Boron coated urea application improved growth, yield and nitrogen use efficiency of maize under semi-arid climatic conditions

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Abstract

Maize is one of the most important cereals that has immense use in food and livestock industries. It is a highly fertilizer-dependent crop, whereas less availability of fertilizers reduces maize growth and productivity. Nitrogen is amongst the topmost macronutrients required for proper growth, physiological functions, amino acid and protein production under diverse climatic conditions. However, normal urea granules have significant environmental losses, which also affect the crop yield. Coated urea application could be a promising option to counteract urea losses and increase nitrogen uptake and nitrogen use efficiency. For this, two-factor research trial viz., Factor A (source of urea coatings), $SOUC_1$= simple urea, $SOUC_2$= boron coated urea and Factor B (doses of application), ND_0= Control (no application), ND_1= 75% of recommendation, ND_2= 100% of recommendation, ND_3= 125% of recommendation, was conducted at University of Agriculture Faisalabad, Pakistan. The results showed that increasing urea doses improved maize height (16.42%), cob length (32.66), grains rows/cob (26.32), grains/cob (11.67), thousand-grain weight (16.94), grain yield (29.29), biological yield (13.03), and harvest index (18.62) compared to control treatment. Moreover, grain and biological yield obtained from boron-coated urea using 100% of recommendations gave similar results as those obtained from 125% of simple urea application. Furthermore, nitrogen use efficiency was 10.54% higher in boron-coated urea-treated plants compared to simple urea.

***Keywords*: Coated urea, Boron, maize, yield, nitrogen use efficiency.**

I. Introduction

Maize (*Zea mays* L.) is a C4 plant from the Poaceae family. Globally, maize has immense use in food, animal feed, and bioenergy production (Erenstein *et al*., 2022). Maize seeds contain 70-87% carbohydrates, 6-13% proteins, 4% fat, 2-6% oil, 1-3% sugar, and vitamin B necessary to meet human food's global protein requirement (Kausch *et al*., 2021). In Pakistan, maize ranks as the third most significant cereal, contributing 0.7% of the national gross domestic product (Economic Survey of Pakistan, 2023; Akhtar *et al*., 2023). Research studies indicate that various environmental factors and improper field management are continuously decreasing maize crop growth, development, and yield (Liliane and Charles, 2020; Luo *et al*., 2023). In Pakistan, high temperatures, insufficient water availability, excessive tillage, and inadequate fertilizer application decrease maize productivity (Shahbaz *et al*., 2021).

Nitrogen (N) fertilizers are essential for photosynthesis, improving growth and developmental stages and grain quality attributes. Maize is a nutrient-responsive crop and requires comparatively higher nitrogen doses than wheat and rice (Hammad *et al*., 2022). Urea is the most commonly used for nitrogen application, whereas high nitrogen losses are reported in fields with urea application (Zhang *et al*., 2023). Research investigation indicated the urease enzyme for urea hydrolysis and higher N losses to the environment (Tong *et al*., 2023).

Ochieng *et al*. (2021) reported less nitrogen losses with coated urea application. Combining urease inhibitors and biodegradable materials provides nutrients to plants while slowing down urea hydrolysis. Other studies suggested a significant decrease in NH4 and N2O emissions with coated urea applications (Qi *et al*., 2022). Coated urea improves nitrogen use efficiency by minimizing urea losses (Prasad and Power, 2005; Mustafa *et al*., 2022). Besides, boron (B) deficiency reduces plant growth, productivity, and quality of maize. Boron supplementation improves plant nutrient remobilization, cell division, and metabolic processes. It plays a vital role in plant reproduction, cell division, water relations, disease resistance, and nitrogen metabolism (Kohli *et al*., 2023; Aslam *et al*., 2023a,b). In addition, boron as a coating agent on urea granules provides promising results (Pooniya *et al*., 2018). Boron-coated urea (BCU) application lowers the nitrogen losses from field crops and improves nitrogen uptake and NUE (Saquee *et al*., 2023). BCU also serves as an additional source of B, which helps increase plant growth and maximize crop yield (Beig *et al*., 2020). Similarly, Ba *et al*. (2021) reported high phosphorus and extractable B contents from boron-diammonium phosphate application compared to the control treatment.

