PAKISTAN JOURNAL OF AGRICULTURE
ISSN: 3079 – 3866 (ONLINE), 3079 – 3858 (PRINT)
https://isciencepress.com/journals/index.php/pja
Research Article

Bonemeal Biocompost Enhances Wheat Yield and Phosphorus Use Efficiency in Phosphorus Deficient Soil

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Received: 01.02.2025, **Accepted:** 26.02.2025, **Published Online:** 06.03.2025 **DOI:** https://doi.org/10.38211/PJA.2025.02.87

Abstract | Bonemeal biocompost is a valuable organic fertilizer rich in phosphorus (P) and primarily derived from animal bones. A field study was conducted at the experimental fields of the Soil & Environment Research Institute, Agriculture Research Center, Tandojam, to study wheat yield and P use efficiency in relation to different rates of bonemeal biocompost. The experiment was arranged in a randomized complete block design with four treatments involving graded application doses of bonemeal biocompost, viz., T1: 0 kg ha^{-1} (control), T2: 2500 kg ha^{-1}, T3: 3000 kg ha^{-1}, T4: 3500 kg ha^{-1}. Each treatment was replicated thrice. The results showed that the growth and yield parameters, P content, and P use-efficiency of wheat were significantly influenced by different rates of bonemeal biocompost. The application of bonemeal biocompost at 3500 kg ha^{-1} along with recommended doses of nitrogen (N) and phosphorus produced maximum plant height (80.3 cm), numbers of tillers (332.9 m^{-2}), spike length (10.6 cm), number of spikelet spike^{-1} (16.2 cm), number of grains spike^{-1} (39.6), seed index (44.4 g), straw yield (3556 kg ha^{-1}), grain yield (3951 kg ha^{-1}), P content of grain (0.98%) and straw (0.07%), and P use-efficiency (62.9%). The harvest index of various treatments was non-significant. It is concluded from this study that the application of bonemeal biocompost at 3500 kg ha^{-1} significantly improves the growth, yield, P content and P use efficiency of wheat. We suggest further studies to evaluate the efficacy of bonemeal to support and/or lower the use of chemical fertilizers involving different crops, soil types, and climatic conditions.

Keywords: Wheat, Yield, Bonemeal, Biocompost, Phosphorus use efficiency

Introduction

The FAO (2024) estimates the global wheat (*Triticum aestivum* L.) production to be around 800 million metric tons. In Pakistan, around 9.0 million hectares of arable land is utilized to grow wheat, which produces about 26 million metric tons of grain with an average yield of 3.0 Mg ha^{-1} (GoP, 2024).

Phosphorus (P) and nitrogen (N) are essential macronutrients for plant growth and development. However, arable lands in Pakistan exhibit low availability of these nutrients (Mussarat et al., 2021) and require inorganic fertilizer application for optimum crop production. Although it is not feasible to recycle organic wasteland, the substantial use of chemical fertilizers for cereals indicates significant effects on terrestrial ecosystems and promotes the use of these lands for crop cultivation. It has been discovered that wheat responds to the utilization of organic manures, solely or in mix with chemical fertilizers (Xin et al., 2017).

Research studies conducted to evaluate the efficiency of bonemeal biocompost advocate that it serves as an effective P source, enhancing crop production and quality (Chen et al., 2011; Konopka et al., 2012; Stepien & Wojtkowiak, 2015). Regardless, using bonemeal biocompost as a source of compost, it contains high amounts of phosphate and calcium. Furthermore, bonemeal biocompost may also be used as a source of magnesium (Zheng et al., 2022).

Phosphorus is a key macronutrient for plants and an important component of ATPs, phosphate esters, phospholipids, and nucleic acids. It is essential for seed formation, root growth, plant reproduction, photosynthesis, and energy transfer (Lambers, 2022). Fertilizers are a crucial component of agricultural inputs that increase crop yield by assuring the most effective possible nutrient transportation.

