



RESEARCH ARTICLE

Legume intercropping and phosphorus management enhance the productivity and profitability of winter maize in calcareous soil

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Abstract

Winter maize exhibits an extended growth duration. Due to this longer growth period, it requires greater nutrient inputs, particularly phosphorus (P). However, in calcareous soils, a substantial portion of applied P becomes fixed due to reactions with calcium and magnesium, forming insoluble calcium-phosphate complexes. Additionally, the low soil temperature during the winter season further decreases phosphorus mobility and diffusion in the rhizosphere, thereby reducing its availability for plant uptake. Winter maize is sown in October–November and shows limited growth until mid-February, offering a suitable window for intercropping. The field experiment was conducted at Dr. Rajendra Prasad Central Agricultural University (RPCAU), Pusa, Bihar during the rabi season of 2024 and 2025, comprising 2 factors that were laid out in split plot design (SPD) with 3 intercrop combinations and 5 nutrient management practices in 3 replications. The maize variety chosen for the study, DKC 9081. Among the intercropping treatments, winter maize + vegetable pea was the most effective, showing superiority over all other treatments in terms maize equivalent yield (10.69 and 11.82 t ha⁻¹) along with the maximum net return (₹187430 and 228423 ha⁻¹) and the highest benefit-cost ratio (2.13 and 2.58), the other intercropping treatments. Under nutrient management, 100 % recommended dose of phosphorous (RDP) + nano di-ammonium phosphate (nano-DAP) (10.43 and 11.10 t ha⁻¹) recorded about 45 % and 43 % yields than the control (7.18 and 7.77 t ha⁻¹) in both year of experimentation. Winter maize + vegetable pea with 100 % RDP and nano-DAP achieved the highest yield and profitability, outperforming legume intercropping systems.

Keywords: calcareous soils; economics; intercropping; lentil; maize; maize equivalent yield; nano-DAP; vegetable pea; yield

Introduction

Maize (*Zea mays* L.) is a major cereal crop of global significance. It serves dual roles as a staple food for humans and an important source of food for livestock. Often referred to as the queen of cereals, maize is distinguished by its exceptionally high yield potential compared to other cereal crops. Its versatility, wide industrial applicability, diverse range of by-products and remarkable adaptability across different agro-ecological regions have earned it the title of a miracle crop (1). In India, maize is cultivated throughout the year and across all states. It ranks as the 3rd most important cereal after rice and wheat, occupying approximately 10.0 million hectares (Mha) during 2021-22 with a total production of 33.6 Mt and an average productivity of 3.35 t ha⁻¹ (2). In Bihar, rabi maize covered 0.64 Mha in the same period, producing 4.65 million tonnes with an impressive average yield of 7.32 t ha⁻¹ (2).

Intercropping is widely recognized as an efficient strategy to maximize the use of soil, water, nutrients and solar radiation across temporal and spatial scales. When implemented with scientific precision, intercropping confers multiple agronomic advantages

over monocropping. The relative maturity duration of component crops, their population dynamics and the appropriate management of irrigation and nutrient inputs play critical roles in determining the success of an intercropping system (3). Studies have shown that variation in growth duration among component crops, even when belonging to the same species, can significantly influence the overall productivity of the cropping mixture (3). Specifically, cereal–legume intercropping is considered an ecologically sound practice that enhances biodiversity and improves system sustainability. Legumes, through biological nitrogen fixation, enrich the soil nitrogen pool (4, 5), although the magnitude of fixation and yield advantage depends on nitrogen input levels and the cropping pattern employed (6, 7).

Phosphorus (P) remains one of the most limiting nutrients in crop production due to its extremely low mobility in soil. Only about 20 % of applied fertilizer P becomes available to plants, while the remainder accumulates in various soil pools. The enhancement of P-use efficiency, especially in legumes and diversified cropping systems, is therefore crucial for both economic viability and environmental sustainability. A substantial proportion of soil P becomes unavailable because of reactions with metal cations, its

stabilization within soil organic matter and losses through leaching (8). As a key macronutrient, P plays essential roles in plant metabolic processes, including energy transfer and the synthesis of nucleic acids, thereby directly influencing reproductive development (9). Plant response to P fertilization is regulated by both soil P availability and root distribution relative to localized P sources. Given the minimal diffusion rate of P approximately one-eighth of an inch per year roots must grow near fertilizer P to enable effective uptake (10).

In Bihar's calcareous soils, high P fixation severely restricts nutrient availability and crop productivity, necessitating innovative nutrient-delivery approaches for optimizing plant uptake. Recently, nano-P fertilizers have emerged as a promising alternative due to their enhanced solubility, reduced fixation and potential to improve P-use efficiency (11). Integrating nano-P with conventional fertilizers could further enhance nutrient availability under calcareous conditions. Additionally, intercropping legumes with maize may improve P acquisition through enhanced root exudation, modified nutrient stoichiometry and increased nitrogen fixation, ultimately improving P-use efficiency in maize-based systems (12, 13). Considering these constraints and opportunities, we hypothesized that optimized P fertilization and legume intercropping can enhance the overall performance of winter maize. The study aims to standardize P application strategies and evaluate their effects on growth, yield and profitability of winter maize under different legume intercropping systems.

Materials and Methods

Site description

Field experiments were conducted at the Crop Research Centre, Dr. Rajendra Prasad Central Agricultural (RPCAU), Pusa during the winter (Rabi) season of 2024 and 2025 for enhancing the productivity and profitability of winter maize-inter cropping systems. The soil at the study site is classified under the order 'Entisols', which is characterized by minimal profile development and alluvial floodplains. The soil falls under the sub-order 'Fluvents', the great group 'Ustifluvents' and is taxonomically categorized as Calciothrems. These soils, have immature and weak profiles due to their recent formation. Calcareous concretions, known as kankar beds, are visible along the riverbanks. The soils are well-drained and porous, and they are frequently replenished by recurring floods. The soil has a clayey loam texture and an alkaline reaction (pH 8.1) with normal electrical conductivity. It contains medium levels of soil organic carbon (5.6 g kg⁻¹), available nitrogen (139.6 kg ha⁻¹), available P (36.7 kg ha⁻¹) and available potassium (123.7 kg ha⁻¹). During both 2024 and 2025, January recorded the lowest mean minimum temperature of 7.5 °C. In the 2023-24 cropping season, the highest mean maximum temperature (39.5 °C) and maximum average evaporation rate (9.1 mm day⁻¹) were observed in May. Similarly, in the 2024–25 season, May exhibited the highest temperature (37.0 °C) with an average evaporation rate of 6.0 mm day⁻¹. Most of the annual rainfall occurred during the monsoon period, extending from June to September. However, a total rainfall of 75 mm was recorded during the first trial period, whereas only 10.1 mm was received during the second trial period.

