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ENHANCING PHOSPHORUS AND ZINC USE EFFICIENCY IN FODDER COWPEA

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ABSTRACT

A field experiment was conducted during the *rabi* season of 2024-25 at the dryland farm of S.V. Agricultural College, Tirupati, to evaluate the effects of varying levels of phosphorus (0, 20, 40, 60 kg P_2O_5 ha^{-1}) and zinc (0, 25, 50 kg $ZnSO_4$ ha^{-1}) on growth, yield, quality, fertilizer use efficiency and nutrient balance of fodder cowpea (MFC-09). The experiment was laid out in a randomized block design with factorial concept and replicated thrice. Fertilizer use efficiency indices, including agronomic efficiency (AE), apparent recovery fraction (ARF), partial factor productivity (PFP), phosphorus use efficiency (PUE) and zinc use efficiency (ZUE), were calculated. Results indicated that moderate doses of phosphorus (20 kg P_2O_5 ha^{-1}) and zinc (25 kg $ZnSO_4$ ha^{-1}) enhanced nutrient use efficiency, while higher doses reduced AE and PFP due to luxury consumption and nutrient fixation. Nutrient balance sheets showed increased residual phosphorus and zinc with higher fertilization, especially under combined application. Correlation analysis revealed positive relationships between growth parameters and green fodder yield. Overall, the combined application of 60 kg P_2O_5 ha^{-1} with 25 kg $ZnSO_4$ ha^{-1} resulted in superior growth, yield, quality and economic nutrient management under sandy loam soils of southern Andhra Pradesh.

Keywords **:** Green fodder yield, fertilizer use efficiency, fodder cowpea, nutrient balance, phosphorus and zinc.

Introduction

Fodder cowpea (*Vigna unguiculata* L.) is an important leguminous forage crop, widely cultivated for its high biomass and protein-rich green fodder. Efficient nutrient management, particularly with phosphorus and zinc, is critical to enhance crop growth, yield, and quality, especially in sandy loam soils of semi-arid regions. Phosphorus is essential for root development, energy transfer, and overall plant growth, while zinc plays a crucial role in enzymatic functions and protein synthesis. Imbalanced or excessive application of fertilizers can lead to reduced nutrient use efficiency due to luxury consumption or fixation in the soil.

Understanding fertilizer use efficiency through indices such as agronomic efficiency, apparent recovery fraction, partial factor productivity, and nutrient use efficiency is vital to optimize fertilization strategies. Additionally, nutrient balance analysis provides insights into the residual soil fertility status and guides sustainable nutrient management. This study aimed to evaluate the effects of varying phosphorus and zinc levels on growth, yield, quality, and nutrient use efficiency of fodder cowpea under the sandy loam soils of southern Andhra Pradesh.

Material and Methods

The experiment was conducted during late *rabi*, 2024-25 at dryland farm of S.V. Agricultural College, Tirupati Campus of Acharya N.G. Ranga Agricultural University, Andhra Pradesh. The experiment was laid out in randomized block design with factorial concept and the treatments comprises of four phosphorus levels *viz.*, 0 kg P_2O_5 ha^{-1} (P_0), 20 kg P_2O_5 ha^{-1} (P_1), 40 kg P_2O_5 ha^{-1} (P_2) and 60 kg P_2O_5 ha^{-1} (P_3) were allotted to Factor-I and three zinc levels *viz.*, 0 kg $ZnSO_4$ ha^{-1} (Z_0), 25 kg $ZnSO_4$ ha^{-1} (Z_1) and 50 kg $ZnSO_4$ ha^{-1} (Z_2) were allotted to Factor-II and replicated thrice. The test variety of fodder cowpea used in the present experiment was MFC-09, released from Mandya Research Station, Karnataka. The crop was supplied with 25 kg N and 20 kg K_2O ha^{-1} through urea and muriate of potash was applied uniformly as common dose to all the treatments at the time of basal and P_2O_5 through SSP was applied as per the treatments. Nitrogen was applied in two equal splits *i.e.,* 50 % as basal and 50 % at 30 DAS. Soil application of zinc sulphate at 20 kg ha^{-1} was done at 10 DAS as per the treatments. The crop was harvested for green fodder purpose by cutting the plants close to the ground at 50 per cent flowering.

(A) Fertiliser Use Efficiency

Fertiliser use efficiency or the amount of increase in the economic yield of the crop per unit of fertiliser applied has been calculated to indicate the dose of fertiliser at which the crop shows the greatest increase in the seed yield. Under this, fertiliser use indices *viz.*, agronomic efficiency, physiological efficiency and apparent recovery fraction were calculated as given by Harmsen (1984).

