

Augmenting Seed Potato Yield Through Nutritional Protocols and Investigating Their Residual effect on Spring Maize

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Abstract

Punjab, contributing over 85% of India's seed potato demand, faces a paradox of high production area but suboptimal productivity due to imbalanced nutrient management, particularly phosphorus. A field study was conducted over two years at two sites (Ludhiana and Jalandhar) to evaluate the effect of integrated phosphorus management—using organic amendments (farmyard manure and biofertilizer) and graded phosphorus levels—on the growth, yield, and seed efficiency of potato and its residual impact on subsequent spring maize. Results revealed that farmyard manure (FYM) significantly enhanced dry matter accumulation, tuber bulking rate, and seed tuber yield, with average increases in medium-sized tuber yield by 21–28% and total tuber yield by 16–22% over the unfertilized control. Phosphorus application at 125 kg P₂O₅ ha⁻¹ further improved yield attributes, resulting in 14–19% higher total tuber yield compared to lower P levels. Seed production efficiency was maximized (up to 38.72) under FYM and high phosphorus regimes, indicating improved resource utilization. Notably, the residual phosphorus from potato treatments positively influenced spring maize, with FYM plots showing 8.2–11.5% yield enhancement over the control, highlighting sustained soil fertility benefits. The findings underscore the value of integrating organic and mineral phosphorus sources for sustainable seed potato production while maintaining productivity in succeeding maize crops.

Keywords: Seed potato, phosphorus, Tuber yield, Spring maize, Biofertilizer

Introduction

Punjab plays a crucial role in fulfilling the nation's seed potato requirements, accounting for approximately 85% of the demand, with around 60% of its potato-growing area dedicated to seed production (Thind *et al.*, 2007). However, despite its dominance in seed potato production, the region's productivity remains suboptimal, primarily due to inadequate nutrient management. Phosphorus, the second most limiting nutrient after nitrogen, is essential for optimizing tuber yield, enhancing dry matter content, and improving the crop's resistance to diseases (Kelling *et al.*, 2020). It plays a pivotal role in tuber initiation and

development, particularly during the early growth stages, and influences the maturity of the crop at later stages. A sufficient phosphorus supply is critical for maximizing both the number and size of tubers, making its management key to overall productivity. Several studies have confirmed the beneficial effects of phosphorus on potato yields, showing that higher phosphorus levels improve tuber formation, leaf area development, and dry matter accumulation (Rosen and Bierman, 2008; Cui *et al.*, 2020). Conversely, insufficient phosphorus hampers these physiological processes, reducing the crop's potential for optimal tuber



production. Potatoes have higher phosphorus needs than most cereals, making the integration of organic, inorganic, and microbial phosphorus sources essential to enhance nutrient-use efficiency and ensure adequate nutrient supply. In Punjab, the overuse of phosphorus fertilizers has led to soil accumulation, diminishing nutrient uptake efficiency, and adversely affecting seed potato quality over time (Fernandes *et al.*, 2014). Hence, optimized phosphorus management strategies are needed to enhance tuber yield and quality while maintaining soil fertility. This study not only evaluates the effects of organic sources and phosphorus levels on potato growth, yield, and tuber distribution but also assesses the residual impact of these phosphorus treatments on succeeding spring maize crops. The residual phosphorus effect on maize is significant, as it influences nutrient availability in the soil, thereby affecting maize yield and growth. Previous studies have shown that phosphorus applied in one cropping season can have lasting effects on subsequent crops, enhancing nutrient availability and improving crop productivity (Kelling *et al.*, 2020; Sanderson *et al.*, 2003). This research examines how different phosphorus levels and organic amendments influence both seed potato production and its residual effect on spring maize, providing insights into sustainable nutrient management practices.

Materials and Methods

The field experiments were conducted during Autumn 2019-20 and 2020-21 at two locations in Punjab: the School of Organic Farming, PAU Ludhiana, and a farmer's field in Jalandhar. Both sites lie in the subtropical, semi-arid region of north-west India. Ludhiana (30°56' N, 75°52' E; 247 m AMSL) falls in the Trans-Gangetic agro-climatic zone and experiences hot, dry summers (April–June), hot and humid monsoon months (July–September), and cold winters (November–January). Temperatures range from above 46°C in June to below 5°C in December. About 75% of its annual 759 mm rainfall occurs during July–September. Jalandhar (31°32' N, 75°57' E; 228 m AMSL) has similar climatic conditions, with summer temperatures often exceeding 39°C and winter temperatures occasionally dropping below 6°C. The average annual rainfall is 703 mm. Soil characteristics of both sites are presented in Table 1. The soils at both locations were low in organic carbon, neutral to slightly acidic in reaction, and medium in available NPK. Ludhiana soil was loamy sand, while