Experimental details and crop management

The experiment comprising 2 factors was laid out in Split Plot Design (SPD) with 3 intercrop combinations, viz., sole winter maize,

winter maize + lentil, winter maize + vegetable pea and 5 nutrient management practices, viz., Control (No P), 75 % Recommended dose of phosphorus (RDP), 100 % RDP, 75 % RDP + nano DAP and 100 % RDP + nano DAP in 3 replications. Sowing operations of maize as well as intercrops (lentil and vegetable pea) were completed in the 3rd week of November in both seasons. Maize crops were sown at a seed rate of 20 kg ha⁻¹ with a spacing of 60 cm × 20 cm (row-to-row × plant-to-plant) and the intercrops were sown in the inter-row space between 2 maize rows. For the winter maize crop, the recommended dose of fertilizers was applied at the rate of 180-80-60 kg ha⁻¹ N, P₂O₅ and K₂O. In addition, nano-DAP was supplied as a foliar spray at the concentration of 2 mL L⁻¹ of water, maintaining a spray volume of 500 L ha⁻¹. No external nutrient supplementation was provided to the intercrops. The high-yielding variety DKC-9081 was used for the experiment.

Plant sampling and estimation

Growth and yield attributes and yield

Excluding the outer border rows, 10 plants were randomly selected and tagged from each net plot within every treatment to record various growth and yield attributes. Plant height was measured from these 10 tagged plants per plot using a measuring scale, extending from the soil surface to the tip of the uppermost fully expanded leaf at harvest and the mean values were expressed in cm. The leaf area index (LAI) was determined using a Systronics leaf area meter. At different growth stages of winter maize, 10 randomly chosen plants were uprooted from the sampling rows of each plot. The collected samples were thoroughly washed to remove adhering soil particles before recording fresh weight. They were then sun-dried for 3-4 days, placed in labelled brown paper bags and oven-dried at 65 °C for 48 hr or until a constant weight was obtained. The mean dry matter accumulation (DMA) per treatment was calculated and expressed as g m⁻². Crop growth rate (CGR) was determined based on the rate of dry matter accumulation over a specific period. It was calculated using the following expression (Eq. 1):

$$\text{CGR (g day}^{-1} \text{ plant}^{-1}) = \frac{W_2 - W_1}{T_2 - T_1} \quad (\text{Eq. 1})$$

W₁ and W₂: Total dry matter at times T₁ and T₂, respectively.

The yield attributes of maize comprise cob length and cob girth (which together influence cob weight), the number of grains per cob and the weight of grains per cob were recorded after harvest using 10 randomly selected plants from each net plot. Grain and straw yields (t ha⁻¹) were estimated from a net plot area in the centre of each plot. Grain yield was standardized to a 12 % moisture content and stover yield from each net plot was sun-dried for 3-4 days before weighing and the recorded weights (kg plot⁻¹) were later converted to t ha⁻¹.

To facilitate a direct comparison of productivity between sole cropping and intercropping systems, the maize equivalent yield (MEY) was estimated by converting lentil and vegetable pea yield into its maize-equivalent value using current market prices. The MEY was derived using the following formula (Eq. 2):

$$\text{MEY} = \text{Yield of maize (t ha}^{-1}) + \frac{\text{Yield of intercrop (t ha}^{-1}) \times \text{Price of intercrop (₹ t}^{-1})}{\text{Price of maize (₹ t}^{-1})} \quad (\text{Eq. 2})$$

Economic analysis

Economic evaluation was carried out based on prevailing market rates for both inputs and outputs. The total production cost was estimated by accounting for variable expenditures, which included costs related to seeds, fertilizers, labor, soil preparation equipment, fertilizer application, irrigation, weeding, pest control, harvesting, threshing and other associated operations. Labor requirements for various field tasks were expressed on a hectare basis as person-days ha^{-1} (one person-day representing 8 working hours, in accordance with Indian government labor regulations). Labor costs were calculated by multiplying the total labor input for all operations by the statutory minimum wage rates prescribed under Indian labor laws. Gross income was computed by multiplying the grain yield by the minimum support price (Eq. 3) announced by the Government of India (2024 and 2025), while stover value was estimated based on current local market prices. Net income and benefit cost ratio for each treatment was then derived using the formula (Eq. 4, 5):

$$\text{Gross return } (\text{₹ ha}^{-1}) = (\text{Seed yield} \times \text{Price}) + (\text{Byproduct yield} \times \text{Price}) \quad (\text{Eq. 3})$$

$$\text{Net returns } (\text{₹ ha}^{-1}) = \text{Gross return } (\text{₹ ha}^{-1}) - \text{Cost of cultivation } (\text{₹ ha}^{-1}) \quad (\text{Eq. 4})$$

$$\text{Benefit cost ratio} = \text{Net returns } (\text{₹ ha}^{-1}) / \text{Cost of cultivation } (\text{₹ ha}^{-1}) \quad (\text{Eq. 5})$$

Statistical analysis

The recorded data were analyzed through analysis of variance (ANOVA) (14). For statistical computation, OPSTAT online software along with Microsoft Excel was employed. The treatment means were compared using the least significant difference (LSD) tests at a 5% probability level ($p < 0.05$) among the treatments.

Results and Discussion

Growth attributes

Legume intercrop and nutrient management practices significantly ($p < 0.05$) affected the plant height, LAI and DMA of winter maize. During the 2-year study the highest plant height (196.2 and 197.2 cm), LAI (3.20 and 3.29) and DMA (2074 and 2099 g m^{-2}) of winter maize was observed under sole maize cropping system compared to intercropping treatment, respectively (Table 1). Whereas, among the nutrient management the treatment comprising 100% RDP + nano-DAP produced the significantly higher plant height, LAI, DMA

and CGR of winter maize where plant height was recorded the maximum (196.8 cm and 198.0 cm) which is statistically at par with 100% RDP in 2024 and 2025, respectively. The LAI of winter maize exhibited a similar trend. The treatment 100% RDP + nano DAP recorded the highest DMA of (2127 g m^{-2} and 2135 g m^{-2}) which was 16% and 15% higher as compared to control (No P) in 2024 and 2025, respectively but statistically at par with 100% RDP. The CGR of winter maize showed a progressive increase up to 90 DAS, with a marked rise observed during the 90-120 DAS interval. This sharp increase in CGR may be attributed to the development of new, actively photosynthesizing tissues contributing to higher dry matter accumulation during this phase. Beyond 120 DAS, CGR exhibited a steady decline until the harvest stage in both years of experimentation (Fig. 1).