Furthermore, Hu *et al*. (2023) stated the efficient use of fertilizer application can augment maize production by decreasing nitrogen losses. The increasing nitrogen application levels enhanced the growth and physiological attributes, yield, and yield-related components (Ali and Anjum, 2017). Likewise, Anwar *et al*. (2017) reported 160 Kg N/ha application enlarged leaf area index, plant height, grains/cob, total plant biomass, and grain yield of maize compared to 120 kg/ha. Other studies suggested that moderate nitrogen fertilization gave optimal grain production with higher net crop benefits (Mosisa *et al*., 2023; Aslam *et al*., 2024). Ali and Anjum (2017) reported less NUE, high N emissions, and runoff with the overuse of N application in maize crops (Ali and Anjum, 2017).

Bilir and Saltali (2023) reported the combined use of B and N with the most promising results for the environment and farmer's economics. Therefore, the present study aimed to improve yield and NUE by identifying the optimum rate of boron-coated urea application for maize crops.

II. MATERIALS AND METHODS

Experimental location:

A field trial was conducted during 2021-22 at Postgraduate Agricultural Research Station (PARS), University of Agriculture Faisalabad, Pakistan.

Soil analysis:

A random soil sampling was carried out to the depth of 20 cm using Auger from the research area to confer the soil properties before the plantation by using the prescribed method of Aslam *et al*. (2021). The soil analysis indicated the pH level up to 7.657, available nitrogen, phosphorous and potassium up to 0.042%, 5.84% and 165 mg/kg respectively and soil was sandy loam in nature.

Experimental design:

Randomized complete block design (RCBD) under split plot array having 3 replicates was maintained in a field trial to evaluate the effect of boron coated urea application on growth, productivity and nitrogen use efficiency of maize crop.

Crop husbandry:

To prepare a proper seed bed, the soil was tilled 2-3 times with tractor-mounted tillage instruments to a depth of 10-12 cm, followed by planking. Later, an approved maize hybrid "HYCORN-339" was manually planted at 75cm apart ridges and maintained 20 cm plant-to-plant distance. Recommended dose of phosphorus (140 Kg/ha) and potassium (91 Kg/ha) were applied using single super phosphate (SSP) and sulphate of potash (SOP) at basal, respectively, while nitrogen was given according to the set treatments. In further, two different sources of urea coatings ($SOUC_1$= simple urea, $SOUC_2$= boron coated urea) were applied at different nitrogen levels as: ND_0= Control (no application), ND_1= 75%, ND_2= 100%, ND_3= 125%. The recommended number of irrigation was given using tube well waster throughout the crop season. Furthermore, pre-emergence and post-emergence herbicide application was sprayed using S-metolachlor + atrazine (Primaxtra gold 960 EC) at a rate of 740 g a.i. ha^{-1} + 550 g a.i. ha^{-1}, and mesotrine and attrazine (flesto gold 55% SC) at a rate of 687.5 grams a.i. ha^{-1} to keep the reduce the weed-crop competition during crop growing season. In addition, a recommended protocol of Khan *et al*. (2019) was followed tor insect pest control measure in maize crop (Okweche *et al*., 2013). The crop was harvested manually at harvest maturity.

Data collection:

The readings of growth attributes (leaf area index (LAI), leaf area duration (LAD), crop growth rate (CGR), net assimilation rate (NAR), total dry matter (TDM)) were started from 30 days after sowing (DAS) and followed by 15 days interval until 75 DAS from half of the experimental unit. For this, 1m long plant row from every treatment was harvested to record fresh weight (W1) and this sample was placed at 70°C till constant weight for recording TDM or dry weight (W2). A prescribed method of Watson (1947) was used find the leaf area index using the given formula:

$$LAI = \text{leaf area} / \text{land area}$$

Further, LAI was used to find the LAD, CGR, and NAR according to Hunt's (1978):

$$LAD = \frac{LAI_1 + LAI_2}{2} \times 100$$

$$CGR\ (g\ m^{-2}\ day^{-1}) = (W_2-W_1) / (T_2-T_1)$$

Where, T1 and T2 indicated the time taking for W1 and W2, respectively.

$$NAR = TDM / LAD$$

Whereas, yield and yield related parameters were recorded from the plants in remaining half portion of the experimental unit at harvesting stage. The cobs were cut off and sun dried to minimize moisture content in the grain and facilitate shelling. The grains were then separated from the pith using a maize sheller and additional yield and yield-related parameters were recorded using measuring rod and electric balance where applicable. Later, the recorded readings were converted into desired unit using unitary method.

