International Journal of Advanced Biochemistry Research

ISSN Print: 2617-4693
ISSN Online: 2617-4707
NAAS Rating (2026): 5.29
IJABR 2026; SP-10(1): 287-290
www.biochemjournal.com
Received: 08-10-2025
Accepted: 12-11-2025

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Effect of integrated phosphorus management on yield attributes of maize (*Zea mays* L.)

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DOI: https://www.doi.org/10.33545/26174693.2026.v10.i1Sd.6933

Abstract
A field experiment was conducted during the *Kharif* seasons of 2023 and 2024 at instructional Farm of Rajasthan Collage, MPUAT, Udaipur, Rajasthan, India to evaluate the effect of integrated phosphorus management on yield attributes of maize (*Zea mays* L.) grown on Typic Haplustepts. The experiment consisted of twelve treatments involving different combinations of recommended dose of phosphorus (RDP) through single super phosphate (SSP) and organic sources viz., farmyard manure (FYM), vermicompost (VC), enriched compost (EC) and poultry manure (PM). The treatments were laid out in a randomized block design with three replications. Yield attributes such as cob length, number of cobs per plant and number of grains per cob were recorded and pooled analysis was carried out. The results revealed that integrated application of phosphorus significantly improved all the yield attributes of maize compared to control and sole application of inorganic phosphorus. Among the treatments, application of 50% RDP through SSP + 25% RDP through vermicompost + 25% RDP through enriched compost recorded the maximum cob length (21.38 cm), number of cobs per plant (1.67) and grains per cob (309.53) in pooled data. These treatments were significantly superior to control and remained statistically at par with other integrated phosphorus management treatments. Improved yield attributes under integrated phosphorus management may be attributed to enhanced phosphorus availability, improved soil biological activity and better nutrient synchronization during crop yield. The study concludes that integrated use of inorganic and organic phosphorus sources is an effective strategy for improving yield of maize under Typic Haplustepts.

Keywords: Maize, integrated phosphorus management, SSP, organic manures, yield attributes

Introduction
Maize (*Zea mays* L.) is a globally important cereal crop due to its high yield potential, wide adaptability and diverse uses as food, feed and industrial raw material. In India, maize has emerged as a key crop for ensuring food and nutritional security, particularly in rainfed and semi-arid regions. Crop productivity of maize is strongly governed by balanced nutrient management, among which phosphorus plays a pivotal role in energy transfer, root development, enzymatic activity and grain formation (Brady and Weil, 2017; Havlin *et al.*, 2014) [1, 3].

Phosphorus deficiency is a widespread constraint in many agricultural soils due to fixation with calcium, iron and aluminum compounds, especially in Inceptisols such as Typic Haplustepts. Despite adequate fertilizer application, phosphorus use efficiency remains low, often ranging between 15-25 percent under field conditions, primarily due to fixation and poor synchronization with crop demand (Dhillon *et al.*, 2021; Sharma *et al.*, 2022) [2, 6]. Continuous application of inorganic phosphorus fertilizers alone may further deteriorate soil biological health and reduce long-term sustainability.

Integrated nutrient management, involving the combined use of inorganic fertilizers and organic manures, has gained considerable attention as a sustainable strategy to improve phosphorus availability and soil health. Organic sources such as farmyard manure, vermicompost, enriched compost and poultry manure contribute to gradual phosphorus release through mineralization, reduce fixation losses and enhance soil organic carbon, microbial biomass and enzymatic activity (Manna *et al.*, 2020; Meena *et al.*, 2023) [4, 5]. Improved microbial activity under organic amendments also plays a crucial role in solubilization and mobilization of native and applied phosphorus.

Recent studies have demonstrated that integrated phosphorus management significantly enhances yield attributes and productivity of maize by improving nutrient uptake efficiency and ensuring continuous nutrient supply throughout the crop growth period (Yadav *et al.*, 2021; Singh *et al.*, 2024) [8, 7]. The synergistic effect of organic and inorganic phosphorus sources improves root growth, cob development and grain filling, ultimately resulting in higher yield attributes.