Yield attributes

Sole winter maize recorded the highest cob length (16.22 and 17.41 cm), followed closely (8 and 14% lower) by winter maize + vegetable pea intercropping (15.00 and 15.27 cm) during 2024 and 2025, respectively. The lowest cob length was observed in maize + lentil (13.51 and 14.16 cm), about 20 and 23% shorter than sole maize. Among nutrient management treatments, 100% RDP + nano-DAP produced the maximum cob length (15.96 and 16.50 cm), while the control (No P) recorded the minimum (13.07 and 13.30 cm), representing a reduction of approximately 22 and 24%. In both years, sole winter maize recorded the highest cob girth (15.25 and 15.89 cm), followed closely by winter maize + vegetable pea, which was about 5 and 7% lower (14.50 and 14.89 cm in 2024 and 2025, respectively). The lowest cob girth was observed in maize + lentil (14.25 and 14.64 cm). Among nutrient management practices, 100% RDP + nano-DAP produced the maximum cob girth (15.88 and 16.47 cm), showing 32% and 30% increase in the first and second year, respectively over the control where P was not applied. Grain count per cob and grain weight per cob was significantly affected by both intercropping and nutrient management practices. Grain count per cob was highest in sole winter maize (391.1 and 399.8), with winter maize + vegetable pea about 5 and 7% lower but statistically similar, while maize + lentil recorded the lowest count (11 and 12% lower) during 2024 and 2025, respectively. Among nutrient treatments, 100% RDP + nano-DAP produced the maximum grain count, 30 and 30% higher than the control in the first and second year, respectively. Grain weight per cob was highest in sole winter maize (121.9 and 124.9 g), with maize +

Table 1. Effect of intercropping and nutrient management practices on plant height, LAI and DMA of winter maize

| Treatment | Plant height (cm) | | LAI | | DMA (g m^{-2}) | |
|---|-------------------|-------|------|------|---------------------------|-------|
| | 2024 | 2025 | 2024 | 2025 | 2024 | 2025 |
| Inter crop combinations | | | | | | |
| C ₁ : Sole winter maize | 196.2 | 197.2 | 3.20 | 3.29 | 2074 | 2099 |
| C ₂ : Winter maize + lentil | 189.0 | 189.9 | 3.05 | 3.10 | 1996 | 2014 |
| C ₃ : Winter maize + vegetable pea | 191.6 | 192.4 | 3.13 | 3.21 | 2022 | 2042 |
| SEm(±) | 1.16 | 1.29 | 0.02 | 0.03 | 14.52 | 15.98 |
| LSD ($p \leq 0.05$) | 4.56 | 5.06 | 0.10 | 0.12 | 57.01 | 62.76 |
| Nutrient management practices | | | | | | |
| P ₁ : Control (No P) | 185.0 | 186.6 | 2.76 | 2.82 | 1828 | 1854 |
| P ₂ : 75% RDP | 191.9 | 192.8 | 3.14 | 3.22 | 2045 | 2067 |
| P ₃ : 100% RDP | 194.6 | 194.8 | 3.28 | 3.34 | 2094 | 2116 |
| P ₄ : 75% RDP + nano-DAP | 193.0 | 193.5 | 3.17 | 3.25 | 2061 | 2088 |
| P ₅ : 100% RDP + nano-DAP | 196.8 | 198.0 | 3.29 | 3.37 | 2127 | 2135 |
| SEm(±) | 1.12 | 1.86 | 0.06 | 0.06 | 28.37 | 28.67 |
| LSD ($p \leq 0.05$) | 3.26 | 5.42 | 0.19 | 0.19 | 82.81 | 83.67 |
| Interaction (C×P) | NS | NS | NS | NS | NS | NS |

*Sem = Standard error of the mean, LSD = Least significant difference, NS= non-significant, RDP = 80 kg $\text{P}_2\text{O}_5 \text{ ha}^{-1}$, Recommended dose of fertilizer - 180:80:60 kg N: P_2O_5 : $\text{K}_2\text{O} \text{ ha}^{-1}$, nano-DAP - at 2 mL L^{-1} of water keeping 500 L of water ha^{-1} .