Harvest index (%)

The harvest index was calculated using the following formula:

$$\text{Harvest index } \% = \text{Grain yield} / \text{Biological yield} \times 100$$

Nitrogen use efficiency (NUE):

Nitrogen use efficiency was estimated by following the standard protocol mentioned in Fageria and Baligar (2005)

Statistical analysis:

The recorded observation were examined using Fisher's analysis of variance technique (ANOVA) and their differences were compared using LSD at 5% (Steel *et al*., 1997).

III. Results

Growth and yield-related traits

The results showed a significant effect of nitrogen doses (ND) and source of urea coatings (SOUC) on maize growth, productivity and nitrogen use efficiency in the semi-arid region of Pakistan. Plant height increased up to 213.66 cm with 125% of recommended urea in ND_3 followed by ND_2, and the decreased plant height (178.58 cm) was attained from the control (ND_0) treatment (Table 1). As for sources, urea received boron as coating material gave promising results with a maximum plant height (203.80 cm) than the conventional urea ($SOUC_1$), where no coating was applied (Table 1). Amongst interaction, no significant difference was recorded by increasing the recommended dose of boron-coated urea in ND_3

× $SOUC_2$, while the conventional urea applied at 125% increased plant height up to 210.78 cm. However, the number of cobs/plants remained non-significant (Table 1). Furthermore, the maximum cob length was recorded up to 20.00 cm when boron-coated urea was applied at a rate of 125%, though it was statistically similar to the ND_2 × $SOUC_2$ treatment. In contrast, the most decreased cob length was attained from the control (Table 1).

Table 1: Effect of sources of urea coating and nitrogen doses on growth and yield related characters of maize crop.

Nitrogen Doses (ND)	Plant Height (cm)	No. of cobs per plant	Cob length (cm)
ND_0	178.58 D	1.29	13.05 C
ND_1	202.64 C	1.50	16.90 B
ND_2	208.93 B	1.08	19.02 AB
ND_3	213.66 A	0.83	19.38 A
LSD≤0.05P	2.27	NS	0.49
Sources of Urea coating (SOUC)			
$SOUC_1$	198.10 B	1.08	16.48 B
$SOUC_2$	203.80 A	1.28	17.60 A
LSD≤0.05P	1.61	NS	0.34
Interactions			
ND_0 × $SOUC_1$	177.15 e	1.00	13.103 e
ND_1 × $SOUC_1$	200.42 d	1.33	16.00 d
ND_2 × $SOUC_1$	204.07 c	1.00	18.49 b
ND_3 × $SOUC_1$	210.78 b	1.00	18.73 b
ND_0 × $SOUC_2$	180.00 e	1.58	13.00 e
ND_1 × $SOUC_2$	204.86 c	1.67	17.80 c
ND_2 × $SOUC_2$	213.79 ab	1.17	19.55 ab
ND_3 × $SOUC_2$	216.55 a	0.67	20.02 a
LSD≤0.05P	3.22	NS	0.69

ND_0 = Control; ND_1 = 75% of recommended dose; ND_2 = 100% of recommended dose; ND_3 = 125% of recommended dose, $SOUC_1$ = Conventional urea; $SOUC_2$ = Boron coated urea, P= 0.05%, NS = non-significant

Yield and yield contributing factors

The recorded observation indicated that ND and SOUC significantly impacted the number of grain rows per cob, grains/cob and thousand-grain weight (Table 2). The maximum number of grains rows per cob (20.00) obtained from using boron-coated urea at the rate of 125% of recommendation (ND_3 × $SOUC_2$) was found statistically at par with the conventional urea application (ND_3 × $SOUC_1$), as shown in Table 2. In addition, the highest number of grains/cob was attributed to the 25% higher dose of recommendation in ND_3, which was at par with ND_2 and followed by ND_1 compared to the control (ND_0) treatment (Table 2). Moreover, boron-coated urea gave the utmost number of grains per cob (673.36) than conventional urea application, as shown in Table 2. In addition, ND_3 and ND_2 were statistically similar in thousand-grain weight, whereas the 16.93% decreased thousand-grain weight was computed from the control (ND_0) treatment (Table 2). As for the sources, boron-coated urea elevated a thousand-grain weight (305.46 g), which was 3.30% higher than the $SOUC_1$ treatment (Table 2).