However, limited information is available on the combined use of inorganic phosphorus with multiple organic phosphorus sources under Typic Haplustepts, particularly with respect to yield attributes of maize. Therefore, the present investigation was undertaken to evaluate the effect of integrated phosphorus management on yield attributes of maize under Typic Haplustepts.

Materials and Methods

Experimental site and soil

A field experiment was conducted during the *Kharif* seasons of 2023 and 2024 at the instructional farm of the, Rajasthan College of Agriculture, Maharana Pratap University of Agriculture and Technology Udaipur, Rajasthan, India. The experimental site is located in a semi-arid agro-climatic region of southern Rajasthan. The soil of the experimental field was classified as Typic Haplustepts. Prior to the initiation of the experiment, composite soil samples were collected from the plough layer (0-15 cm) and analyzed for physico-chemical properties using standard procedures. The soil was medium in available nitrogen, phosphorus and potassium with neutral to slightly alkaline reaction.

Experimental design and treatments

The experiment consisted of twelve treatments involving different combinations of recommended dose of phosphorus (RDP) supplied through inorganic and organic sources. The treatments included control, 100 percent RDP through single super phosphate (SSP), and integrated application of SSP with farmyard manure (FYM), vermicompost (VC), enriched compost (EC) and poultry manure (PM) in various proportions (Control (T_1), 100% RDP through SSP (T_2), 75% RDP through SSP + 25% RDP through FYM (T_3), 75% RDP through SSP + 25% RDP through Vermicompost (T_4), 75% RDP through SSP + 25% RDP through Enriched Compost (T_5), 75% RDP through SSP + 25% RDP through Poultry Manure(T_6), 50% RDP through SSP + 25% RDP through FYM + 25% RDP through Vermi Compost (T_7), 50% RDP through SSP + 25% RDP through FYM + 25% RDP through Enriched Compost (T_8), 50% RDP through SSP + 25% RDP through FYM + 25% RDP through Poultry Manure (T_9), 50% RDP through SSP + 25% RDP through Vermi Compost + 25% RDP through Enriched Compost (T_{10}), 50% RDP through SSP + 25% RDP through Vermi Compost + 25% RDP through Poultry Manure (T_{11}), 50% RDP through SSP + 25% RDP through Enriched Compost + 25% RDP through Poultry Manure (T_{12})). The treatments were laid out in a randomized block design (RBD) with three replications.

Crop management practices

Maize (*Zea mays* L.) was grown following recommended agronomic practices for the region. The crop was sown at the onset of the monsoon season using recommended spacing 60 cm x 20 cm. Nitrogen and potassium were applied uniformly to all the treatments as per the recommended dose, while phosphorus was applied according to treatment details. Organic manures were incorporated into the soil before sowing, whereas SSP was applied as basal dose at sowing. Timely irrigation, weed management and plant protection measures were adopted uniformly for all the treatments to ensure normal crop growth.

Observations recorded

Yield attributes such as cob length (cm), number of cobs per plant and number of grains per cob were recorded at the time of harvest. Cob length was measured from randomly selected cobs using a measuring scale. The number of cobs per plant was counted from tagged plants in each plot, and grains per cob were counted from representative cobs.

Statistical analysis

The data collected during both the years were subjected to analysis of variance (ANOVA) appropriate for randomized block design to test the significance of treatment effects. Pooled analysis of data over two years was carried out after testing the homogeneity of error variances. Treatment means were compared using critical difference (CD) at 5 percent level of significance.

Results and Discussion

Effect of integrated phosphorus management on yield attributes of maize

The results clearly demonstrated that integrated phosphorus management significantly influenced the yield attributes of maize during both the years of experimentation as well as in pooled analysis (Table 1). Yield attributes, namely cob length, number of cobs per plant and number of grains per cob, exhibited a consistent increasing trend with the integration of inorganic phosphorus fertilizer with organic sources compared to control and sole application of inorganic phosphorus. This clearly highlights the importance of balanced and integrated nutrient management for improving crop performance under Typic Haplustepts.