Balanced fertilization holds the potential to improve the yield of any crop, particularly on poorly fertile soils (Wang et al., 2021). To recycle vital nutrients in food systems, alternative fertilizers based on biomass and byproducts of various origins have been developed and utilized. Due to its high levels of micronutrients, organic matter (about 700 kg^{-1}), and essential nutrients (N, P, and Ca), bonemeal can serve as a suitable alternative to synthetic fertilizers (Jeng et al., 2006). Many major crops, including oilseeds and cereals, exhibit deficiency symptoms under a P-deficit environment, particularly at the early seedling growth stage (Yan et al., 2022). Usually, the most critical time is between the second and fourth weeks of development, when seedling emergence is occurring and seed P storage is low (Veneklaas et al., 2012). Phosphorus deficiency influences many developmental stages, such as stunted plant growth, low P content, and other disorders that inhibit phenological development (Meng et al., 2021). Plants are capable of enhancing P mobility for improved uptake through various strategies in soils deficient with available P (Ibrahim et al., 2022). One of these strategies involves altering the pH of the rhizosphere by releasing P-mobilizing substances from the roots. Furthermore, altering the length and number of adventitious roots, increasing the number of root hairs, and symbiotic relationships with microbes like mycorrhizal fungi and bacteria (Chen et al., 2006).

Studies have shown that the application of bonemeal enhances nutrient availability, improves soil structure, and promotes plant growth and yield (García-Díaz et al., 2024). Specifically, research has indicated that the utilization of bonemeal as a P source can increase P content in the soil and improve crop productivity. These studies highlight the potential benefits of using bonemeal biocompost, particularly bonemeal, as it improves P availability and crop yield. Keeping in view the above concept, a field experiment was planned to investigate the efficacy of bonemeal biocompost in enhancing growth, yield, and P-use efficiency of wheat

Materials and Methods

Venue of experiment: This field study was conducted at the experimental fields of the Soil & Environment Research Institute, Agriculture Research Center, Tandojam, Sindh, following a randomized complete block design (RCBD) with three replications, involving wheat variety TD-1.

Bonemeal biocompost treatments: Four application doses of bonemeal biocompost were administered, viz., 0 (Control), 2500, 3000, and 3500 kg ha^{-1}.

Nutrient content of bonemeal biocompost: The nutrient content of bonemeal biocompost was determined following standard procedures (Ryan et al., 2001). It contained 10.3% nitrogen, 6.4% phosphorus, and 15.4% calcium.

Fertilizer application: A blanket dose of 168 kg N and 84 kg P_2O_5 was applied to all experimental units. Nitrogen was applied as urea in three equal splits at the time of sowing and second and third irrigation, respectively. While P was applied as SSP at sowing, coupled with bonemeal biocompost.

Soil sampling and analysis: Soil samples were collected from the experimental field at the depth of 0-15 cm and 15-30 cm before wheat sowing and fertilizer application to analyze various soil properties, i.e. texture, EC, pH, organic matter, and ABDTPA extractable P (Ryan et al., 2001).

Harvesting: The crop was harvested at the maturity stage. Five randomly selected plants were harvested from each experimental unit to record various growth and yield parameters.

Plant analysis: Phosphorous content in grain and straw samples was determined using wet digestion method as described by Rashid (1986).

Phosphorus use efficiency: The P-use efficiency was calculated following the formula given by Baligar et al. (2001).

Statistical analysis: The analysis of variance (ANOVA) approach was used to analyze data by computer software Statistix ver.8.1 (Analytical Software, 2023). The LSD test was applied to compare treatment means at alpha 0.05.

Results

Physicochemical properties of soil: The results revealed that soil was classified as clay loam, alkaline-calcareous and low in organic matter and ABDTPA-P content at both depts. However, for the salinity status, the soil was slightly saline and non-saline at 0-15 cm and 15-30 cm, respectively (Table 1).