Agronomic Efficiency

The agronomic efficiency (AE) of fertiliser application is defined as the 'the partial derivative of the function relating economic or seed yield (SY) to applied fertiliser nutrient'. The AE for different phosphorus and zinc levels is obtained as:

$$\text{AE} = \frac{\begin{array}{c}\text{(crop yield (kg ha}^{-1}\text{) with applied nutrient}\\ \text{- Crop yield (Kg ha}^{-1}\text{) without nutrient applied}\end{array}}{\text{Amount of nutrient applied (kg ha}^{-1}\text{)}}$$

Partial Factor Productivity

Partial factor productivity indicates kg crop yield per kg nutrient applied.

$$\text{Partial Factor Productivity (PFP)} = \frac{\text{Yield}\left(\text{kg ha}^{-1}\right)}{\text{Amount of nutrient applied}\left(\text{kg ha}^{-1}\right)}$$

Apparent Recovery Fraction

The apparent recovery fraction (ARF) is the fraction of fertiliser nutrient recovered in the crop over the fertiliser nutrient applied and normally lies between 0 and 1. The ARF in percentage for the given nutrient rate was calculated as follows.

$$\text{ARF\%} = \frac{\begin{array}{c}\text{Nutrient N accumulated in fertilized crop}\\ \text{- Nutrient N accumulated in control crop}\end{array}}{\text{Nutrient N applied}} \times 100$$

Phosphorus Use Efficiency

Phosphorus Use Efficiency is calculated by dividing the crop yield per hectare by the amount of phosphorus fertilizer applied per hectare, and multiplying by 100.

$$\text{PUE} = \frac{\text{Yield (kg ha}^{-1}\text{)}}{\text{Applied fertiliser}} \times 100$$

Zinc Use Efficiency

$$\text{ZUE} = \frac{\text{Yield (kg ha}^{-1}\text{)}}{\text{Applied fertiliser}} \times 100$$

(B) Nutrient Balance Sheet

Nutrient balance was worked out as:

$$X = a - (b + c)$$

Where,

X = phosphorus or zinc (kg ha^{-1}) gain or loss at the end of the experiment

a = sum of initial status of the available phosphorus in soil and addition of phosphorus (or) zinc through inorganic source

b = quantity of phosphorus (or) zinc removed by crop

c = actual balance of available phosphorus (or) zinc at the end of the experiment

(C) Correlation Analysis

Fodder yield (depended variable) was assumed as a function of various yield components (independent variables) and the following straightline model was established by least square technique (Gomez and Gomez, 1984).

$$Y = a + bx$$

Where,

Y	=	Fodder yield (kg ha^{-1})
a	=	Y-axis intercept
b	=	Regression coefficient
x	=	Yield components (plant height, number of branches, number of leaves, leaf to stem ratio, leaf area index, dry matter production, days to 50 % flowering, days to maturity, protein content, fibre content, ash content, zinc content).

Results and Discussion

(A) Fertilizer use efficiency

The various measures of fertilizer se efficiency *viz.*, partial factor productivity (PEF), agronomic efficiency (AE) and apparent recovery fraction (ARF) were calculated for phosphorus and zinc separately and presented in the Table 1.

Partial Factor Productivity

Partial factor productivity of fodder cowpea was influenced by varied levels of phosphorus and zinc.

Partial factor productivity is a useful measure of nutrient use efficiency as it provides an integrative index that quantifies total economic output relative to the utilization of all nutrient resources in the system. It indicates kg of crop yield per kg of nutrient applied.

The decline in partial factor productivity with application of 60 kg P_2O_5 ha^{-1} (P_3) alone might be due to the lack of luxury consumption of nutrients on one hand and higher fixation of nutrients in soil is the another one, which was followed by 40 kg P_2O_5 ha^{-1} (P_2) while higher partial factor productivity was noticed with 20 kg P_2O_5 ha^{-1} (P_1), because of higher nutrient use efficiency with lower nutrient application. Decline in partial factor productivity at higher nutrient levels is consistent with recent findings (Jiang *et al*., 2024; Moreira *et al*., 2025).

The lower partial factor productivity was recorded with application of 50 kg $ZnSO_4$ ha^{-1} (Z_2). While, higher partial factor productivity with 25 kg $ZnSO_4$ ha^{-1} (Z_1), while higher nutrient use efficiency was noticed with 25 kg $ZnSO_4$ ha^{-1} (Z_1). Results are in conformity with Kumawat and Kinchi (2017).