Cob length

Cob length is an important yield attribute that reflects the overall nutritional status of the crop during vegetative and reproductive growth stages. In the present study, cob length varied significantly among different phosphorus management treatments. The minimum cob length was recorded under control treatment, which may be attributed to poor phosphorus availability leading to restricted root development, reduced photosynthetic efficiency and limited assimilate translocation towards the developing cob.

Application of 100 percent RDP through SSP significantly increased cob length over control, indicating the positive response of maize to phosphorus fertilization. However, cob length under sole inorganic fertilization remained lower compared to integrated phosphorus treatments, suggesting lower phosphorus use efficiency under exclusive chemical fertilizer application.

The maximum cob length in pooled analysis (21.38 cm) was observed under the treatment receiving 50 percent RDP through SSP + 25 percent RDP through vermicompost + 25 percent RDP through enriched compost. This treatment was statistically at par with other integrated treatments involving combinations of organic manures. The superiority of

integrated treatments may be attributed to continuous and synchronized release of phosphorus from organic sources, reduction in phosphorus fixation and improvement in soil physical and biological properties. Organic manures also stimulate microbial activity, which enhances phosphorus solubilization and availability, thereby promoting better cob development (Manna *et al.*, 2020; Meena *et al.*, 2023) [4, 5].

Number of cobs per plant

Number of cobs per plant is a critical reproductive parameter that determines the yield potential of maize. The results revealed a significant increase in number of cobs per plant with integrated phosphorus management compared to control and sole application of SSP. The lowest number of cobs per plant recorded under control treatment indicates inadequate nutrient supply during critical growth stages, resulting in poor reproductive development.

Integrated treatments involving combined application of inorganic and organic phosphorus sources recorded significantly higher number of cobs per plant. The maximum number of cobs per plant in pooled analysis was observed under the treatment receiving 50 percent RDP through SSP + 25 percent RDP through vermicompost + 25 percent RDP through enriched compost, which was statistically comparable with other integrated treatments.

The increase in cobs per plant under integrated phosphorus management can be attributed to improved phosphorus nutrition, enhanced photosynthetic activity and better partitioning of assimilates towards reproductive organs. Organic amendments improve soil microbial biomass and enzymatic activity, leading to enhanced nutrient availability and uptake efficiency. Improved soil environment under integrated nutrient management supports better crop growth and reproductive development (Yadav *et al.*, 2021; Singh *et al.*, 2024) [8, 7].

Number of grains per cob

Number of grains per cob is directly influenced by nutrient availability during flowering and grain filling stages. In the present investigation, number of grains per cob was significantly affected by different phosphorus management treatments. Control treatment recorded the lowest number of grains per cob, which may be attributed to poor nutrient availability during reproductive stages, resulting in incomplete pollination and poor grain set.

Sole application of SSP significantly increased grains per cob compared to control, but integrated phosphorus treatments recorded markedly higher values. The maximum number of grains per cob (309.53) in pooled analysis was recorded under 50 percent RDP through SSP + 25 percent RDP through vermicompost + 25 percent RDP through enriched compost. This treatment was statistically at par with other integrated treatments, indicating the beneficial role of organic sources in improving grain formation.

Higher grains per cob under integrated phosphorus management may be attributed to improved grain filling due to sustained phosphorus availability, enhanced nutrient uptake and improved metabolic activities during reproductive growth. Organic manures also enhance soil moisture retention and microbial activity, which play a crucial role in nutrient mineralization and availability during grain development (Dhillon *et al.*, 2021; Sharma *et al.*, 2022) [2, 6].

Integrated effect and sustainability perspective

The overall results clearly indicate that integrated phosphorus management is superior to sole inorganic fertilization in improving yield attributes of maize. The synergistic interaction between inorganic phosphorus fertilizer and organic manures ensures immediate as well as sustained nutrient supply, improves soil fertility and enhances phosphorus use efficiency. Organic sources not only supply nutrients but also improve soil structure, organic carbon content and biological activity, which collectively contribute to improved crop performance.