Table 1. Physicochemical properties of soil used in the experiment

Characteristics	0-15 cm	15-30 cm
Texture	Clay loam	Clay loam
EC (dS m^{-1})	1.42	0.89
pH	7.7	7.8
$CaCO_3$ (%)	17.3	18.5
Organic matter (%)	0.50	0.30
Phosphorous (mg kg^{-1})	2.6	2.3

Growth and yield parameters of wheat: The results regarding the average plant height of wheat crop as affected by bonemeal biocompost are shown in Table 2. The impact on plant height due to different rates of bonemeal biocompost was significant (p <0.05). The tallest plant height (80.3 cm) was obtained from plots receiving 3500 kg bonemeal biocompost ha^{-1}, followed by 3000 kg bonemeal biocompost ha^{-1}, and 2500 kg bonemeal biocompost ha^{-1}, with 71.3 cm and 61.2 cm, respectively.

Table 2. Growth and yield parameters of wheat as affected by bonemeal biocompost

Bonemeal biocompost (kg ha^{-1})	Plant height (cm)	Number of tillers (m^{-2})	Spike length (cm)	Number of spikelets $spike^{-1}$	Number of grains $spike^{-1}$	1000-grain-weight (g)	Grain yield (kg ha^{-1})	Straw yield (kg ha^{-1})
T_1 = 0 (Control)	53.0 d	300.4 d	7.5 d	13.1 c	26.3 d	29.1 d	2425 c	2182 d
T_2 = 2500	61.2 c	312.2 c	8.5 c	14.2 c	32.3 c	32.3 c	2861 c	2575 c
T_3 = 3000	71.3 b	323.8 b	9.1 b	15.6 b	36.8 b	41.0 b	3425 b	3082 b
T_4 = 3500	80.3 a	332.9 a	10.6 a	16.2 a	39.6 a	44.4 a	3951 a	3556 a

Different letters in the same column indicate significant difference by LSD at alpha 0.05 ($p \leq 0.05$)

The different rates of bonemeal biocompost significantly (p <0.05) enhanced the number of tillers (m-2) of wheat (Table 2) with the maximum value recorded (332.9 m^{-2}) in plots received 3500 kg bonemeal biocompost ha^{-1}, followed by 3000 kg bonemeal biocompost ha^{-1}, and 2500 kg bonemeal biocompost ha^{-1}, with 323.8 m^{-2} and 312.2 m^{-2} respectively.

The spike length (cm) of wheat was significantly (p <0.05) improved by bonemeal biocompost (Table 2). The maximum spike length (cm) was noticed (10.6 cm) at 3500 kg bonemeal biocompost ha^{-1}, followed by 3000 kg bonemeal biocompost ha^{-1}, and 2500 kg bonemeal biocompost ha^{-1}, with 9.1 cm and 8.5 cm respectively. However, the control treatment (0 kg bonemeal biocompost ha^{-1}) obtained the minimum spike length.

The results indicated that the average number of spikelets $spike^{-1}$ of wheat crop is affected by bonemeal biocompost (Table 2). The application of bonemeal biocompost substantially enhanced the number of spikelets $spike^{-1}$. The maximum number of spikelets $spike^{-1}$ (16.2) were noticed under the treatment receiving 3500 kg bonemeal biocompost ha^{-1}. The application of bonemeal biocompost at 3000 kg ha^{-1}, and 2500 kg bonemeal biocompost ha^{-1} results in 15.6 and 14.2 spikelets $spike^{-1}$ respectively.

The data regarding number of grains $spike^{-1}$ is presented in Table 2. The maximum value of grains $spike^{-1}$ (39.6) was noticed under the treatment receiving 3500 kg bonemeal biocompost ha^{-1}, followed by 3000 kg bonemeal biocompost ha^{-1}, and 2500 kg bonemeal biocompost ha^{-1}, with 35.4 and 32.3, respectively. Moreover, the minimum value was recorded as 26.3 at 0 kg bonemeal biocompost ha^{-1}, (control).