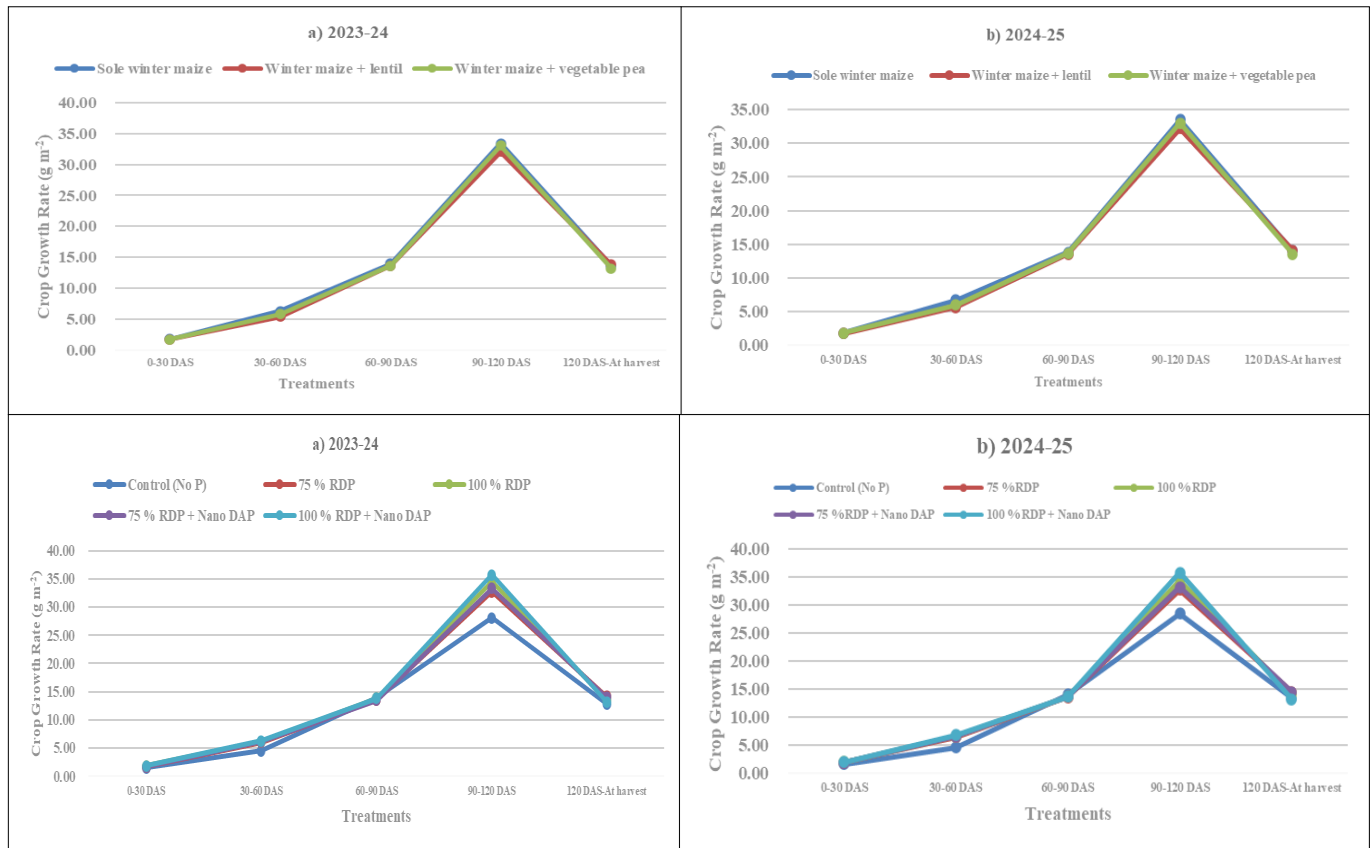


Fig. 1. Effect of intercropping and nutrient management practices on crop growth rate of winter maize, RDP = 80 kg P₂O₅ ha⁻¹, Recommended dose of fertilizer - 180:80:60 kg N: P₂O₅: K₂O ha⁻¹, nano-DAP - at 2 mL L⁻¹ of water keeping 500 L of water ha⁻¹.

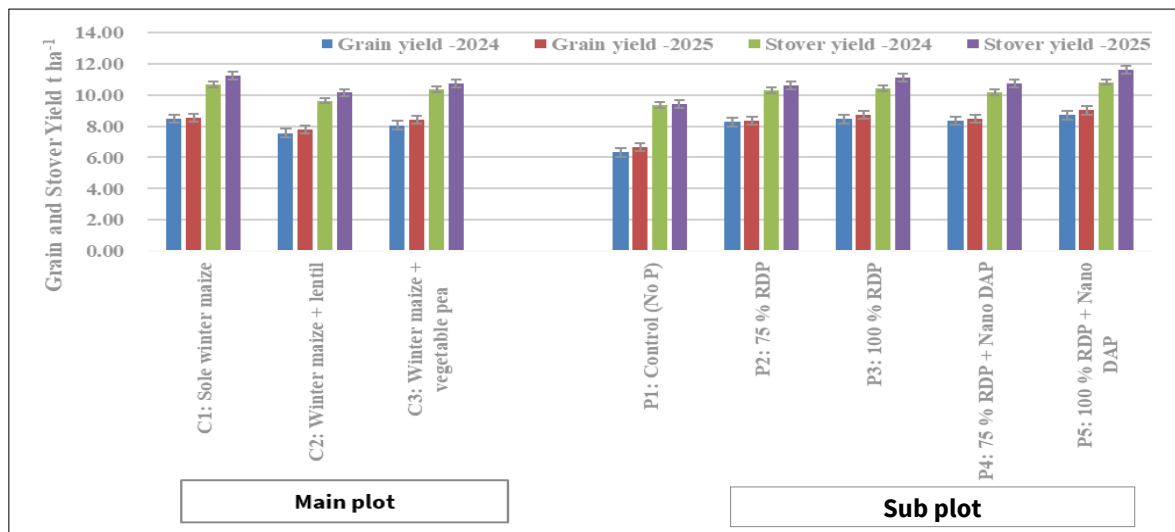


Fig. 2. Effect of intercropping and nutrient management practices on grain yield (t ha⁻¹) and stover yield (t ha⁻¹) of winter maize, RDP = 80 kg P₂O₅ ha⁻¹, Recommended dose of fertilizer - 180:80:60 kg N: P₂O₅: K₂O ha⁻¹, nano-DAP - at 2 mL L⁻¹ of water keeping 500 L of water ha⁻¹.

vegetable pea about 6 and 7 % lower but statistically similar, while maize + lentil showed the lowest values, 10 and 13 % lower. Among nutrient treatments, 100 % RDP + nano-DAP produced the heaviest cobs, with 100 % RDP about 2 and 3 % lower but comparable and the control recording 14 and 12 % less grain weight in the first and second year of the study, respectively (Table 2).

Yield

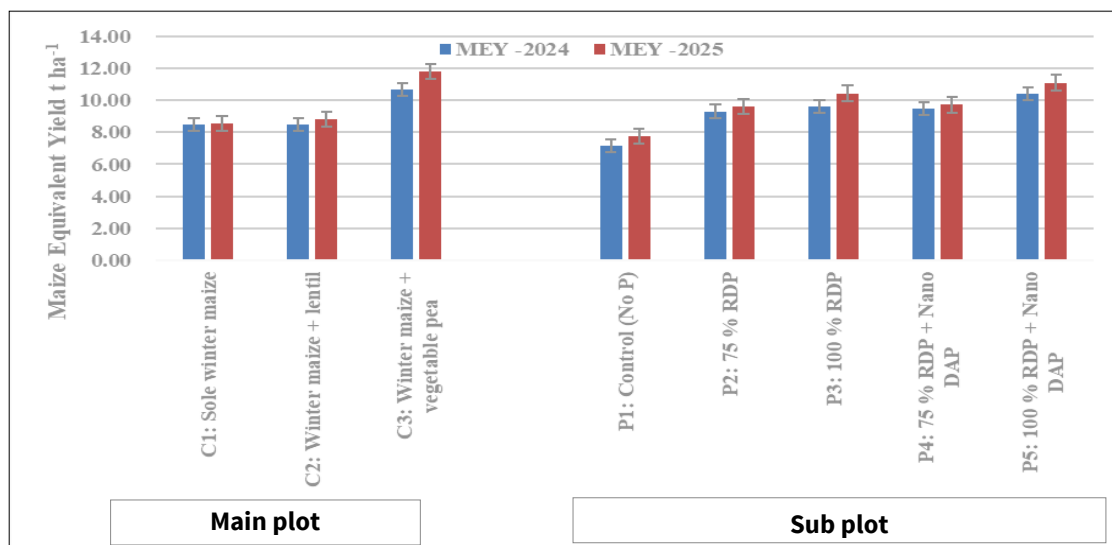
The highest grain yield was recorded in sole winter maize (8.47 and 8.56 t ha⁻¹ during 2024 and 2025, respectively), which was statistically at par with winter maize + vegetable pea (8.05 and 8.42 t ha⁻¹) while the winter maize + lentil system produced significantly lower yields showing about 12 and 10 % lower yields, respectively.