Table 2: Effect of sources of urea coating and nitrogen doses on yield contributing traits of maize crop.

Nitrogen Doses (ND)	No. of grains rows per cob	No. of grains per cob	Thousand grain weight (g)
ND_0	14.00 C	613.50 C	265.49 C
ND_1	15.33 BC	672.00 B	288.09 B
ND_2	16.33 B	682.67 AB	313.06 A
ND_3	19.00 A	694.56 A	319.63 A
LSD≤0.05P	1.57	16.02	7.43
Sources of Urea coating (SOUC)			
$SOUC_1$	15.33 B	658.00 B	295.28 B
$SOUC_2$	17.00 A	673.36 A	305.36 A
LSD≤0.05P	1.11	7.09	5.25
Interactions			
ND_0 × $SOUC_1$	14.00 d	608.67 e	265.54 e
ND_1 × $SOUC_1$	14.00 d	662.00 d	291.66 d
ND_2 × $SOUC_1$	15.33 cd	674.67 cd	306.69 c
ND_3 × $SOUC_1$	18.00 ab	686.67 bc	317.22 a

$ND_0 \times SOUC_2$	14.00 d	618.33 e	265.44 e
$ND_1 \times SOUC_2$	16.67 bc	682.00 bc	314.52 ab
$ND_2 \times SOUC_2$	17.33 bc	690.67 ab	319.44 a
$ND_3 \times SOUC_2$	20.00 a	702.44 a	322.03 a
LSD≤0.05P	2.22	14.18	10.51

ND_0 = Control; ND_1 = 75% of recommended dose; ND_2 = 100% of recommended dose; ND_3 = 125% of recommended dose, $SOUC_1$ = Conventional urea; $SOUC_2$ = Boron coated urea, P= 0.05%, NS = non-significant

Boron-coated urea gave the utmost grain yield (3.73 t/ha) to conventional urea application, whereas the increasing urea application (ND_3) increased the grain yield to 29.28% compared to the control treatment (Table 3). For interaction, the highest grain yield (4.26 t/ha) was recorded when boron-coated urea was given at 125% of the recommended dose and found statistically similar to the $ND_2 \times SOUC_2$ and $ND_1 \times SOUC_2$ treatments (Table 3). Likewise, maximum biological yield (13.90) was achieved by applying boron as a coating agent on conventional urea granules. Furthermore, increasing the nitrogen dosage level maximizes the biological yield up to 14.43 t/ha than 12.55 t/ha recorded in the control treatment (Table 3). Similarly, the maximum value of harvest index (HI) (28.79%) was recorded in a crop that received 125% of the recommended dose and was observed to be similar to the HI from ND_2 treatment. The lowest HI value (23.43%) was attained from the control. Amongst SOUC, boron-coated urea remained superior by 6.03% over conventional urea application (Table 3).

Table 3: Effect of sources of urea coating and nitrogen doses on grain and biological yield, and harvest index of maize crop.

