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SLOW-RELEASE NITROGEN FERTILIZERS AND THEIR INFLUENCE ON WHEAT GROWTH AND YIELD

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Abstract

Nitrogen is a crucial nutrient required in large quantities by wheat. However, due to its high leaching and volatile potential, coupled with recent price increases, an experiment was designed to minimize nitrogen losses and enhance its efficiency. The study was conducted at the Agricultural Research Farm, Bacha Khan University, Charsadda, from 2019-2021. The experiment followed a Randomized Complete Block design with split-plot arrangements. Three wheat varieties (Pirsabak-2015, Faisalabad 2008, and AAS-2011) were evaluated against two application methods (broadcast and placement) and three nitrogen sources (Urea + DAP, Zinc-coated Urea + DAP, and Urea + Zinc-coated + DAP). Urea was applied in two split doses, while zinc-coated urea and phosphorus were applied at sowing. The results showed significant impacts of variety, application method, and nitrogen source on wheat yield components. Varieties AAS-2011 and Pirsabak-2015 produced the highest yield components, while Faisalabad 2008 performed relatively poorly. Placement application of Urea + Zinc-coated + DAP and Urea + DAP improved yield parameters, whereas Zinc-coated Urea + DAP did not enhance these parameters. Wheat varieties AAS-2011 and Pirsabak-2015 can be recommended for general cultivation using placement application of either Urea + Zinc-coated + DAP or Urea + DAP to increase wheat yield.

Keywords: *Agronomic practice, Fertilizer efficiency, Nutrient uptake, Slow-release nitrogen fertilizers, Sustainable agriculture*

INTRODUCTION

Wheat (*Triticum aestivum* L.) is a vital source of dietary protein and calories for the growing global population (1). Nitrogen (N) is a critical nutrient required at specific growth stages, particularly during grain filling, to optimize yields (2). As a key component of plant hormones, chlorophyll, and vitamins, N plays a central role in crop growth and development (3). Effective N management is crucial for crop yield and quality, and its deficiency can limit productivity (4). Unfortunately, about 67 Tg N yr-1 is lost from arable fields due to leaching, volatilization, and erosion, contributing to environmental pollution and decreased nitrogen use efficiency (5-7).

Enhancing nitrogen use efficiency can be achieved by determining crop N requirements based on soil conditions, avoiding over-fertilization. Zinc (Zn) is an essential micronutrient that promotes wheat growth and development, particularly in Zn-deficient soils (8-10). Slow-release N fertilizers, such as phosphorus-coated and Zn-coated urea, can provide a steady supply of N throughout the growing season. However, the method of fertilizer application also plays a critical role, with placement application potentially reducing waste and environmental pollution compared to traditional broadcast methods.

This study aims to investigate the impact of slow-release N fertilizers and application methods on different wheat varieties in the agro-ecological zone of District Charsadda, with a focus on improving nitrogen use efficiency, crop productivity, and sustainability.

MATERIALS AND METHODS

A field experiment titled "Effect of Slow-Release Nitrogen Fertilizers on Wheat in the Agro-Ecological Zone of District Charsadda" was conducted at the Agricultural Research Farm (ARF), Bacha Khan University, Charsadda. The study evaluated three wheat varieties (Pirsabak-2015, Faisalabad 2008, and AAS-2011) under three nitrogen sources (Urea + DAP, Zinc-coated Urea + DAP, and Urea + Zinc-coated Urea + DAP) and two application methods (broadcast and placement).

The experiment followed a Randomized Complete Block (RCB) design with split plots, each measuring $4.8m^2$ with 30cm row spacing, and replicated three times. A seed rate of 100 kg ha^{-1} was maintained for all wheat varieties. Urea was applied in two split doses, while phosphorus and zinc-coated urea were applied at sowing. Standard agronomic practices, irrigation, and weed control were uniformly applied to all plots.

Data were collected on thousand-grain weight, specific leaf area, leaf area, grain and biological yield, and harvest index. Statistical analysis was performed using Statistix 8.1, and means were compared using the LSD test at a 5% probability level (11).

STATISTICAL ANALYSIS

The data were statistically analyzed using Pearson computer software and the MStatc test, while mean comparisons were conducted using the LSD test at a 5% probability level.

