

Seed coating and band placement of phosphorus improved phosphorus use efficiency and maize productivity

Haroon Zaman Khan¹, Mobeen Arshad¹, Muhammad Atif Shabir^{1,2*}, Asif Iqbal¹, Muhammad Aslam³, Muhammad Farrukh Saleem¹, Muhammad Asad^{1,4} and Mohsin Ali¹

¹ Department of Agronomy, University of Agriculture, Faisalabad 38040, Pakistan

² Cotton Research Sub-Station Rajanpur 33500, Pakistan

³ Department of Plant Breeding and Genetics, University of Agriculture, Faisalabad 38040, Pakistan

⁴ Agricultural College, Northeast Agricultural University, 600 Changjiang Road, Harbin 150030, China

* Correspondence: aatif.shabir@yahoo.com (Shabir MA)

Abstract

Low phosphorus use efficiency (PUE) limits maize productivity in calcareous soils due to severe fixation losses. In this context, improved fertilizer placement strategies such as band placement (BP) and seed coating (SC) may enhance nutrient recovery and contribute to sustainable phosphorus management. A field experiment was conducted to evaluate maize productivity and PUE following seed coating and band placement using di-ammonium phosphate (DAP) and single superphosphate (SSP). Treatments included control (no P), SC with SSP, SC with DAP, BP with SSP, BP with DAP, SC with SSP + BP with SSP, SC with SSP + BP with DAP, SC with DAP + BP with SSP, and SC with DAP + BP with DAP, arranged in RCBD with three replications. The combined application of SC with SSP + BP with SSP produced the highest grain yield (7.72 t ha⁻¹), biological yield (19.33 t ha⁻¹), grains per cob (382.9), 1,000-grain weight (260.3 g), PUE (30.76%), and grain protein content (9.54%). Results indicate that integrating SC and BP improves phosphorus recovery, reduces fixation losses, and enhances maize productivity under alkaline calcareous conditions, supporting circular nutrient management strategies.

Citation: Khan HZ, Arshad M, Shabir MA, Iqbal A, Aslam M, et al. 2026. Seed coating and band placement of phosphorus improved phosphorus use efficiency and maize productivity. *Circular Agricultural Systems* 6: e014 <https://doi.org/10.48130/cas-0026-0013>

Introduction

Phosphorus (P) is one of the most important macronutrients for plant growth and life cycle. To ensure sustainable crop production, judicious use of P is always recommended^[1]. As it cannot be biologically fixed, a large amount of P is applied through fertilizers^[2]. However, globally PUE remains only at 20%^[3], and short-term P recovery is as low as 30%^[4]. This mainly results from higher P fixation into the soil. Approximately 80% of the applied P becomes unavailable to plants because of its immediate fixation into soils^[5]. Moreover, P is adsorbed onto Al oxides and Fe and precipitated with calcium (Ca) and CaCO₃^[6]. P availability is affected by soil type. For example, calcareous soils which are alkaline in nature (pH > 7) and contain 3% CaCO₃ exhibit increased P fixation^[7,8].

The fixation problem can be intensified if a proper fertilization method is not used. When P is broadcast in bulk soil, its fixation is exacerbated due to conversion into insoluble forms^[9]. It is thus important to design suitable P application methods aiming to improve PUE^[10]. One option is band placement (BP), which ensures that the concentration of applied fertilizers is localized near plant roots, thereby enhancing P uptake by plants. Due to minimal exposure to soil, P fixation may also decrease^[11]. This method is particularly suitable for granular fertilizers, as it retains them near the seed in the form of bands, which has been reported to improve PUE and yield^[12]. In general, seed coating with beneficial nutrients can minimize nutrient immobilization problems, consequently improving nutrient use efficiency. Previously, seed treatment with P has been shown to improve its uptake and utilization, with positive effects on the environment^[13,14]. This method also promotes rapid P availability for uptake, particularly during seedling stages, thereby enhancing crop growth and stand establishment^[15,16].