Weight of 1000 grains of wheat (g) was significantly (p <0.05) altered by bonemeal biocompost fertilization (Table 2). The maximum 1000-grain weight (44.4 g) was recorded at 3500 kg bonemeal biocompost ha^{-1}. Applying bonemeal biocompost at 3000 kg ha^{-1}, and 2500 kg ha^{-1} obtained 39.1 g and 32.3 g average 1000 grains weight, respectively; while the minimum 1000 grains weight (g) was recorded 29.1 in 0 kg bonemeal biocompost ha^{-1}, (control).

The results demonstrated that bonemeal biocompost at different doses improved wheat grain yield (Table 2). The treatment receiving bonemeal biocompost at 3500 kg ha^{-1} obtained the maximum grain yield (3951 kg ha^{-1}). The application of bonemeal biocompost at 3000 kg ha^{-1} and 2500 kg ha^{-1} produced a grain yield of 3424 and 2861 kg ha^{-1}, respectively.

The application of bonemeal biocompost substantially (p <0.05) enhanced the straw yield (kg ha^{-1}) (Table 2). The results from ANOVA revealed that bonemeal biocompost at 3500 kg ha^{-1} achieved the highest straw yield (3556 kg ha^{-1}). Treatments with 3000 kg bonemeal biocompost ha^{-1}, and 2500 kg bonemeal biocompost ha^{-1} recorded a straw yield of 3424 and 2861 kg ha^{-1}, respectively.

Phosphorus concentration of wheat: Grain P concentration as affected by bonemeal biocompost is shown in Table 3. The P content in grain (%) was significantly increased by bonemeal biocompost. The maximum concentration of P in grains (0.98%) was determined at 3500 kg bonemeal biocompost ha^{-1}, followed by 3000 kg bonemeal biocompost ha^{-1} and 2500 kg bonemeal biocompost ha^{-1}, with 0.81 and 0.78 average P content in grain (%) respectively; while the minimum P content in grain (%) was recorded 0.54 in 0 kg bonemeal biocompost ha^{-1}, (control).

Table 3. Phosphorus concentration of wheat as affected by bonemeal biocompost

Bonemeal biocompost (kg ha^{-1})	Straw P (%)	Grain P (%)
T_1 = 0 (Control)	0.05 b	0.54 b
T_2 = 2500	0.06 ab	0.78 ab
T_3 = 3000	0.07 ab	0.81 ab
T_4 = 3500	0.08 a	0.98 a

Different letters in the same column indicate significant difference by LSD at alpha 0.05 ($p \leq 0.05$)

The result regarding P content in straw (%) of wheat crop as affected by bonemeal biocompost is shown in Table 3. The P content in straw (%) was substantially enhanced by the different rates of bonemeal biocompost.

The maximum P content was found to be 0.08% recorded at 3500 kg bonemeal biocompost ha^{-1}. Applying bonemeal biocompost at 3000 kg ha^{-1} and 2500 kg ha^{-1} obtained 0.07% and 0.06% straw P content, respectively.

P use efficiency: The average P-use efficiency (%) of the wheat crop as affected by bonemeal biocompost is shown in Figure 1. The P-use efficiency of wheat due to different rates of bonemeal biocompost was recorded as maximum (62.9%) in plots that received 3500 kg bonemeal biocompost ha^{-1}, followed by 3000 kg bonemeal biocompost ha^{-1}, and 2500 kg bonemeal biocompost ha^{-1}, with 18.0 and 41.2 average P-use efficiency in wheat, respectively.

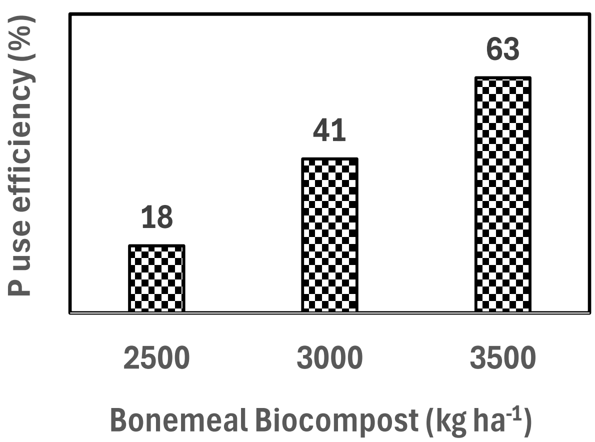

Figure 1. P use efficiency of wheat as affected by bonemeal biocompost

Discussion

Phosphorus deficiency stress due to its reduced availability seriously affects crop yield and produce quality (Meng et al., 2021). Bonemeal biocompost is a novel organic fertilizer rich in P and can be supplied to increase crop yield and P accumulation (Jeng et al., 2006).