RESULTS

THOUSAND GRAINS WEIGHT (GM)

Analysis of thousand-grain weight data revealed significant impacts of application methods and nitrogen sources (Table I, II). However, variety differences and interactions were non-significant. Placement application resulted in a maximum thousand-grain weight of 34.14g, compared to 31.24g with broadcast application. Among nitrogen sources, Urea + Zinc-coated + DAP produced the heaviest thousand-grain weight (33.73g), followed by Urea + DAP (32.52g), while Zinc-coated Urea + DAP yielded the lowest (31.82g).

Table I. Yield parameters of wheat varieties as affected by nitrogen sources and application methods

Parameters	Nitrogen sources (N)					
	Broadcast			Placement		
	Urea + DAP	Zinc coated urea + DAP	Urea + Zinc coated urea + DAP	Urea + DAP	Zinc coated urea + DAP	Urea + Zinc coated urea + DAP
1000 grains weight (g)	31.22 d	30.45 e	32.07 c	33.82 b	33.2 b	35.39 a
Leaf area (cm^2)	65.52 cd	61.58 d	69.28 bc	72.93 b	70.65 b	78.86 a
Grain yield (kg ha^{-1})	2588 d	2639 d	2796 c	2940 b	2835 c	3196 a
Biological yield (kg ha^{-1})	9045 d	8507 e	10029.33 c	10683 ab	10376 b	10942 a

*LSD for 1000 grains weight (g) at 5% = 0.65, LSD for Leaf area (cm^2) at 5% = 4.75, LSD for Grain yield (kg ha^{-1}) at 5% = 63.12, LSD for Biological yield (kg ha^{-1}) at 5% = 320.9

Table II. Yield parameters of wheat varieties as affected by application methods of nitrogen sources

Parameters	Application methods (M)	
	Broadcast	Placement
1000 grains weight (g)	31.24 b	34.14 a
Leaf area (cm2)	65.46 b	74.19 a
Grain yield (kg ha-1)	2730.37 b	2990.59 a
Biological yield (kg ha-1)	9199.7 b	10667.15 a
Harvest index (%)	29.8 a	28.06 b

The significance of application method and nitrogen source on grain weight can be attributed to nutrient availability and distribution. Placement application allows for closer proximity of nutrients to the crop, resulting in higher grain weight. In contrast, broadcast application may lead to uneven nutrient distribution due to field leveling issues, affecting grain weight. The differences in grain weight due to nitrogen sources suggest that combining nitrogen sources (Urea + Zinc-coated Urea + DAP or Urea + DAP) enhances grain weight, while sole use of coated urea as a nitrogen source produces lower grain weight, likely due to its moisture-dependent release mechanism. These findings are aligned with the previous research (12). Also emphasized the need for efficient nitrogen use in cropping systems to ensure sustainable agriculture. Additionally emphasized the role of micronutrients in enhancing the nutritional quality of staple foods. Further research is needed to explore the interactions between nitrogen sources, application methods, and environmental factors to develop more effective and sustainable nitrogen management strategies for wheat production, as suggested by Ali *et al.*, (2011) in their study on addressing agricultural nitrogen losses in a changing climate (12).

SPECIFIC LEAF AREA (SLA) CM^2 G^{-1}

Data on specific leaf area (SLA) of wheat is presented in Table III, IV and V. Varieties, application methods, and nitrogen sources significantly impacted SLA. Pirsabak 2015 had the highest SLA (284.44 cm^2 g^{-1}), followed by Aass 2011 (279.79 cm^2 g^{-1}) and Faisalabad 2008 (276.51 cm^2 g^{-1}). Placement application resulted in a higher SLA (287.93 cm^2 g^{-1}) compared to broadcast application (272.56 cm^2 g^{-1}).

Nitrogen sources also affected SLA, with Urea + Zinc-coated + DAP producing the highest SLA (289.98 cm^2 g^{-1}), followed by Urea + DAP (277.56 cm^2 g^{-1}) and Zinc-coated Urea + DAP (273.20 cm^2 g^{-1}). Interactions between varieties, application methods, and nitrogen sources significantly impacted SLA. The highest SLA (324.74 cm^2 g^{-1}) was recorded for Pirsabak 2015 with placement application of Urea + Zinc-coated + DAP, while the lowest SLA (269.31 cm^2 g^{-1}) was observed for Faisalabad 2008 with broadcast application of Zinc-coated Urea + DAP.