Under nutrient management, 100 % RDP + nano-DAP (8.70 and 9.01 t ha⁻¹) and 100 % RDP (8.45 and 8.74 t ha⁻¹) were statistically similar and recorded about 37 and 35 % higher yields than the control (6.33 and 6.68 t ha⁻¹) in 2024 and 2025, respectively. The enhanced yield was attributed to the pivotal role of P in supporting plant growth and yield formation. Stover yield was significantly affected by both intercropping and nutrient management practices. The sole winter maize system recorded the highest stover yield (10.66 and 11.23 t ha⁻¹ in 2024 and 2025, respectively), which was statistically at par with winter maize + vegetable pea (10.35 and 10.74 t ha⁻¹). The winter maize + lentil system produced significantly lower yields (9.63 and 10.14 t ha⁻¹) showing about 11 and 11 % lower yields, respectively. Among nutrient management practices, 100% RDP + nano-DAP (10.82 and 11.62 t ha⁻¹) recorded the highest stover yield,

Table 2. Effect of intercropping and nutrient management practices on cob length, cob girth (cm), no. of grains cob⁻¹ and grain weight cob⁻¹ of winter maize

| Treatment | Cob length (cm) | | Cob girth (cm) | | No. of grains cob ⁻¹ | | Grain weight cob ⁻¹ | |
|---|-----------------|-------|----------------|-------|---------------------------------|-------|--------------------------------|-------|
| | 2024 | 2025 | 2024 | 2025 | 2024 | 2025 | 2024 | 2025 |
| Intercrop combinations | | | | | | | | |
| C ₁ : Sole winter maize | 16.22 | 17.41 | 15.25 | 15.89 | 391.1 | 399.8 | 121.9 | 124.9 |
| C ₂ : Winter maize + lentil | 13.51 | 14.16 | 14.25 | 14.64 | 350.9 | 357.2 | 110.5 | 110.9 |
| C ₃ : Winter maize + vegetable pea | 15.00 | 15.27 | 14.50 | 14.89 | 371.8 | 373.3 | 115.4 | 116.8 |
| SEm(±) | 0.35 | 0.34 | 0.20 | 0.24 | 5.06 | 7.50 | 1.92 | 2.63 |
| LSD ($p \leq 0.05$) | 1.38 | 1.33 | 0.77 | 0.94 | 19.86 | 29.47 | 7.55 | 10.33 |
| Nutrient management practices | | | | | | | | |
| P ₁ : Control (No P) | 13.07 | 13.30 | 12.05 | 12.65 | 313.9 | 318.0 | 106.2 | 109.8 |
| P ₂ : 75 % RDP | 14.93 | 15.89 | 14.93 | 15.29 | 363.2 | 372.2 | 116.6 | 117.2 |
| P ₃ : 100 % RDP | 15.58 | 16.37 | 15.33 | 15.88 | 396.1 | 399.1 | 118.5 | 119.1 |
| P ₄ : 75 % RDP + nano-DAP | 14.99 | 16.02 | 15.14 | 15.42 | 375.4 | 380.6 | 117.5 | 118.9 |
| P ₅ : 100 % RDP + nano-DAP | 15.96 | 16.50 | 15.88 | 16.47 | 407.8 | 414.1 | 120.8 | 122.9 |
| SEm(±) | 0.52 | 0.28 | 0.35 | 0.34 | 6.95 | 8.22 | 1.62 | 2.44 |
| LSD ($p \leq 0.05$) | 1.52 | 0.82 | 1.01 | 1.00 | 20.27 | 23.99 | 4.73 | 7.13 |
| Interaction (C×P) | NS | NS | NS | NS | NS | NS | NS | NS |

*Sem = Standard error of the mean, LSD = Least significant difference, NS= non-significant, RDP = 80 kg P₂O₅ ha⁻¹, Recommended dose of fertilizer - 180:80:60 kg N: P₂O₅: K₂O ha⁻¹, nano-DAP - at 2 mL L⁻¹ of water keeping 500 L of water ha⁻¹.

**Fig. 3.** Effect of intercropping and nutrient management practices on maize equivalent yield (t ha⁻¹) of winter maize, RDP = 80 kg P₂O₅ ha⁻¹, Recommended dose of fertilizer - 180:80:60 kg N: P₂O₅: K₂O ha⁻¹, nano-DAP - at 2 mL L⁻¹ of water keeping 500 L of water ha⁻¹.

closely followed by 100 % RDP (10.43 and 11.11 t ha⁻¹), both statistically similar and about 15 and 23 % higher than the control (9.37 and 9.42 t ha⁻¹) in 2024 and 2025, respectively. The improvement in straw yield reflects the beneficial effect of P on biomass accumulation and overall plant growth. The interaction between intercropping systems and nutrient management practices was found to be significant for both grain and stover yield, indicating that the combined influence of these factors played a crucial role in enhancing overall productivity (Fig. 2).

Maize equivalent yield (MEY)

Maize equivalent yield, an indicator of overall system productivity, varied noticeably across the 2 study years under different intercropping arrangements (Fig. 3). In both years, maize intercropped with vegetable pea consistently outperformed the sole crops in terms of MEY. The maize + vegetable pea system produced the highest MEY, registering 10.69 t ha⁻¹ in 2023-24 and 11.82 t ha⁻¹ in 2024-25. In comparison, sole winter maize yields were 8.47 t ha⁻¹ in 2023-24 and 8.56 t/ha in 2024-25 showing about 26 and 39 % lower yields, respectively.

Economics

Over the 2-year study period, the economic performance of winter

maize was statistically influenced by intercropping and nutrient management practices (Table 3). In both years, winter maize intercropped with vegetable pea consistently recorded the highest economic returns, with gross returns of ₹275162 and ₹316616 ha⁻¹, net returns of ₹187430 and ₹228423 ha⁻¹ and benefit cost ratios of 3.13 and 2.58 during the first and second years, respectively, followed by the sole winter maize. The winter maize + lentil system produced significantly lower value in terms of economics, reduction of 22 and 28 % in gross return, 38 and 46 % in net return and 42 and 59 % in B:C ratio, during the first and second years, respectively. Among nutrient treatments, the combined application of 100 % RDP + nano-DAP proved most profitable in both years, producing gross returns of ₹272062 and ₹305096 ha⁻¹, net returns of ₹183968 and ₹216541 ha⁻¹ and B:C ratios of 2.09 and 2.44, respectively. These corresponded to increases of 38 and 39 % in gross return, 61 and 58 % in net return and 50 and 48 % in B:C ratio over the control treatment where P was not applied, demonstrating the consistent economic superiority of integrated P management with nano-DAP in winter maize cultivation (Table 3).