Maize requires a high amount of P to sustain increased growth and yield. Efficient P management is increasingly recognized as an essential component of sustainable and circular agricultural systems, particularly because global phosphate resources are finite, and large proportions of applied phosphorus become immobilized in soils^[4,17]. Improving P use efficiency through innovative fertilizer placement strategies can therefore contribute to more sustainable nutrient management, and reduced environmental losses^[18,19]. Although seed coating and band placement have individually been reported to enhance P availability and plant uptake, limited information is available regarding the combined effectiveness of these approaches under alkaline calcareous soil conditions. Therefore, the present study was conducted to evaluate the effects of seed coating and band placement of different P sources on P use efficiency, and maize productivity. We hypothesized that integrating these two placement strategies would improve P recovery and enhance maize yield under field conditions.

Material and methods

Experimental site

The field experiment was conducted at the Agronomic Research Farm, University of Agriculture, Faisalabad (31.26° N, 73.06° E; 184.4 m above sea level). To determine the pre-experiment physiochemical properties of soils, samples were collected from the topsoil layer (0–30 cm) using an auger (Table 1). The study site is located in a subtropical region.

Table 1. Pre-experiment soil analysis.

Properties	Value
pH	8
EC (dS m ⁻¹)	1.8
Available phosphorus (ppm)	10.4
Potassium (ppm)	180
Organic matter (%)	0.49
Texture	Loam

Experimental design

The experiment was laid out in a randomized complete block design (RCBD) with three replications and a plot size of 3 m × 6 m. Maize (single cross hybrid; 31R88) was grown with the following treatments: control (no P application), SC with SSP, SC with DAP, BP with SSP, BP with DAP, SC with SSP + BP of SSP, SC with SSP + BP with DAP, SC with DAP + BP with SSP, and SC with DAP + BP with DAP. The seedbed was prepared by two ploughings, followed by one planking. Seeds were sown with the dibbling method on the seedbed, maintaining a row spacing of 75 cm and a plant-to-plant distance of 25 cm, using a seed rate of 25 kg ha⁻¹. First irrigation was applied 25 d after sowing, and subsequent irrigations were applied at 15 d intervals until the crop reached the flowering stage. Thereafter, irrigation was applied every 7 d until seed formation. Recommended doses of nitrogen (N) and potassium (K), (250 and 125 kg ha⁻¹, respectively), were applied through urea and sulphate of potash (SOP). For band placement, P was applied at 125 kg ha⁻¹ in bands through a drill at sowing. To ensure comparability among

$$P \text{ uptake (kg ha}^{-1}\text{)} = \frac{P \text{ concentration (\%)} \text{ in plant dry matter} \times \text{Biological yield (kg ha}^{-1}\text{)}}{100}$$

P use efficiency was calculated using the formula as described by Fageria et al. [23].

$$PUE = \frac{\text{Total P uptake (kg}^{-1}\text{) from fertilized plot} - \text{Total P uptake (kg}^{-1}\text{) from unfertilized plot}}{\text{Rate of P applied (kg}^{-1}\text{)}} \times 100$$

Statistical analysis

The data was analyzed using analysis of variance (ANOVA) under RCBD using Statistix 8.1 software. Treatment means were compared using LSD at a 5% probability level.[24].

Results and discussion

Seed germination time differed significantly between SC and BP under different P sources (Table 2). The maximum seed germination time (8.44 d) was at SC with SSP. This was statistically at par under SC with DAP, SC with SSP + BP with SSP, SC with SSP + BP with DAP,

treatments, the total phosphorus application rate was kept equivalent across all fertilized treatments. Differences among treatments were based solely on application method (seed coating, band placement, or their combination), not on total P quantity applied. For seed coating, single superphosphate (SSP) was applied at 70 mg kg⁻¹ of seed, and diammonium phosphate (DAP) 60 mg kg⁻¹ of maize seed. The total amount of P and K, along with half of the N was applied as a basal dose according to the treatments, while the remaining half of the N was applied with the first irrigation.