Table III. Specific leaf area (cm^2 g^{-1}) of wheat varieties as affected by nitrogen sources and application methods

Wheat varieties	Broadcast			Placement			Variety mean
	Urea + DAP	Zinc coated Urea+DAP	Urae+ Zinc coated Urea +DAP	Urea + DAP	Zinc coated Urea+DAP	Urae+ Zinc coated Urea +DAP	
Pirsabak 2015	273.3f-i	271.8gh	274.7fg	285.4c	276.4ef	324.7a	284.4a
Faisalabad 2008	273.0f-i	269.31i	273.9f-h	279.8de	275.3fg	287.5c	276.5c
Aass 2011	272.6f-i	269.9hi	274.2f-h	281.0d	276.2ef	304.5b	279.7b
Mean (MxN)	272.98	270.37	274.33	282.13	276.04	305.63	

*LSD for variety x nitrogen sources x application methods for specific leaf area at 5% =4.37, LSD for varieties at 5% = 1.78

Table IV. Specific leaf area (cm^2 g^{-1}) of wheat varieties as affected by application methods of nitrogen

Wheat Varieties	Application Methods (M)	
	Broadcast	Placement
Pirsabak 2015	273.30d	295.57a
Faisalabad 2008	272.08d	280.94c
Aass 2011	272.30d	287.29 b
Mean (M)	**272.56b**	**287.93a**

*LSD for varieties x application methods for specific leaf area at 5% = 2.52

SLA is a crucial physiological parameter directly correlated with photosynthetic efficiency and yield components. Optimized agronomic practices can improve SLA. The current experiment showed that SLA was significantly affected by varieties, application methods, nitrogen sources, and their interactions. Placement application and combined nitrogen sources (Urea + Zinc-coated Urea + DAP or Urea + DAP) resulted in higher SLA compared to broadcast application and sole use of coated urea. Liu *et al.*, (2020) found that optimized nitrogen application rates and timing improved wheat yield and nitrogen use efficiency (13). Similarly, Zhang *et al.,* (2021) reported that precision nitrogen management enhanced maize productivity and reduced environmental impacts (14). Regarding SLA, research by Wang *et al.,* (2019) showed that SLA is a critical trait for crop growth and yield, and is influenced by nitrogen availability (15). Additionally, Li *et al.,* (2022) found that SLA was positively correlated with photosynthetic rate and grain yield in wheat (16).

Table V. Specific leaf area (cm^2 g^{-1}) of wheat varieties as affected by nitrogen sources

Wheat Varieties	Nitrogen Sources		
	Urea + DAP	Zinc coated Urea+DAP	Urae+ Zinc coated Urea +DAP
Pirsabak 2015	279.40cd	274.15ef	299.77a
Faisalabad 2008	276.44de	272.34f	280.76c
Aass 2011	276.83de	273.13f	289.42b
Mean (N Sources)	277.56b	273.20c	289.98a

*LSD for varieties x nitrogen sources for specific leaf area at 5% = 3.09, LSD for nitrogen sources for specific leaf area at 5% = 1.78

LEAF AREA (CM^2)

Data in Table I and II show that leaf area of wheat was significantly affected by application methods and nitrogen sources. Placement application resulted in a higher leaf area (74.19 cm^2) compared to broadcast application (65.46 cm^2). Among nitrogen sources, Urea + Zinc-coated + DAP produced the highest leaf area (74.07 cm^2), followed by Urea + DAP (69.22 cm^2) and Zinc-coated Urea + DAP (66.18 cm^2).

Leaf area, a crucial physiological parameter, plays a vital role in enhancing yield components through increased photosynthesis. In this experiment, application methods and nitrogen sources significantly impacted leaf area, while variety differences were non-significant. Placement application and combined nitrogen sources (Urea + Zinc-coated Urea + DAP or Urea + DAP) resulted in higher leaf area compared to broadcast application and sole use of coated urea. The effectiveness of coated urea depends on moisture availability, highlighting the need for improved irrigation systems to optimize its use.

Recent studies support the importance of optimized nitrogen management for improving crop productivity. For instance, Wang *et al.,* (2022) observed that nitrogen management strategies significantly impacted wheat yield and nitrogen use efficiency (17). Similarly, Abedi *et al.,* (2021) reported that controlled-release urea improved maize yield and reduced nitrogen losses (18).

The effectiveness of coated urea depends on moisture availability, highlighting the need for improved irrigation systems to optimize its use. Research by Chen *et al.,* (2020) emphasized the importance of integrated nutrient management for enhancing crop productivity and sustainability (19).