The results of the current field experiment revealed that wheat yield and P accumulation and use efficiency were substantially influenced by the application of bonemeal biocompost. The highest application rate of bonemeal biocompost (3500 kg ha^{-1}) attained maximum plant height (80.3 cm), number of tillers (332.9 m^{-2}), spike length (10.6 cm), spikelet's $spike^{-1}$ (16.2), grains $spike^{-1}$ (39.6), seed index (44.4), grain (3951 kg ha^{-1}) and straw yield (3556 kg ha^{-1}), and straw (0.076%) and grain (0.544%) P content. Previous research reflected that adequate P nutrition exerts a positive impact on the growth, yield, and P content of legumes under P deficiency stress (Mohammadi, 2012; Zia-ul-Hassan et al., 2024).

Phosphorus uptake and its use-efficiency of plants, as one of the most important macronutrients, must be understood clearly in order to devise management strategies that augment its use and reduce the input cost of this most important natural resource. This is because wheat requires higher amounts of P nutrition than any other crop (Fageria et al., 2013), and especially in Pakistan, about half of the total P fertilizer consumption is recorded for the wheat crop (GoP, 2024).

Growth of plant roots, cell division, seed growth, and stunted growth of plants are highly affected by phosphorus deficiency. Bio-compost bonemeal (BCBM) fertilizer is an excellent source of P as it contains 6.4% of that nutrient and it can be easily absorbed by plant roots (Zain et al., 2022).

According to Warren et al. (2009) in comparison to chemical source of phosphate, bonemeal biocompost offers a higher supply of accessible P for crops under low P-containing soils. The enhancement of cereal production was witnessed due to adequate P nutrition. It was reported that P contributed significantly to key physiological processes of plants during the entire growth period, especially during the tillering and grain-filling stages (Adnan et al., 2022). Other researchers (Yosefi et al., 2011) also witnessed a two-fold increased harvest index of maize by the application of Bio-phosphate along with balanced chemical fertilization, when compared to the use of chemical fertilizers alone. Moreover, the application of bonemeal biocompost significantly enhanced growth, biomass production, and macronutrient contents of wheat (García-Díaz et al., 2024).

Wheat needs a higher P content in the soil than some other crops. Growth of plant roots, cell division, seed growth, and stunted growth of plants are highly affected by P-deficient soils. As P is an important mineral nutrient for plants, the pattern of P-use efficiency and its uptake from soil must be well-evaluated to make management decisions regarding its wise use for a better environment and low-input sustainable agriculture (Fageria et al., 2013).

Conclusion

Bonemeal biocompost and commercial phosphorus fertilizers significantly increased growth, yield, and P accumulation and use-efficiency of wheat. The present study concludes that the application of bonemeal at 3500 kg ha^{-1} along with the recommended doses of N and P can enhance wheat productivity and P accumulation. Future studies are suggested for the validation of the results of this research.

Acknowledgements

This research study received no outside funding.

Author Contribution

NAT: Conceived idea, executed field study, analyzed data, edited all drafts of MS; NJD: Conducted field trial, collected data, performed chemical analyses, wrote initial draft of MS; KHT: Validated data analyses, helped in results interpretation; SAQ & HSR: Presentation of data;

IAJ: Literature review, format and style, revision of all drafts of MS. All authors approved and assumed the responsibility of the content of MS.

Conflict of Interest

No competing interests are disclosed by the authors.

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