Observations

From each plot, ten plants were selected randomly. The total number of grains was counted and averaged to record the number of grains cob⁻¹. Grains were weighed to determine the 1,000-grain weight. The mature crop was harvested from each plot separately and sun-dried. The weight of cobs along with stalks was recorded using a digital balance to determine biological yield, which was converted into t ha⁻¹. The cobs were then shelled, and grain weight from each plot was recorded and converted into t ha⁻¹.

The N content of the grain was determined using the micro-Kjeldhal method[20], and the values were multiplied by 6.25 to calculate protein content. Oil content was estimated using the Soxhlet method[21].

Phosphorous was determined using the vanadate-molybdate yellow color procedure[22]. P concentration was quantified by measuring the intensity of the vanadomolybdate yellow color with a spectrophotometer (Shimadzu, UV-1201, Kyoto, Japan).

P uptake was determined as follows:

and SC with DAP + BP with SSP. Improved germination was possible because of immediate access of the plant to P fertilizer during early growth stages, increasing root development through supporting improved root emergence during seed establishment[25]. Combining SC and BP, either with SSP or DAP alone, or in combination (SSP + DAP or DAP + SSP), resulted in a higher no. of grains cob⁻¹. The application of SC with SSP + BP with SSP or SC with DAP + BP with SSP resulted in the maximum 1,000-grain weight (28%–32%), and grain yield (89%–97%). Moreover, biological yield (53%) was highest after application of SC with SSP + BP with SSP. The application of SC with SSP + BP with DAP, SC with DAP + BP with SSP, and SC with DAP + BP with DAP also resulted in a statistically similar

Table 2. Effect of seed coating (SC) and band placement (BP) of phosphorous on yield and yield-related parameters.

Treatments	Germination time (d)	No. of grains cob ⁻¹	1,000-grain weight (g)	Grain yield (t ha ⁻¹)	Biological yield (t ha ⁻¹)
Control	7.85 c	292.1 d	197.7 e	3.92 e	12.66 e
SC with SSP	8.44 a	316.0 c	216.7 de	5.07 d	15.29 d
SC with DAP	8.35 ab	308.9 cd	208.3 e	4.87 d	14.27 d
BP with SSP	7.79 cd	358.0 b	236.0 bcd	6.79 c	17.66 bc
BP with DAP	7.70 d	355.6 b	232.0 cd	6.39 c	17.02 c
SC with SSP + BP with SSP	8.41 ab	382.9 a	260.3 a	7.72 a	19.33 a
SC with SSP + BP with DAP	8.36 ab	359.4 b	236.7 bcd	6.90 bc	18.96 ab
SC with DAP + BP with SSP	8.39 ab	366.6ab	253.7 ab	7.40 ab	18.59 ab
SC with DAP + BP with DAP	8.31 b	361.7ab	237.3 bc	6.96 bc	18.78 ab
LSD value	0.119	22.52	20.25	0.60	1.45

SSP-single super superphosphate. DAP-diammonium phosphate.

Phosphorus application methods in maize

biological yield. The superior performance of combined SC + BP treatments can be attributed to the creation of localized P-rich zones near emerging roots, which enhance early root proliferation and improve nutrient interception^[19,26]. Band placement minimizes soil-fertilizer contact, thereby reducing P fixation in calcareous soils^[27], while seed coating ensures immediate P availability during early growth stages. This synergistic effect likely increased root surface area, improved P diffusion gradients, and reduced immobilization losses^[23]. In general, higher yields, particularly under the combined application of SC and BP with SSP as the P source, was due to the higher availability and uptake of P, thereby reducing early P deficiency and early stress for plants^[28]. As a result of an increase in total number of grains, and 1,000-grain weight, we observed a higher grain yield. Similarly^[29–31], found that BP and SC with P, increased P availability, resulting in a 22%–27% increase in grain and biological yield. In conclusion, SC and BP are the best fertilization strategies to increase maize yield. The combined use of both P application methods could increase maize productivity. However, such outcomes are P source dependent.