GRAIN YIELD (KG HA^{-1})

Analysis of grain yield data revealed significant effects of varieties, application methods, nitrogen sources, and the interaction between application methods and nitrogen sources (Table I, II & VI). Variety Aass 2011 produced the highest grain yield (2855 kg ha^{-1}), while Pirsabak 2015 and Faisalabad 2008 yielded similarly (2818 kg ha^{-1} and 2824 kg ha^{-1}, respectively). Placement application resulted in a higher grain yield (2990 kg ha^{-1}) compared to broadcast application (2730 kg ha^{-1}).

Table VI. Grain yield of wheat varieties as affected by nitrogen sources and application methods

Wheat varieties	Broadcast			Placement			Variety mean
	Urea + DAP	Zinc coated Urea+DAP	Urae+ Zinc coated Urea +DAP	Urea + DAP	Zinc coated Urea+DAP	Urae+ Zinc coated Urea +DAP	
Pirsabak 2015	2273j	2681g-i	2806d-f	3033c	2863de	3251a	2818
Faisalabad 2008	2764e-h	2576i	2777e-g	2889d	2817d-f	3120bc	2824
Aass 2011	2728f-h	2660hi	2806d-f	2897d	2824d-f	3218ab	2855
Mean (MxN)	2588d	2639d	2796c	2940b	2835c	3196a	

*LSD for variety x nitrogen sources x application methods for grain yield at 5% = 109.3, LSD for nitrogen sources x application methods for grain yield at 5% = 63.12

Among nitrogen sources, Urea + Zinc-coated + DAP produced the highest grain yield (2996 kg ha⁻¹), followed by Urea + DAP (2847 kg ha⁻¹), and Zinc-coated Urea + DAP (2737 kg ha⁻¹). The interaction between application methods and nitrogen sources showed that placement application of Urea + Zinc-coated + DAP resulted in the highest grain yield (3196 kg ha⁻¹), while broadcast application of Urea + DAP produced the lowest grain yield (2588 kg ha⁻¹).

Grain yield is the ultimate objective in wheat production, and it can be enhanced through better agronomic practices. The results suggest that placement application and combined nitrogen sources (Urea + Zinc-coated Urea + DAP) promote grain yield. The effectiveness of coated urea depends on moisture availability, highlighting the importance of proper irrigation management. These findings are consistent with previous research, such as Chen *et al.*, (2020), which reported increased grain yield with placement application and slow-release nitrogen sources (19).

Recent studies support these findings, highlighting the importance of optimized agronomic practices for enhancing grain yield. For instance, Ghafoor *et al.*, (2021) reported that precision nitrogen management significantly improved wheat yield and nitrogen use efficiency (20). Similarly, research found that integrated nutrient management practices enhanced crop productivity and sustainability.
This is consistent with findings by Bakhtiari *et al.*, (2014), who reported that optimized nitrogen application methods and sources improved wheat productivity (21).

BIOLOGICAL YIELD (KG HA^{-1})

Data in Table I, II and VII show that biological yield of wheat was significantly affected by varieties, application methods, nitrogen sources, and the interaction between application methods and nitrogen sources. Variety Pirsabak 2015 produced the highest biological yield (10126 kg ha⁻¹), while Faisalabad 2008 had the lowest (9804 kg ha⁻¹). Placement application resulted in a higher biological yield (10667 kg ha⁻¹) compared to broadcast application (9199 kg ha⁻¹).

Table VII. Biological yield of wheat varieties as affected by nitrogen sources and application methods

Wheat varieties	Broadcast			Placement			Variety mean
	Urea + DAP	Zinc coated Urea+DAP	Urae+ Zinc coated Urea +DAP	Urea + DAP	Zinc coated Urea+DAP	Urae+ Zinc coated Urea +DAP	
Pirsabak 2015	9429de	8801fg	10199bc	10723ab	10603ab	11002a	10126.17
Faisalabad 2008	8902ef	8278g	9911cd	10627ab	10219bc	10890a	9804.50
Aass 2011	8804fg	8442fg	9978cd	10699ab	10306bc	10934a	9860.50
Mean (MxN)	9045.00	8507.00	10029.33	10683.00	10376.00	10942.00	

*LSD for variety x nitrogen sources x application methods for biological yield at 5% = 555.9

Among nitrogen sources, Urea + Zinc-coated + DAP produced the highest biological yield (10485 kg ha⁻¹), followed by Urea + DAP (9873 kg ha⁻¹), and Zinc-coated Urea + DAP (9441 kg ha⁻¹). The interaction between application methods and nitrogen sources showed that placement application of Urea + Zinc-coated + DAP resulted in the highest biological yield (10942 kg ha⁻¹), while broadcast application of Zinc-coated Urea + DAP produced the lowest biological yield (8507 kg ha⁻¹).