Jalandhar soil was sandy loam. The experimental fields were initially prepared by two passes with a disc harrow, followed by two ploughings using a tractor-drawn cultivator and subsequent planking to achieve a fine tilth. The short-duration potato cultivar 'Kufri Pukhraj' (70–90 days maturity) was selected for field trials at both locations. Medium-sized seed tubers (3.5–4.5 cm size of tuber) were planted during mid-autumn—on 9 October 2019 and 16 October 2020 at Ludhiana, and 28 October 2019 and 13 November 2020 at Jalandhar—in gross plots measuring 3.25 m × 4.05 m, maintaining row and plant spacing of 65 cm and 15 cm, respectively, with a seed rate of 4.5 t/ha. Immediately after planting, irrigation was applied to ensure uniform emergence, followed by five irrigations during the crop season. The crop was raised following the recommended package of practices for seed potato by the Punjab Agricultural University, Ludhiana. (POP) A fertilizer dose of 187.5 kg N and 62.5 kg K₂O per hectare was applied through urea and muriate of potash, respectively. Half of the nitrogen and the full potassium, FYM, Biofertilizer dose were applied at sowing, while the remaining nitrogen was top-dressed at 30 days after sowing (DAS). Dehaulming was carried out on 3 January 2019 and 11 January 2020 at Ludhiana, and on 1 February 2019 and 15 February 2020 at Jalandhar. After the harvest of potato, spring maize was sown each year to assess the residual effect of organic manure and phosphorus nutrition. Standard agronomic practices recommended for spring maize in the region were followed.

Dry matter accumulation (DMA) in potato haulm and tubers was recorded at haulm cutting. Two representative plants were randomly selected from each treatment plot during each sampling event. The haulm and tubers were separated, and fresh weights were recorded. Samples were then oven-dried at 65 °C to a constant weight to determine the dry matter content, expressed in grams per plant. Tuber bulking rate (TBR), indicating the rate of dry matter accumulation in tubers, was calculated for the 30–45 DAS period using the formula: $TBR = (M_2 - M_1) / \text{days of bulking}$, where M_2 and M_1 represent the final and initial tuber dry weights, respectively. The TBR was expressed in grams per square meter per day ($\text{g m}^{-2} \text{day}^{-1}$). At haulm cutting, the average tuber weight per plant was determined by dividing the total tuber weight by the number of tubers per plant. For marketable seed yield assessment, tubers were graded into five size categories:



Table 1: Effect of organic sources and phosphorus nutrition on dry matter accumulation of seed potato at Haulm cutting

Treatment	DMA in haulm (g plant ⁻¹)				DMA in tubers (g plant ⁻¹)			
	Ludhiana		Jalandhar		Ludhiana		Jalandhar	
	2019	2020	2019	2020	2019	2020	2019	2020
Organic source								
Control	19.5	21.1	21.7	17.5	44.8	45.8	47.3	41.5
Biofertilizer	23.6	25.6	27.3	21.0	51.1	53.7	56.3	48.8
FYM	29.2	31.5	33.0	25.9	64.3	67.4	70.3	60.2
LSD	2.1	1.2	2.4	1.5	4.5	4.9	6.1	2.2
Fertilizer phosphorus (Kg/ha)^b								
0	20.4	22.0	22.7	18.1	44.8	45.8	47.4	42.0
46.9	22.7	24.7	26.2	20.4	50.3	52.8	54.9	47.5
62.5	24.0	26.0	27.4	21.4	53.3	55.6	58.0	50.2
93.8	25.9	27.9	29.2	22.9	57.3	59.1	62.7	53.9
125	27.6	29.6	31.3	24.5	61.3	64.1	66.8	57.2
LSD	1.9	2.4	2.7	1.9	5.2	4.2	6.4	3.7

Table 2: Effect of organic sources and phosphorus nutrition on growth attributes of seed potato

