrical conductivity (Fig. 2). Significantly higher SOC was recorded in all the treatments as compared to control; however, all other treatments were statistically similar with each other. The higher SOC in fertilizer applied plots could be adduced to increased plant carbon inputs in soil through root residues, stubble, rhizodeposition as a consequence of increase in yield (Ghosh *et al.,* 2012). By and large, the application of prilled urea with or without foliar application of nano-urea significantly resulted in higher content of post-harvest available N, P and K as compared to control (Fig. 3). Significantly higher available N was recorded in T_5 as compared to control, T_2 and T_4 but was statistically at par with T_3, T_6 and T_7. Available P was significantly higher in T_5 as compared to control, T_2, T_4 and T_6 but was statistically at par with other treatments. Moreover, the suboptimal nitrogen fertilizer treatments did not exhibit any significant effect on available P as compared to control. All the treatments had significantly higher available K as compared to control but were statistically similar with each other. The increment in available P could be due to reduced P sorption and higher initial P (Thakur and Pandey, 2018). The increase in available K might be ascribed to the release of K from the K reserves held in the clay inter layer or non-exchangeable K (Bhat *et al.,* 2023).

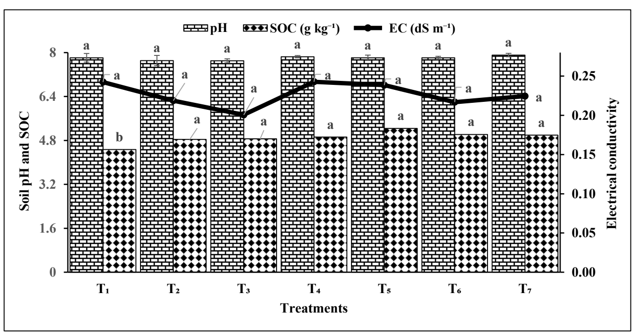

Fig. 2: Effect of prilled and nano-urea on pH, EC and SOC of the soil

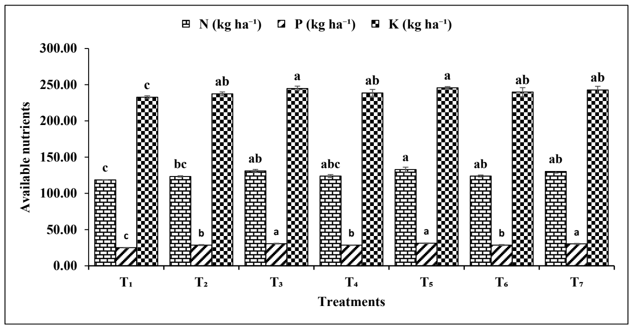

Fig. 3: Effect of prilled and nano-urea on available NPK of the soil

Correlation

The yield attributing characters of the maize, i.e., cob length, 1000-grain weight, cob girth and number of seeds per cob, and plant height were significantly and positively correlated with grain and straw yield (Table 3). Moreover, there were significant interrelationships among these parameters. Therefore, the improvement in yield attributing characters will result in enhanced yield of the maize. The positive correlations indicate that the increase in cob girth increases the space to accommodate a greater number of kernel rows thereby the total number of grains per cob which eventually enhances the grain yield (Patil *et al.,* 2024).

Conclusion

The recommended doses of nitrogen with and without nano-urea improved yield attributes, yield, net returns and B: C ratio of maize as compared to control and suboptimal doses of nitrogen with or without nano-urea spray. The treatments having recommended doses with and without nano-urea spray, by and large, improved soil properties as compared to control and other treatments. Supplementing recommended dose of nitrogen with foliar spray of nano-urea could be resilience plan for enhancing yield and monetary returns and improving soil fertility under soils with low nitrogen status and rainfed conditions.

Table 3: Pearsons correlation among different crop yield attributing characters and yield of rainfed maize

Parameter	Plant height (cm)	Cob length (cm)	1000-grain weight (g)	Cob girth (cm)	Number of grains per cob	Grain yield (kg/ha)	Straw yield (kg/ha)
Plant height	1						
Cob length	0.80**	1					
1000-grain weight	0.88**	0.77*	1				
Cob girth	0.79**	0.93**	0.96**	1			
Number of grains per cob	0.82**	0.91**	0.97**	0.98**	1		
Grain yield	0.87**	0.93**	0.95**	0.98**	0.98**	1	
Straw yield	0.91**	0.95**	0.94**	0.92**	0.97**	0.96**	1

*** Significant at 0.01 probability level and * significant at 0.05 probability level*

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