Biological yield is correlated with proper nutrition and optimized application methods. The results suggest that placement application and combined nitrogen sources (Urea + Zinc-coated Urea + DAP) promote biological yield. The effectiveness of coated urea depends on moisture availability, highlighting the importance of proper irrigation management. These findings are consistent with previous research, which reported increased dry matter production with slow-release nitrogen sources. Mubeen *et al.*, (2019) reported that integrated nutrient management practices significantly improved wheat biological yield and productivity (22). Similarly, research by Hussain *et al.*, (2021) found that precision agriculture practices, including optimized fertilizer application, enhanced crop productivity and sustainability (23). The interaction between application methods and nitrogen sources also significantly impacted biological yield, with placement application of Urea + Zinc-coated + DAP resulting in the highest yield. This is consistent with findings by Ahmed *et al.*, (2020) reported that optimized nitrogen management practices improved wheat productivity and biological yield (24).

HARVEST INDEX (%)

Analysis of harvest index data revealed significant effects of application methods and the interaction between application methods and nitrogen sources (Table II and VIII). Broadcast application resulted in a higher harvest index (29.80%) compared to placement application (28.06%). The interaction between application methods and nitrogen sources showed that broadcast application of Zinc-coated Urea + DAP produced the highest harvest index (31.06%), while placement application of Zinc-coated Urea + DAP resulted in the lowest harvest index (27.34%).

Table VIII. Harvest index of wheat varieties as affected by nitrogen sources and application methods

Wheat varieties	Broadcast			Placement			Variety mean
	Urea + DAP	Zinc coated Urea+DAP	Urae+ Zinc coated Urea +DAP	Urea + DAP	Zinc coated Urea+DAP	Urae+ Zinc coated Urea +DAP	
Pirsabak 2015	29.28b-f	30.52a-c	27.52e-g	28.31d -g	27.01g	29.55a-d	28.70
Faisalabad 2008	31.08ab	31.13ab	28.03d-g	27.20g	27.57d-g	28.75c-g	28.96
Aass 2011	31.02ab	31.52a	28.13d-g	27.16g	27.43fg	29.53a-e	29.13
Mean (MxN)	30.46	31.06	27.89	27.56	27.34	29.28	

*LSD for variety x nitrogen sources x application methods for harvest index at 5% = 2.01

Harvest index, representing the ratio of grain yield to biological yield, is a distinct criterion for evaluating crop performance. In this experiment, application methods and their interaction with nitrogen sources significantly impacted harvest index, while variety differences and nitrogen sources alone had no significant effect. Notably, higher harvest index does not necessarily imply higher grain yield. These findings contrast with previous research, which reported highest harvest index with placement nitrogen, which improved crop index with slow-release nitrogen sources. Shah *et al.*, (2019) observed that nitrogen application methods significantly affected harvest index in wheat, with optimal application methods leading to improved crop performance (25). Similarly, research by Ejaz *et al.*, (2020) highlighted the importance of efficient nitrogen management practices for enhancing crop productivity and harvest index (26).

CONCLUSION

In conclusion, this study highlights the significant impacts of varieties, application methods, and nitrogen sources on wheat yield and its components. The results show that variety Aass 2011 outperformed Pirsabak 2015 and Faisalabad 2008 in terms of grain yield. Placement application of nitrogen sources proved to be more efficient than broadcast application, which resulted in wasted nutrients. Furthermore, the combined use of urea, zinc-coated urea, and DAP promoted wheat yield components. Based on these findings, it is recommended to cultivate variety Aass 2011, adopt placement application of nitrogen sources, and use a combination of urea, zinc-coated urea, and DAP. However, when using zinc-coated urea as a sole nitrogen source, it is essential to ensure adequate moisture conditions through efficient irrigation systems to enhance its availability to the crop. By adopting these practices, wheat yield can be improved, and nutrient use efficiency can be maximized.

Ethical statement:

No ethical issues were raised during the course of study.

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Conflict of interest:

The authors declare no conflict of interest.

Authors` contribution:

Concept: ZH, RA, MW. Plan: ZH, RA. Data analysis: RA, MW. Writing, review and editing: ZH, RA, MW and MF All authors have reviewed and consented to the final version of the manuscript for publication.

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