Plant P nutrition was significantly influenced by SC and BP under different P sources (Table 3). The highest increases in plant P concentrations were observed in the following order: SC with SSP + BP with SSP > SC with DAP + BP with SSP. Application of SC with SSP + BP with SSP plant P uptake increased by 357%, followed by application of SC with DAP + BP with SSP. Similarly, PUE increased from 263% to 308% following the application of SC with SSP + BP with SSP and SC with DAP + BP with SSP. These results showed that plants proficiently explored P, eventually improving plant P concentration and uptake^[14,16]. Improving P recovery through precise placement strategies contributed to sustainable fertilizer management, and aligned with circular nutrient use principles^[17,32]. Enhanced PUE reduced the requirement for excessive fertilizer inputs, lowered potential environmental losses such as runoff and leaching, and promoted efficient utilization of finite phosphate resources^[18,19]. Thus, the combined use of SC and BP, particularly with SSP proved an improved strategy to increase P availability and uptake and ultimately PUE.

Seed quality indicators showed significant differences across SC and BP treatments (Table 4). Application of BP with DAP or SSP resulted in the highest seed oil content. The minimum seed oil content was observed after the application of SC with DAP + BP with DAP. Seed protein content was highest under the combined application of SC and BP with SSP as the P source. Furthermore, application of SC with DAP + BP with SSP or SC with DAP + BP with DAP resulted in a statistically higher seed oil content. Increased seed protein content was due to higher P uptake, which is a central

Table 3. Effect of seed coating (SC) and band placement (BP) of phosphorus (P) on plant P concentration, plant P uptake and phosphorus use efficiency (PUE).

Treatments	Plant P concentration (%)	Plant P uptake (%)	PUE (%)
Control	0.08 e	10.77 f	0.000 f
SC with SSP	0.14 d	22.02 e	11.25 e
SC with DAP	0.13 d	19.05 e	8.283 e
BP with SSP	0.21 bc	37.19 cd	21.14 cd
BP with DAP	0.19 c	33.52 d	18.19 d
SC with SSP + BP with SSP	0.25 a	49.23 a	30.76 a
SC with SSP + BP with DAP	0.22 abc	42.55 bc	25.42 bc
SC with DAP + BP with SSP	0.23 ab	43.66 ab	26.31 ab
SC with DAP + BP with DAP	0.22 abc	41.71 bc	24.75 bc
LSD value	0.0349	5.85	5.02

SSP-single super superphosphate. DAP-diammonium phosphate.

Table 4. Effect of seed coating (SC) and band placement (BP) of phosphorus on the seed quality.

Treatment	Seed oil content (%)	Seed protein content (%)
Control	3.30 b	6.28 e
SC with SSP	3.69 ab	8.09 cd
SC with DAP	3.46 ab	7.84 d
BP with SSP	3.79 a	8.82 abc
BP with DAP	3.85 a	8.50 bcd
SC with SSP + BP with SSP	2.28 d	9.54 a
SC with SSP + BP with DAP	3.49 ab	8.53 bcd
SC with DAP + BP with SSP	2.57 cd	9.17 ab
SC with DAP + BP with DAP	2.80 c	8.90 ab
LSD value	0.4471	0.765

SSP-single super superphosphate. DAP-diammonium phosphate.

component of the phosphate group in nucleic acids that link DNA or RNA^[33].

From a practical perspective, seed coating requires relatively small fertilizer quantities and can be integrated into existing seed treatment operations, while band placement utilizes conventional drilling equipment^[27]. The combined strategy therefore, represents a feasible and potentially cost-effective approach for improving yield per unit of phosphorus applied, particularly in calcareous soils where fixation losses are high^[32].

Conclusions

This study demonstrates that integrating seed coating and band placement significantly enhances phosphorus use efficiency and maize productivity under alkaline calcareous soil conditions. By reducing fixation losses and improving phosphorus recovery, the combined SC and BP strategy supports sustainable phosphorus management. The approach offers a practical solution for improving fertilizer efficiency in calcareous soils and contributes to long-term nutrient sustainability. Further long-term studies are recommended to evaluate system-level benefits.