The findings of the present study are in close agreement with earlier reports, which emphasized the importance of integrated nutrient management for enhancing yield attributes and productivity of maize under different agro-ecological conditions (Manna *et al.*, 2020; Yadav *et al.*, 2021; Singh *et al.*, 2024) [4, 8, 7]. Therefore, integrated phosphorus management emerges as a sustainable and efficient strategy for improving maize productivity under Typic Haplustepts.

Table 1: Effect of phosphorus management on cob length, cobs plant^{-1} and grains cob^{-1} of maize

Treatments	Cob length (cm)			Cobs plant^{-1}			Grains cob^{-1}		
	2023	2024	Pooled	2023	2024	Pooled	2023	2024	Pooled
Phosphorus management									
Control (T_1)	13.93	15.37	14.65	1.15	1.23	1.19	224.00	225.73	224.87
100% RDP through SSP (T_2)	15.86	17.02	16.44	1.26	1.32	1.29	241.88	247.16	244.52
75% RDP-SSP + 25% RDP-FYM (T_3)	17.74	18.62	18.18	1.37	1.44	1.41	259.07	267.53	263.30
75% RDP-SSP + 25% RDP-V.C. (T_4)	17.98	19.53	18.75	1.46	1.52	1.49	275.79	289.85	282.82
75% RDP-SSP + 25% RDP-E.C. (T_5)	18.15	18.98	18.57	1.40	1.47	1.44	273.65	280.17	276.91
75% RDP-SSP + 25% RDP-P.M. (T_6)	17.89	18.72	18.30	1.42	1.45	1.44	269.81	276.35	273.08
50% RDP-SSP + 25% RDP-FYM + 25% RDP-V.C. (T_7)	20.38	21.53	20.95	1.60	1.67	1.64	298.36	311.46	304.91
50% RDP-SSP + 25% RDP-FYM + 25% RDP-E.C. (T_8)	19.84	21.60	20.72	1.59	1.66	1.62	294.97	309.91	302.44
50% RDP-SSP + 25% RDP-FYM + 25% RDP-P.M. (T_9)	19.74	21.11	20.42	1.57	1.65	1.61	292.92	308.96	300.94
50% RDP-SSP + 25% RDP-V.C. + 25% RDP-E.C. (T_{10})	20.80	21.96	21.38	1.64	1.70	1.67	304.14	314.91	309.53
50% RDP-SSP + 25% RDP-V.C. + 25% RDP-P.M. (T_{11})	20.51	22.17	21.34	1.63	1.69	1.66	301.04	313.69	307.36
50% RDP-SSP + 25% RDP-E.C. + 25% RDP-P.M. (T_{12})	20.18	21.64	20.91	1.62	1.68	1.65	300.62	312.78	306.70
SEm ±	0.57	0.53	0.28	0.02	0.03	0.01	5.77	6.37	3.04
CD (p = 0.05)	1.68	1.57	0.79	0.07	0.08	0.04	16.94	18.68	8.66

Conclusion

Based on the pooled analysis of two years of experimentation, it can be conclusively stated that integrated phosphorus management had a pronounced and significant effect on yield attributes of maize grown under Typic Haplustepts. The results clearly demonstrated that combined

application of inorganic phosphorus fertilizer with organic sources was superior to control and sole application of inorganic phosphorus in improving cob length, number of cobs per plant and number of grains per cob.

Among the different treatments, application of 50 percent recommended dose of phosphorus (RDP) through single super phosphate in conjunction with 25 percent RDP through vermicompost and 25 percent RDP through enriched compost recorded the highest values of yield attributes in pooled analysis. This treatment proved most effective in enhancing cob development and grain formation due to improved phosphorus availability, better nutrient synchronization and enhanced soil biological activity.

The study further highlighted that integrated phosphorus management not only improves crop performance but also contributes to sustainable soil fertility by reducing phosphorus fixation, enhancing phosphorus use efficiency and improving soil physical and biological properties. Therefore, integrated application of inorganic and organic phosphorus sources may be recommended as a viable and sustainable nutrient management strategy for maize cultivation under Typic Haplustepts

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