Nitrogen Doses (ND)	**Grain yield (t/ha)**	**Biological yield (t/ha)**	**Harvest index (%)**
ND_0	2.97 C	12.55 C	23.43 C
ND_1	3.86 B	14.02 AB	27.39 B
ND_2	4.07 AB	14.22 AB	27.92 AB
ND_3	4.20 A	14.43 A	28.79 A
LSD≤0.05P	0.21	0.21	1.38
Sources of Urea coating (SOUC)			
$SOUC_1$	3.64 B	13.70 B	26.05 B
$SOUC_2$	3.73 A	13.90 A	27.72 A
LSD≤0.05P	0.15	0.15	0.98
Interactions			
$ND_0 \times SOUC_1$	2.95 c	12.53 d	22.82 d
$ND_1 \times SOUC_1$	3.58 c	13.82 c	26.38 c
$ND_2 \times SOUC_1$	3.91 bc	14.13 b	26.91 bc
$ND_3 \times SOUC_1$	4.13 ab	14.32 ab	28.08 bc
$ND_0 \times SOUC_2$	2.30 c	12.56 d	24.05 d
$ND_1 \times SOUC_2$	4.14 ab	14.21 b	28.41 ab
$ND_2 \times SOUC_2$	4.22 ab	14.31 ab	28.92 a
$ND_3 \times SOUC_2$	4.26 a	14.54 a	29.49 a
LSD≤0.05P	0.30	0.30	1.96

ND_0 = Control; ND_1 = 75% of recommended dose; ND_2 = 100% of recommended dose; ND_3 = 125% of recommended dose, $SOUC_1$ = Conventional urea; $SOUC_2$ = Boron coated urea, P= 0.05%, NS = non-significant

Nitrogen use efficiency (NUE)

Using boron-coated urea resulted in the highest value of NUE (10.44 kg N/kg) compared to the conventional urea application. As for fertilizer, N supply at 125% of recommended provided the highest NUE up to 14.38 kg N/kg, statistically similar to the recommended N application. Amongst interaction, the highest NUE value (14.63 kg N/kg) was recorded when 125% of the recommended dose of boron-coated urea was given in $ND_3 \times SOUC_2$ treatment and observed to similar to the $ND_2 \times SOUC_2$ than control ($ND_3 \times SOUC_2$) treatment (Table 4).

Table 4: Effect of sources of urea coating and nitrogen doses on nitrogen use efficiency of maize crop.

Nitrogen Doses (ND)	NUE (kg N kg^{-1})
ND_0	0.00 C
ND_1	12.07 B
ND_2	13.68 A
ND_3	14.38 A
LSD≤0.05P	1.08
Sources of Urea coating (SOUC)	
$SOUC_1$	9.63 B
$SOUC_2$	10.44 A
LSD≤0.05P	0.76
Interactions	
$ND_0 \times SOUC_1$	0.00 d
$ND_1 \times SOUC_1$	11.33 c
$ND_2 \times SOUC_1$	13.03 b
$ND_3 \times SOUC_1$	14.13 ab
$ND_0 \times SOUC_2$	0.00 d
$ND_1 \times SOUC_2$	12.80 bc
$ND_2 \times SOUC_2$	14.33 ab
$ND_3 \times SOUC_2$	14.63 a
LSD≤0.05P	1.6

ND_0 = Control; ND_1 = 75% of recommended dose; ND_2 = 100% of recommended dose; ND_3 = 125% of recommended dose, $SOUC_1$ = Conventional urea; $SOUC_2$ = Boron coated urea, P= 0.05%, NS = non-significant

IV. Discussions

The results identified tha boron-coated urea augmented the plant height, which could be due to the better nitrogen uptake during the vegetative stage. Our observations are supported by the results of Beig *et al*. (2020), who reported more extensive leaf area index and leaf area duration from coated urea application, which also characterized by fewer nitrogen losses and improved nitrogen use efficiency; as a result, plant height increased (Pooniya *et al*., 2018). Kumar *et al*. (2010) reported similar results with more significant plant height from coated urea application. On the other hand, increasing urea application positively affected plant height (Table 1). The results of Kakar *et al*. (2014) supported the increased maize height with increasing urea application during the vegetative stage (Santiago-Arenas *et al*., 2021).

However, the increasing dose of boron-coated urea did not significantly impact the number of cobs per plant (Table 1), and this observation trend is in line with the outcomes reported by Jansen *et al*. (2015). They further described the number of cobs development as a genetically controlled trait unaffected by the urea application. Others reported that cob development is cultivar-specific and mainly controlled by specific QTL genes, and coated urea did not influence their upregulation (Beulah *et al*., 2018).