Sole maize exhibited superior growth due to the absence of interspecific competition (15, 16), while intercropping with legumes enhanced LAI and canopy development through better resource

Table 3. Effect of intercropping and nutrient management practices on gross return, net return and benefit cost ratio of winter maize

| Treatment | Gross return (₹ ha ⁻¹) | | | | | | | | | | | |
|----------------|------------------------------------|----------------|----------------|----------------|----------------|--------|----------------|----------------|----------------|----------------|----------------|--------|
| | 2024 | | | | | | 2025 | | | | | |
| | P ₁ | P ₂ | P ₃ | P ₄ | P ₅ | Mean | P ₁ | P ₂ | P ₃ | P ₄ | P ₅ | Mean |
| C ₁ | 184109 | 227564 | 246437 | 244546 | 248607 | 230253 | 197523 | 241427 | 266743 | 254686 | 272638 | 246603 |
| C ₂ | 192754 | 225665 | 222130 | 233118 | 251034 | 224940 | 213109 | 241194 | 255778 | 242562 | 279885 | 246506 |
| C ₃ | 214006 | 285000 | 290414 | 269845 | 316546 | 275162 | 249161 | 317712 | 340523 | 312920 | 362766 | 316616 |
| Mean | 196956 | 246076 | 252994 | 249170 | 272062 | | 219931 | 266777 | 287681 | 270056 | 305096 | |
| SEm(±) | | | | 6077 | | | | | 5827 | | | |
| LSD (p ≤ 0.05) | | | | 17737 | | | | | 17009 | | | |

| Treatment | Net return (₹ ha ⁻¹) | | | | | | | | | | | |
|----------------|----------------------------------|----------------|----------------|----------------|----------------|--------|----------------|----------------|----------------|----------------|----------------|--------|
| | 2024 | | | | | | 2025 | | | | | |
| | P ₁ | P ₂ | P ₃ | P ₄ | P ₅ | Mean | P ₁ | P ₂ | P ₃ | P ₄ | P ₅ | Mean |
| C ₁ | 107225 | 147297 | 165043 | 163077 | 166011 | 149731 | 120178 | 160699 | 184888 | 172756 | 189581 | 165620 |
| C ₂ | 106585 | 136113 | 131451 | 142364 | 159153 | 135133 | 126479 | 151181 | 164638 | 151347 | 187543 | 156238 |
| C ₃ | 129912 | 197523 | 201810 | 181166 | 226740 | 187430 | 164606 | 229774 | 251458 | 223780 | 272499 | 228423 |
| Mean | 114574 | 160311 | 166101 | 162202 | 183968 | | 137088 | 180551 | 200328 | 182628 | 216541 | |
| SEm(±) | | | | 6077 | | | | | 5827 | | | |
| LSD (p ≤ 0.05) | | | | 17737 | | | | | 17009 | | | |

| Treatment | Benefit cost ratio | | | | | | | | | | | |
|----------------|--------------------|----------------|----------------|----------------|----------------|------|----------------|----------------|----------------|----------------|----------------|------|
| | 2024 | | | | | | 2025 | | | | | |
| | P ₁ | P ₂ | P ₃ | P ₄ | P ₅ | Mean | P ₁ | P ₂ | P ₃ | P ₄ | P ₅ | Mean |
| C ₁ | 1.39 | 1.84 | 2.03 | 2.00 | 2.01 | 1.85 | 1.55 | 1.99 | 2.26 | 2.11 | 2.28 | 2.04 |
| C ₂ | 1.24 | 1.52 | 1.45 | 1.57 | 1.73 | 1.50 | 1.46 | 1.68 | 1.81 | 1.66 | 2.03 | 1.73 |
| C ₃ | 1.54 | 2.26 | 2.28 | 2.04 | 2.52 | 2.13 | 1.95 | 2.61 | 2.82 | 2.51 | 3.02 | 2.58 |
| Mean | 1.39 | 1.87 | 1.92 | 1.87 | 2.09 | | 1.65 | 2.09 | 2.30 | 2.09 | 2.44 | |
| SEm(±) | | | | 0.07 | | | | | 0.07 | | | |
| LSD (p ≤ 0.05) | | | | 0.21 | | | | | 0.19 | | | |

*Sem = Standard error of the mean, LSD = Least significant difference, NS = non-significant, RDP = 80 kg P₂O₅ ha⁻¹, Recommended dose of fertilizer - 180:80:60 kg N: P₂O₅: K₂O ha⁻¹, nano-DAP - at 2 mL L⁻¹ of water keeping 500 L of water ha⁻¹, C₁: Sole winter maize, C₂: Winter maize + lentil, C₃: Winter maize + vegetable pea, P₁: Control (No P), P₂: 75 % RDP, P₃: 100 % RDP, P₄: 75 % RDP + nano DAP, P₅: 100 % RDP + nano-DAP.

utilization. This enhanced growth performance can be attributed to the absence of interspecific competition for essential growth resources such as light, water and nutrients. Without the presence of intercrops, winter maize could fully exploit available resources, leading to more vigorous vegetative development and higher biomass production (17). The combined use of conventional and nano-DAP enhanced soil P availability, particularly in calcareous soils where P fixation is a major limitation. The improved P nutrition supported leaf development, chlorophyll synthesis and photosynthetic efficiency, synergistically complementing the benefits derived from intercropping. The beneficial impact of increased P application on maize growth and development was evident through greater root growth, as well as improvements in plant height and LAI, corroborating early findings (18–20).

In the present study, sole winter maize recorded significantly higher growth and yield attributes cob girth, cob length, grain weight per cob, kernel yield and stover yield due to the absence of interspecific competition for resources such as light, nutrients and moisture. Similar findings were reported in previous works, emphasizing efficient assimilate partitioning under sole cropping (21–23). Among nutrient management practices, 100 % RDP supplemented with nano-DAP produced the highest yield components and grain yield, attributed to improved phosphorus availability, enhanced root growth and better nutrient uptake (24). Cob traits showed positive correlations with grain yield, indicating their role as key yield determinants (25, 26). The continuous nutrient supply from nano-DAP enhanced photosynthetic efficiency and assimilate translocation, leading to improved cob and grain development (27–29). Enhanced seed yield resulted from the synergistic effect of conventional and nano-DAP through improved nutrient absorption, root growth and metabolism (30–32).