Author contributions

The authors confirm their contributions to the paper as follows: study conception and design: Khan HZ, Arshad M, Shabir MA; data collection: Asad M, Ali M; analysis and interpretation of results: Shabir MA, Iqbal A, Aslam M, Saleem MF; draft manuscript preparation: Shabir MA, Khan HZ. All authors reviewed the results and approved the final version of the manuscript.

Data availability

The datasets generated during the current study are available from the corresponding author on reasonable request.

Acknowledgments

The authors acknowledge the Department of Agronomy, University of Agriculture Faisalabad for providing research facilities. This research received no external funding.

Conflict of interest

The authors declare that they have no conflict of interest.

Dates

Received 20 February 2026; Revised 8 March 2026; Accepted 15 March 2026; Published online 9 June 2026

References

- [1] Ryan I. 2002. *Efficient use of phosphate fertilizer for sustainable crop production in WANA*. Phosphate Newsletter. USA: International Fertilizer Development Center (IFDC). pp. 2–5
- [2] Ezawa T, Smith SE, Smith FA. 2002. P metabolism and transport in AM fungi. *Plant and Soil* 244:221–230
- [3] Cordell D, Rosemarin A, Schröder JJ, Smit AL. 2011. Towards global phosphorus security: a systems framework for phosphorus recovery and reuse options. *Chemosphere* 84:747–758
- [4] Syers JK, Johnston AE, Curtin D. 2008. *Efficiency of soil and fertilizer phosphorus use: reconciling changing concepts of soil phosphorus behavior with agronomic information*. Fertilizer and Plant Nutrition Bulletin 18. Rome: Food and Agriculture Organization of the United Nations. 108 pp. doi: [10.1017/S0014479708007138](https://doi.org/10.1017/S0014479708007138)
- [5] Leytem AB, Mikkelsen RL. 2005. The nature of phosphorus in calcareous soils. *Better Crops* 89:11–13
- [6] Memon MY, Khan P, Imtiaz M, Shah JA, Depar N. 2011. Response of candidate wheat variety 'NIA-8/7' to different levels/ratios of nitrogen and phosphorus. *Pakistan Journal of Botany* 43:1959–1963
- [7] Sharif M, Sarir MS, Rabi F. 2000. Biological and chemical transformation of phosphorus in some important soil series of NWFP. *Sarhad Journal of Agriculture* 16:587–592
- [8] Gill MA, Ahmad F, Rahmatullah TA, Tahir MA. 2004. Growth and phosphorus uptake by brassica cultivars grown with adequate and deficient phosphorus levels. *Pakistan Journal of Agricultural Sciences* 41:114–118
- [9] Shah SKH, Aslam M, Khan P, Memon MY, Imtiaz M, et al. 2006. Effect of different methods and rates of phosphorus application in mungbean. *Soil & Environment* 25:55–58
- [10] Iqbal Z, Latif A, Ali S, Iqbal MM. 2003. Effect of fertigated phosphorus on P use efficiency and yield of wheat and maize. *Songklanakarin Journal of Science and Technology* 25:697–702
- [11] Borges R, Mallarino AP. 2003. Broadcast and deep-band placement of phosphorus and potassium for soybean managed with ridge tillage. *Soil Science Society of America Journal* 67:1920–1927
- [12] Grant CA, Flaten DN, Tomasiewicz DJ, Sheppard SC. 2001. The importance of early season phosphorus nutrition. *Canadian Journal of Plant Science* 81:211–224
- [13] Grávalos E, García A, Cuerda JC. 2000. *Seminis vegetable seeds: monograph*. Institute for Regional Development (IDR), University of Seville, Seville, Spain. 26 pp.
- [14] Stramkale V, Jukāma K, Vikmane M, Kondratovičs U. 2004. Ar fosforu apstrādātu rapša sēklu fizioloģiskās darbības izpēte [The study of physiological action of phosphorus-treated rape seeds]. *Agronomijas Vēstis [Latvian Journal of Agronomy]* 6:68–74 (Latvian)