Treatment	Tuber bulking rate (g m ⁻² day ⁻¹) 30-45 DAS				Average tuber weight (g)			
	Ludhiana		Jalandhar		Ludhiana		Jalandhar	
	2019	2020	2019	2020	2019	2020	2019	2020
Organic source^b								
Control	3.91	4.12	4.42	3.56	45.3	42.8	36.9	48.7
Biofertilizer	4.44	4.80	5.21	4.15	46.8	44.7	38.9	50.0
FYM	5.50	5.96	6.43	5.18	48.0	46.6	40.1	51.9
LSD	0.37	0.37	0.54	0.21	1.5	2.8	1.4	NS
Fertilizer phosphorus (Kg/ha)^b								
0	3.89	4.12	4.42	3.58	46.3	43.7	37.4	49.3
46.9	4.35	4.70	5.06	4.06	46.7	44.5	38.5	50.3
62.5	4.60	4.96	5.35	4.30	46.7	44.8	38.8	50.3
93.8	4.95	5.33	5.78	4.63	46.8	45.1	38.8	50.1
125	5.29	5.71	6.15	4.92	47.1	45.5	39.7	50.9
LSD	0.42	0.42	0.58	0.36	NS	NS	NS	NS

under-sized (<25 mm), small-sized (25–35 mm), medium-sized (35–45 mm), large-sized (45–55 mm), and over-sized (>55 mm) using grading boards. However, only medium-sized and total tuber yield data were recorded. Yields from each treatment plot were extrapolated to a per-hectare basis. Seed production efficiency was calculated as the proportion of seed-sized tubers (35–55 mm) to the total tuber yield. At physiological maturity, grain yield was recorded by harvesting the central net plot area of each treatment. The harvested cobs were sun-dried, shelled, and the grain moisture content was adjusted to recommended

level before yield was computed and expressed in tonnes per hectare (q ha⁻¹).

Result and Discussion

Growth attributes of seed potato

At the haulm cutting stage, dry matter accumulation (DMA) in haulm was significantly enhanced by both organic amendments and phosphorus fertilization across Ludhiana and Jalandhar during 2019 and 2020. Among organic sources, FYM consistently recorded the highest haulm DMA (Ludhiana: 29.2 and 31.5 g plant⁻¹; Jalandhar: 33.0 and 25.9 g plant⁻¹ in 2019 and 2020,



respectively), followed by Biofertilizer applied at sowing time (23.6–27.3 g plant⁻¹), while the unfertilized control recorded the lowest values (17.5–21.7 g plant⁻¹). Similarly, increasing levels of phosphorus significantly improved haulm DMA, with the highest values observed at 125 kg P ha⁻¹ (Ludhiana: 27.6 and 29.6 g plant⁻¹; Jalandhar: 31.3 and 24.5 g plant⁻¹), which were statistically comparable to 93.8 kg P ha⁻¹, and significantly superior to the unfertilized control (P₀), which recorded the lowest DMA (18.1–22.7 g plant⁻¹). No significant interaction was observed between the organic source and the phosphorus level. The superior performance of FYM and higher P doses may be attributed to enhanced plant vigor and greater leaf area index (LAI), leading to increased photosynthate accumulation in the haulm, aligning with earlier findings by Naghdi *et al.* (2021) and Kumar *et al.* (2007).

The application of organic sources (FYM @ 50 t/ha) and phosphorus fertilization significantly influenced tuber bulking rate (TBR) during the 30–45 DAS interval across both Ludhiana and Jalandhar. Among the organic amendments, FYM resulted in the highest TBR at this stage (Ludhiana: 5.50 and 5.96 g m⁻² day⁻¹; Jalandhar: 6.43 and 5.18 g m⁻² day⁻¹ in 2019 and 2020, respectively), followed by biofertilizer, with the unfertilized control recording the lowest TBR (3.56–4.42 g m⁻² day⁻¹). A similar trend was observed among phosphorus levels, where 125 kg P ha⁻¹ consistently produced the highest TBR (Ludhiana: 5.29 and 5.71; Jalandhar: 6.15 and 4.92 g m⁻²

day⁻¹), significantly outperforming the unfertilized control (P₀), which showed the lowest rates. The interaction between organic source and phosphorus level was non-significant. In terms of average tuber weight, FYM treatment recorded the highest values across locations and years (Ludhiana: 48.0 and 46.6 g; Jalandhar: 40.1 and 51.9 g), whereas the control showed the lowest values (Ludhiana: 45.3 and 42.8 g; Jalandhar: 36.9 and 48.7 g). Notably, phosphorus fertilizer levels did not significantly affect average tuber weight at either location. These results suggest that FYM, through improved soil structure and nutrient availability, enhances early tuber bulking and tuber size, corroborating findings by Meena *et al.* (2016), Rosen and Bierman (2008), and Paul *et al.* (2016), while the limited effect of phosphorus on tuber weight aligns with observations by Nyiraneza *et al.* (2017).