Maize equivalent yield, an indicator of overall system productivity, varied noticeably across the 2 study years under

different intercropping arrangements. In both years, maize intercropped with vegetable pea consistently outperformed the sole crops in terms of MEY. The improvement in yield under intercropping can be attributed to the nitrogen-fixing capability of legumes and the robust root structure of cereals. The enhanced total grain productivity under intercropping is largely due to the additional yield obtained from vegetable pea by efficiently utilizing the inter-row spaces of the maize crop. These findings are consistent with earlier observations (33–36).

Economic analysis is crucial for evaluating the profitability and sustainability of intercropping systems. In this study, winter maize intercropped with vegetable pea significantly increased gross returns, net returns and B:C ratio compared to sole winter maize. The higher profitability is attributed to increased maize equivalent yield, efficient land use and enhanced resource utilization efficiency. These benefits were achieved through complementary resource use and allowing both crops to utilize available resources more efficiently. These results align with early findings, who reported enhanced productivity and economic returns in maize-based intercropping systems (37–39).

Conclusion

Based on the experimental findings, it can be concluded that winter maize intercropped with vegetable pea cultivation significantly enhanced productivity compared to sole winter maize. The grain yield of maize was notably higher under winter maize intercropped with vegetable pea cropping. Moreover, the application of 100 % RDP with nano-DAP demonstrated superior performance under winter maize intercropped with vegetable pea, resulting in the highest net returns among the nutrient management practices evaluated. Therefore, winter maize intercropped with vegetable pea integrated with 100 % RDP combined with nano-DAP can be

recommended as an effective strategy for maximizing productivity and profitability under winter maize cultivation. As a result, to enhance the productivity of winter maize, future research should focus on optimizing P management through appropriate combinations of nano-DAP and suitable legume intercropping systems, while also evaluating the long-term impacts on soil health, grain yield and overall profitability.

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Authors' contributions

Conceptualization, methodology, formal analysis, investigation, writing, preparation of the original draft and supervision was done by MC and MK. Review and editing was done by MK, BP, GN, SKS and SK. MK collected the resources. All authors read and approved the final manuscript.

Compliance with ethical standards

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References

- Sanodiya P, Tiwari P, Gupta C. Maize (*Zea mays* L.) – the future potential cereal crop of an indispensable significance in agro-forestry system. *Maize J.* 2023;12(2):61–71.
- Ministry of Agriculture and Farmers Welfare (MoA&FW). Agricultural statistics at a glance. 2022;38–9,78. <https://desagri.gov.in/wp-content/uploads/2023/05/Agricultural-Statistics-at-a-Glance-2022.pdf>
- Anchal, Kaur A, Sharma S. Intercropping: a sustainable holistic approach for improving growth and productivity of crops. *Int J Res Agron.* 2025;8(4):133–9. <https://doi.org/10.33545/2618060X.2025.v8.i4b.2757>
- Jensen ES, Carlsson G, Hauggaard-Nielsen H. Intercropping of grain legumes and cereals improves the use of soil N resources and reduces the requirement for synthetic fertilizer N: a global-scale analysis. *Agron Sustain Dev.* 2020;40(1):5. <https://doi.org/10.1007/s13593-020-0607-x>
- Hauggaard-Nielsen H, Gooding M, Ambus P, Corre-Hellou G, Crozat Y, Dahlmann C, et al. Pea-barley intercropping for efficient symbiotic N₂-fixation, soil N acquisition and use of other nutrients in European organic cropping systems. *Field Crop Res.* 2009;113(1):64–71. <https://doi.org/10.1016/j.fcr.2009.04.009>
- Yong T, Chen P, Dong Q, Du Q, Yang F, Wang X, et al. Optimized nitrogen application methods to improve nitrogen use efficiency and nodule nitrogen fixation in a maize–soybean relay intercropping system. *J Integr Agric.* 2018;17(3):664–76. [https://doi.org/10.1016/S2095-3119\(17\)61836-7](https://doi.org/10.1016/S2095-3119(17)61836-7)
- Zheng B, Zhou Y, Chen P, Zhang X, Du Q, Yang H, et al. Maize–legume intercropping promotes N uptake through changing the root spatial distribution, legume nodulation capacity and soil N availability. *J Integr Agric.* 2022;21(6):1755–71. [https://doi.org/10.1016/S2095-3119\(21\)63730-9](https://doi.org/10.1016/S2095-3119(21)63730-9)
- Yang Z, Zhang Y, Wang Y, Zhang H, Zhu Q, Yan B, et al. Intercropping regulation of soil phosphorus composition and microbially driven dynamics facilitates maize phosphorus uptake and productivity improvement. *Field Crops Res.* 2022;287:108666. <https://doi.org/10.1016/j.fcr.2022.108666>
- Cordell D, Drangert JO, White S. The story of phosphorus: global food security and food for thought. *Glob Environ Change.* 2009;19(2):292–305. <https://doi.org/10.1016/j.gloenvcha.2008.10.009>
- Beegle DB, Durst PT. Managing phosphorus for crop production. *Agronomy Facts.* 2002;13(6).
- Tarafdar JC, Raliya R, Rathore I. Microbial synthesis of phosphorus nanoparticle from tri-calcium phosphate using *Aspergillus tubingensis* TFR-5. *J Bionosci.* 2012;6(2):84–9. <https://doi.org/10.1166/jbns.2012.1077>
- Luo G, Xue C, Jiang Q, Xiao Y, Zhang F, Guo S, et al. Soil carbon, nitrogen and phosphorus cycling microbial populations and their resistance to global change depend on soil C:N:P stoichiometry. *mSystems.* 2020;5(3):e00162–20. <https://doi.org/10.1128/msystems.00162-20>
- Duchene O, Vian JF, Celette F. Intercropping with legume for agroecological cropping systems: complementarity and facilitation processes and the importance of soil microorganisms. *Agric Ecosyst Environ.* 2017;240:148–61. <https://doi.org/10.1016/j.agee.2017.02.019>
- Gomez A, Gomez A. Statistical procedures for agricultural research. 2nd ed. New York: John Wiley and Sons; 1984.
- Marer SB, Lingaraju BS, Shashidhara GB. Productivity and economics of maize and pigeonpea intercropping under rainfed condition in northern transitional zone of Karnataka. *Karnataka J Agric Sci.* 2007;20(1):1–3.
- Kour M, Thakur NP, Kumar P, Charak AS. Productivity and profitability of maize (*Zea mays*) as influenced by intercropping of raj mash (*Phaseolus vulgaris*) and nutrient management techniques under sub-alpine conditions of Jammu, India. *Legume Res.* 2016;39(6):970–5. <https://doi.org/10.18805/lr.v0i0F.11042>
- Fu Z, Chen P, Zhang X, Du Q, Zheng B, Yang H, et al. Maize–legume intercropping achieves yield advantages by improving leaf functions and dry matter partition. *BMC Plant Biol.* 2023;23(1):438. <https://doi.org/10.1186/s12870-023-04408-3>
- Shaikh SN, Waghmare MS, Ighare OA, Ugile SK, Puri AN. Effect of nano-DAP on growth, yield and quality of soybean in Entisol. *Int J Res Agron.* 2024;7(11):256–63. <https://doi.org/10.33545/2618060X.2024.v7.i11Sd.1976>
- Rajput JS, Thakur AK, Nag NK, Chandrakar T, Singh DP. Effect of nano fertilizer in relation to growth, yield and economics of little millet (*Panicum sumatrense* Roth) under rainfed conditions. *J Pharm Innov.* 2022;11(7):153–6.
- Bhargavi G, Sundari A. Effect of nano urea on the growth and yield of rice (*Oryza sativa*) under SRI in the Cauvery delta zone of Tamil Nadu. *Crop Res.* 2023;58(1–2):12–7. <https://doi.org/10.31830/2454-1761.2023.CR-885>
- Sridhar HS, Salakinkop SR, Harlapur SI. Effect of leguminous intercrops on maize productivity and economics. *J Farm Sci.* 2019;411–14.
- Pierre JF, Latournerie-Moreno L, Garruna-Hernandez R, Jacobsen KL, Guevara-Hernandez F, Laboski CA, et al. Maize-legume