Moreover, decreased cob length was recorded from the experimental unit receiving normal urea granules compared to boron-coated urea application, possibly due to the inefficient nitrogen uptake or more considerable nitrogen losses in the environment. The slow release of nitrogen from boron coatings may help augment the cob length, as Mustafa *et al*. (2022) reported better nitrogen uptake from coated urea application. Nitrogen released from coated urea improved the chlorophyll, leaf area, light interception, and photosynthetic production (Beig *et al.,* 2020). These augment the assimilate portioning, increasing the grain rows/cob (Gao *et al*., 2021). Similarly, González Villalba *et al.* (2018) also reported that coated urea maximizes the grain rows development under coated urea application. These findings, confirmed by the observations of Dhakal and Nelson (2019), reported the utmost maize yield under coated urea application.

Higher urea application rate also significantly increased the maize grain yield (Wani *et al*., 2021; Mustafa *et al*., 2022). Maize is mainly receptive to fertilizers, and a larger fertilizer application positively affects crop performance (Liu *et al*., 2022). As for boron coatings, they decrease the release of nitrogen and help in better uptake, resulting in larger amino acid and protein production and, subsequently, increased grain yield (Xing *et al*., 2022). Our results are verified by the observations of Guo *et al*. (2022), who reported high kernel yield due to the slow release of nitrogen from coated urea.

In our experiment, we computed a higher thousand-grain weight and grain yield from boron-coated urea with increasing urea application dose. Fewer nitrogen losses augment the better nitrogen uptake (Jia *et al*., 2021); consequently, nitrogen assimilation and protein formation increased to enhance the thousand-grain weight and grain yield compared to normal urea (Beig *et al*., 2020; Kuchi *et al*., 2021; Tubeileh *et al*., 2023). On the contrary, Adhikari *et al*. (2021) reported a more significant thousand-grain weight due to an ample supply of nitrogen that maximizes photosynthesis and higher assimilate production (Su *et al*., 2020). These supported our results, where thousand-grain weight increased with increasing urea application (Table 2).

Further, higher biological biomass would be because of higher doses of urea throughout the crop-growing season

(Table 3). Our observations are in line with the research study of Leghari *et al*. (2016), who reported increased biomass with urea application at the vegetative growth stage. In contrast, the coated urea extended the nitrogen release and was responsible for higher uptake and less N losses (Beig *et al*., 2020). This further supported our high harvest index value results due to increased grain yield under optimum boron-coated urea application supply. As Hütsch and Schubert (2023) reported, the grain yield is responsible for the harvest index. Nitrogen use efficiency from boron-coated urea was higher than the normal urea treatment observed at the same application rate (Table 4). This increase in NUE may be due to the optimum uptake and utilization of crops. Boron coatings would decrease urea volatilization and leaching, as Timilsena *et al*. (2015) reported less environmental losses from coated urea (Azeem *et al*., 2014). Fan *et al*. (2021) reported decreased N losses and better correspondence of nitrogen release pattern with crop nitrogen uptake from coated urea compared to normal urea application. Similar findings were reported by Ali *et al*. (2020), who observed a significant increase in NUE value using coated urea.

V. Conclusion:

The results indicated that the boron coatings presented promising results for the effective utilization of urea under semi-arid conditions. The enlarged plant height, cob length, maximum grain/cob, grain yield, biomass production and nitrogen use efficiency were noticed with boron-coated urea application compared to simple urea treatment. The boron coatings prevented the urea volatilization and leaching losses of urea, and therefore, higher nitrogen use efficiency was obtained with 100% of the recommended dose of boron-coated urea over the use of 25% extra simple urea in the experiment. Hence, 100% of the recommended dose of boron-coated urea is promising for better grain yield, biomass and NUE than 25% extra use of simple urea for maize grown in semi-arid climatic conditions of Pakistan.

VI. Author's Contribution:

Abdul Ur Rehman- conducted the experiment; Muhammad Umer Chattha and Imran Khan- design the experiment; Muhammad Aftab Ashraf, Muhammad Shakeel Hanif, Aftab Ahmad Khan and Ahmad Hussain- provided resources for experimentation; Abdul Ur Rehman, Rida Batool and Mohammad Moosa- data collection; Abdul Ur Rehman and Muhammad Talha Aslam- wrote the original manuscript; Mina Kharal- reviewed and improved the manuscript; Muhammad Talha Aslam formatted and submitted the final manuscript.

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