- [15] Ros C, Bell RW, White PF. 2000. Phosphorus seed coating and soaking for improving seedling growth of *Oryza sativa* (rice) cv. IR66. *Seed Science and Technology* 28:391–401
- [16] Peltonen-Sainio P, Kontturi M, Peltonen J. 2006. Phosphorus seed coating enhancement on early growth and yield components in oat. *Agronomy Journal* 98:206–211
- [17] Cordell D, Drangert JO, White S. 2009. The story of phosphorus: global food security and food for thought. *Global Environmental Change* 19:292–305
- [18] Tilman D, Cassman KG, Matson PA, Naylor R, Polasky S. 2002. Agricultural sustainability and intensive production practices. *Nature* 418:671–677
- [19] Shen J, Yuan L, Zhang J, Li H, Bai Z, et al. 2011. Phosphorus dynamics: from soil to plant. *Plant Physiology* 156:997–1005
- [20] Yuen SH, Pollard AG. 1953. Determination of nitrogen in soil and plant materials: use of boric acid in the micro-Kjeldahl method. *Journal of the Science of Food and Agriculture* 4:490–496
- [21] Mohd-Setapar SH, Nian-Yian L, Mohd-Sharif NS. 2014. Extraction of rubber (*Hevea brasiliensis*) seed oil using soxhlet method. *Malaysian Journal of Fundamental and Applied Sciences* 10:1–6
- [22] Chapman HD, Pratt PF. 1962. Methods of analysis for soils, plants and waters. *Soil Science* 93:68
- [23] Fageria NK, Baligar VC, Jones C. 1997. *Growth and mineral nutrition of field crops*. 2nd Edition. New York: Marcel Dekker Inc. 494 pp. www.scirp.org/reference/referencespapers?referenceid=231022
- [24] Steel RGD, Torrie JH, Dickey DA. 1997. *Principles and procedures of statistics: a biometrical approach*. 3rd Edition. New York: McGraw-Hill. pp. 172–177 <https://hdl.handle.net/2324/1001394229>
- [25] Cook RJ, Veseth RJ. 1991. *Wheat health management*. St. Paul, MN: APS Press. 152 pp. www.nhbs.com/wheat-health-management-book
- [26] Holford ICR. 1997. Soil phosphorus: its measurement, and its uptake by plants. *Australian Journal of Soil Research* 35:227–240
- [27] Havlin JL, Tisdale SL, Nelson WL, Beaton JD. 2014. *Soil fertility and fertilization: an introduction to nutrient management*. 8th Edition. New York: Pearson Prentice Hall. 516 pp
- [28] Rehim A, Ranjha AM, Rahamtullah, Waraich EA. 2010. Effect of phosphorus application and irrigation scheduling on wheat yield and phosphorus use efficiency. *Soil and Environment* 29:15–22
- [29] Swiader JM, Shoemaker WH. 1998. In-furrow starter fertilization enhances growth and maturity in early sweet corn. *HortScience* 33:1007–1010
- [30] Holloway RE, Bertrand I, Frischke AJ, Brace DM, McLaughlin MJ, et al. 2001. Improving fertiliser efficiency on calcareous and alkaline soils with fluid sources of P, N and Zn. *Plant and Soil* 236:209–19
- [31] Mazengia W. 2011. Effects of methods and rates of phosphorus fertilizer application and planting methods on yield and related traits of maize (*Zea mays* L.) on soil of Hawassa Area. *Innovative Systems Design and Engineering* 2:315–335
- [32] Withers PJA, Sylvester-Bradley R, Jones DL, Healey JR, Talboys PJ. 2015. Feed the crop not the soil: rethinking phosphorus management in the food chain. *Environmental Science & Technology* 49:6523–6530
- [33] Mengel K, Kirkby EA, Kosegarten H, Appel T. 2001. *Principles of plant nutrition*. 5th Edition. Dordrecht: Springer, Kluwer Academic Publishers. 849 pp doi: [10.1007/978-94-010-1009-2](https://doi.org/10.1007/978-94-010-1009-2)



Copyright: © 2026 by the author(s). Published by Maximum Academic Press, Fayetteville, GA. This article is an open access article distributed under Creative Commons Attribution License (CC BY 4.0), visit <https://creativecommons.org/licenses/by/4.0/>.