- intercropping systems in southern Mexico: a review of benefits and challenges. *Ciencia Rural*. 2022;52:e20210409. <https://doi.org/10.1590/0103-8478cr20210409>
23. Jan R, Saxena A, Jan R, Khanday MA, Jan R. Impact of intercropping patterns (maize + black cowpea) on yield attributes and soil physico-chemical properties. *Ecol Environ Conserv*. 2016;13–16.
 24. Ch R, Venkata Ramana M, Jaya Sree G. Management of phosphorus on performance of rice-zero till maize (*Zea mays* L.) cropping system. *Int J Environ Clim Chang*. 2023;13(9):1801–12. <https://doi.org/10.9734/ijec/2023/v13i92410>
 25. Jagadev PN, Kanungo P, Lenka D. Genetic variability, association and path coefficient studies in quality protein maize inbreds. *J Pharm Innov*. 2021;10(12):776–9.
 26. Naik NR, Hemalatha S, Reddy AP, Madhuri KV, Umamahesh V. Need-based nitrogen management on growth attributes of rabi maize (*Zea mays* L.) using leaf colour chart under varied plant density. *Int J Chem Stud*. 2019;7:2591–6.
 27. Alzreejawi SA, Al-Juthery HW. Effect of spray with nano NPK, complete micro fertilizers and nano amino acids on some growth and yield indicators of maize (*Zea mays* L.). *IOP Conf Ser Earth Environ Sci*. 2020;553(1):012010. <https://doi.org/10.1088/1755-1315/553/1/012010>
 28. Ajithkumar K, Kumar Y, Savitha AS, Ajayakumar MY, Narayanaswamy C, Raliya R, et al. Effect of IFFCO nanofertilizer on growth, grain yield and managing turicum leaf blight disease in maize. *Int J Plant Soil Sci*. 2021;33(16):19–28. <https://doi.org/10.9734/ijpss/2021/v33i1630519>
 29. Deo HR, Chandrakar T, Srivastava LK, Nag NK, Singh DP, Thakur A, et al. Effect of nano-DAP on yield, nutrient uptake and nutrient use efficiency by rice under Bastar plateau. *J Pharm Innov*. 2022;11(9):1463–5.
 30. Kumar Y, Singh T, Raliya R, Tiwari KN. Nano fertilizers for sustainable crop production, higher nutrient use efficiency and enhanced profitability. *Indian J Fertilizers*. 2021;17(11):1206–14.
 31. Kumar N, Manuja S, Sankhyan NK, Kumar P, Kumar A, Sharma T, et al. Effect of application of nano-DAP and conventional fertilizers on rice yield. *Sustainable Agricultural Innovations for Resilient Agri-Food Systems*. 2022;373.
 32. Poudel A, Singh SK, Jiménez-Ballesta R, Jatav SS, Patra A, Pandey A, et al. Effect of nano-phosphorus formulation on growth, yield and nutritional quality of wheat under semi-arid climate. *Agronomy*. 2023;13(3):768. <https://doi.org/10.3390/agronomy13030768>
 33. Bedse RD, Patel AM, Raval CH, Rathore BS, Vyas KG. Forage equivalent yield, quality, soil status and economics of maize (*Zea mays* L.) as influenced by intercropping of cowpea (*Vigna unguiculata* L.) and fertility levels during kharif season. *Res Crops*. 2015;16(2):236–42. <https://doi.org/10.5958/2348-7542.2015.00035.2>
 34. Barik E, Behera B, Jena SN, Satapathy MR, Roul PK. Impact of planting pattern and nutrient management strategy on productivity and comparative economics of maize (*Zea mays* L.) + cowpea (*Vigna unguiculata* L. Walp.) intercropping under rainfed condition. *J Crop Weed*. 2016;12(3):79–82.
 35. Chhetri B, Sinha AC. Effect of integrated nutrient management practices on maize (*Zea mays* L.) based intercropping system under Terai region of West Bengal. *Adv Res*. 2018;16(1):1–10. <https://doi.org/10.9734/AIR/2018/41623>
 36. Mohanty TR, Ray M, Sahoo SK, Sahoo KC, Mishra N, Patro HK, et al. Performance of intercrops in hybrid maize under north central plateau zone of Odisha. *J Plant Dev Sci*. 2020;12(5):283–7.
 37. Singh D, Kumar M, Birla D, Gajanand SS. Effect of irrigation methods, nutrient management and intercropping system on grain yield, maize equivalent yield, protein content and economics of maize (*Zea mays* L.). *Int J Plant Soil Sci*. 2022;34(23):1248–53. <https://doi.org/10.9734/ijpss/2022/v34i232539>
 38. Singh MB, Dwivedi DK, Kumar S, Nanda G, Singh SK, Dwivedi A, et al. Effect of different sources of nutrient management on yield and economics of potato + maize intercropping system in north Bihar region. *J Pharm Innov*. 2022;11(8):2154–5. <https://doi.org/10.33545/2618060X.2025.v8.i11.4311>
 39. Verma VK, Meena RN, Singh DN, Upadhyay PK, Singh RK, Singh RK, et al. Cropping geometry and nutrient management study on winter maize (*Zea mays*) + potato (*Solanum tuberosum*) intercropping. *Indian J Agric Sci*. 2021;91(7):1005–9. <https://doi.org/10.56093/ijas.v91i7.115112>

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