Yield attributes of seed potato

Application of farmyard manure (FYM) significantly improved both medium-sized (35–45 mm) and total tuber yields of seed potato at Ludhiana and Jalandhar during 2019 and 2020 (Table 3). FYM recorded the highest medium-sized tuber yields, ranging from 95.9 to 113.6 q ha⁻¹ at Ludhiana and 108.0 to 139.0 q ha⁻¹ at Jalandhar, followed by biofertilizer, while the lowest yields were observed under the unfertilized control. Similarly, total tuber yield was highest with FYM (339.8–349.7 q ha⁻¹ at Ludhiana; 322.6–363.3 q ha⁻¹ at Jalandhar), indicating a

Table 3: Effect of organic sources and phosphorus nutrition on the yield of seed potato

Treatment	Medium-sized (35-45 mm) (q ha ⁻¹)				Total tuber yield (q ha ⁻¹)			
	Ludhiana		Jalandhar		Ludhiana		Jalandhar	
	2019	2020	2019	2020	2019	2020	2019	2020
Organic source^b								
Control	70.6	84.5	100.2	79.5	265.0	269.2	277.6	251.6
Biofertilizer	79.1	94.4	116.5	88.1	290.5	299.5	315.1	281.0
FYM	95.9	113.6	139.0	108.0	339.8	349.7	363.3	322.6
LSD	6.4	9.7	9.2	6.3	17.9	18.8	22.0	17.7
Fertilizer phosphorus (Kg/ha)^b								
0	69.0	82.8	99.0	77.1	266.9	269.2	280.1	255.3
46.9	77.3	91.6	112.7	86.5	289.6	298.0	309.6	277.1
62.5	82.1	97.1	119.4	92.3	298.1	306.4	318.9	285.0
93.8	86.8	104.1	126.3	97.9	312.2	321.5	335.6	298.5
125	94.2	111.9	135.5	105.5	325.5	334.9	349.0	309.5
LSD	7.5	7.8	9.4	7.8	21.2	22.4	25.8	20.2

^bInteraction between organic sources and fertilizer phosphorus was non-significant



positive role of organic matter in enhancing soil structure, microbial activity, and nutrient availability, thereby supporting higher productivity. Among phosphorus treatments, the application of 125 kg P₂O₅ ha⁻¹ resulted in significantly higher medium-sized tuber yields (94.2–111.9 q ha⁻¹ at Ludhiana; 105.5–135.5 q ha⁻¹ at Jalandhar) and total tuber yields (325.5–334.9 q ha⁻¹ at Ludhiana; 309.5–349.0 q ha⁻¹ at Jalandhar), compared to other P levels and the control. These findings are consistent with those of Kumar *et al.* (2007) and Nyiraneza *et al.* (2017), who reported enhanced tuber yield and quality with FYM and higher phosphorus doses. The improvements in yield may be attributed to better phosphorus-induced root growth, greater nutrient uptake, and improved translocation of assimilates to tubers (Kelling *et al.*, 2020). However, the interaction effects between organic sources and phosphorus levels were found to be non-significant, indicating their independent contributions to yield enhancement. These results reinforce the importance of integrated nutrient management using organic amendments and optimal phosphorus fertilization in sustainable seed potato production systems.

Seed production efficiency

The heatmap illustrates the variation in seed production efficiency under different phosphorus fertilizer rates and organic manures (Biofertilizer and Farmyard Manure

- FYM) across two agroecological sites (Ludhiana and Jalandhar) over two consecutive years (2019 and 2020). Higher seed production efficiency was consistently recorded with FYM and 125 kg P ha⁻¹ across both site-years, reaching a maximum of 38.72 at Jalandhar in 2019 under FYM treatment. In contrast, the lowest efficiency (8.81) was observed in Jalandhar during 2020 under the 46.9 kg P ha⁻¹ treatment. Biofertilizer-treated plots generally showed lower efficiency compared to mineral P sources and FYM. The color gradient represents the efficiency levels, ranging from lower values (blue shades) to higher values (red shades), thereby enabling a visual comparison of treatment effects across environments.

Residual impact on spring maize

The residual effect of organic amendments and phosphorus fertilization on the grain yield of spring maize was evaluated at Ludhiana and Jalandhar in the years 2020 and 2021 (Table 4). At both locations, farmyard manure (FYM) exhibited the highest yield, with Ludhiana recording 60.0 q/ha in 2020 and 63.4 q/ha in 2021, while Jalandhar produced 64.7 q/ha in 2020 and 59.7 q/ha in 2021. Application of biofertilizer resulted in marginally lower yields, with Ludhiana yielding 56.7 q/ha in 2020 and 58.5 q/ha in 2021, and Jalandhar recording 61.2 q/ha in 2020 and 55.0 q/ha in 2021. The control treatment yielded the lowest, at 55.6 q/ha in 2020 and 56.9 q/ha in 2021 at

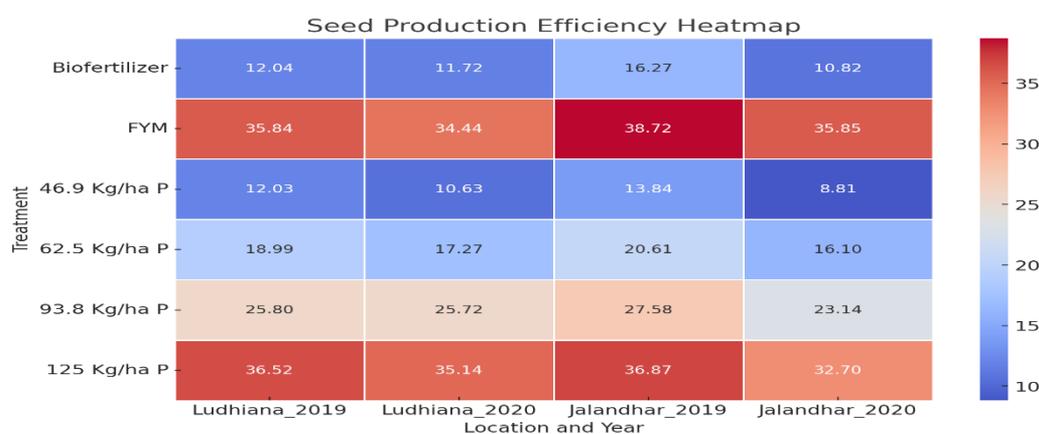


Fig. 1: Seed production efficiency of seed potato during 2019-2020 and 2020-21 at both locations.

Ludhiana, and 59.8 q/ha in 2020 and 53.3 q/ha in 2021 at Jalandhar. The FYM treatment resulted in a substantial yield increment of 8.9% (2020) and 11.5% (2021) over the control at Ludhiana, and 8.2% (2020) and 11.9% (2021) at Jalandhar, underscoring the positive residual effect of organic matter. In contrast, varying phosphorus application

rates did not produce statistically significant effects on the grain yield of spring maize. Phosphorus treatments yielded consistent results, with the highest observed yield of 63.3 q/ha in 2021 at Ludhiana and 57.3 q/ha at Jalandhar, both at the 125 kg/ha P₂O₅ rate. Despite some fluctuations in yield, the percentage increase due to phosphorus was



minimal, with no discernible interactions between organic source and phosphorus levels. This suggests that the residual effect of phosphorus fertilization applied to the preceding potato crop did not meaningfully alter maize yield in the subsequent growing season. The residual effect of farmyard manure (FYM) applied to potato significantly enhanced spring maize yield across locations, attributed to improved nutrient release, microbial activity, and soil health. This aligns with Thind *et al.* (2007), who reported increased productivity in potato–sunflower systems

due to FYM-induced improvements in phosphorus availability and organic matter. Similarly, Sheoran *et al.* (2017) emphasized FYM’s role in sustaining soil fertility, biological activity, and nutrient use efficiency in sequential cropping. In contrast, residual phosphorus had no significant impact, likely due to its fixation in soil and limited mobility. Thus, integrated nutrient management using FYM and biofertilizers is key for sustaining yields in potato–maize systems under semi-arid conditions (Thind *et al.*, 2007; Sheoran *et al.*, 2017).

Table 4: Effect of organic sources and phosphorus nutrition applied in potato on grain yield of spring maize (Residual effect)

Treatment	Spring maize - Grain yield (q/ha) ^a			
	2020		2021	
	Ludhiana	Jalandhar	Ludhiana	Jalandhar
Organic source				
FYM	60.0	64.7	63.4	59.7
Biofertilizer	56.7	61.2	58.5	55.0
Control	55.6	59.8	56.9	53.3
LSD	2.4	2.4	2.2	2.1
Fertilizer phosphorus (Kg/ha)				
46.9	56.4	60.8	58.5	55.0
62.5	57.3	61.8	59.5	56.0
93.8	58.7	63.1	61.0	57.1
125	58.9	63.3	61.1	57.3
0	56.0	60.4	58.0	54.6
LSD	NS	NS	NS	NS

Authors’ contributions

CSA and ASS- compiled and edited the manuscript; AS helped in the statistical analysis of the findings and in editing of the manuscript.

Conflict of interest

The authors declare that they have no conflict of interest.

Ethical Approval

The article doesn’t contain any study involving ethical approval.

Use of Generative AI or AI assisted technologies

Authors declare that no Generative AI or AI assisted technologies have been used in preparation of this manuscript.

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