Table 1: Fertilizer use efficiency indices for fodder cowpea as influenced by different levels of phosphorus

Treatments	Agronomic efficiency (AE) (Fodder yield (kg ha^{-1}) fertilizer applied^{-1})	Apparent recovery fraction (%)	Partial factor Productivity	Phosphors use efficiency (PUE)	Zinc use efficiency (ZUE)
Phosphorus levels (kg P_2O_5 ha^{-1})					
P_0	-	-	-	-	-
P_1	115.28	7.80	651.66	65.2	-
P_2	73.84	6.88	342.03	34.2	-
P_3	71.06	7.91	249.85	25.0	-
Zinc levels (kg $ZnSO_4$ ha^{-1})					
Z_0	-	-	-	-	-
Z_1	103.67	5.44	549.37	-	4.11
Z_2	66.11	5.10	288.96	-	43.0

Agronomic efficiency

Agronomic efficiency reflects the direct production impact of an applied fertiliser and relates directly to the economic returns. It indicates kg of crop yield increases per kg of nutrient applied. The lower agronomic efficiency with application of 60 Kg P_2O_5 ha^{-1} (P_3) might due to luxurious consumption of nutrients on one hand and higher fixation of nutrients in soil followed by 40 kg P_2O_5 ha^{-1} (P_2) while, higher agronomic efficiency with 20 P_2O_5 ha^{-1} (P_1),while higher partial factor productivity was noticed with 20 kg P_2O_5 ha^{-1} (P_1).

The lower agronomic efficiency observed with application of 50 kg $ZnSO_4$ ha^{-1} (Z_2). While, higher agronomic efficiency with 25 kg $ZnSO_4$ ha^{-1} (Z_1), while higher partial factor productivity was noticed with 25 kg $ZnSO_4$ ha^{-1} (Z_1).

A decrease in agronomic efficiency, agronomic efficiency for each extra phosphorus and zinc increment were observed with each higher phosphorus and zinc. Reduction in agronomic efficiency at higher fertilizer doses has been widely reported in recent studies (Jiang *et al*., 2024, Hemasree *et al*., 2025 and Devappa (2024).

Apparent Recovery Fraction (%)

The apparent recovery fraction (ARF) of phosphorus and zinc varied across different levels of fertilization.

Among phosphorus levels, the highest ARF was recorded at P_3 (7.91%), followed by P_1 (7.80%), P_2 (6.88%). A slight decline in ARF at the higher phosphorus level (P_3) may be due to reduced efficiency of nutrient uptake at excessive application rates. Lower recovery at higher fertilizer levels may be due to nutrient fixation and reduced uptake efficiency (Mustafa *et al*., 2022; Oliveira *et al.*, 2024)

Similarly, among zinc treatments, 25 kg $ZnSO_4$ (Z_1) recorded the highest ARF of 5.44 %, followed by Z_2 (5.10 %). The lower ARF under fertilized treatments compared to the Z_1, might be attributed to luxury consumption or fixation of zinc in the soil, reducing recovery efficiency. These results are agreed with Everest *et al*. (2022) and Hemalatha (2001).

Phosphorus Use Efficiency

Higher phosphorus use efficiency was observed at 20 kg P_2O_5 ha^{-1} (P_1) followed by 40 kg P_2O_5 ha^{-1}. Lower PUE noticed at 60 kg P_2O_5 ha^{-1}, which may be attributed to improved nutrient uptake efficiency at lower application rates. This efficiency likely declined at higher levels due to luxury consumption and reduced. Higher phosphorus use efficiency at moderate levels has been reported in cowpea under different agro-ecological conditions (Singh *et al*., 2022; Moreira *et al*., 2025).

Zinc Use Efficiency

Higher zinc use efficiency was recorded with the application of 25 kg $ZnSO_4$ ha^{-1}, likely due to optimal supply enhancing uptake and utilization. At higher doses (50 kg $ZnSO_4$ ha^{-1}), efficiency declined, possibly due to saturation or fixation in soil. These results were agreement with Kumawat and Kinchi (2017) in pigeonpea crop. Zinc use efficiency was higher at optimal doses and declined at higher levels due to possible fixation and reduced uptake (Kumar *et al*., 2025a).

Balance Sheet of Nutrients

Phosphorus Balance

The balance sheet of available soil P at the end of experiment as influenced by the levels of P fertilization in fodder cowpea crop was presented in Table 2.

The initial soil phosphorus level was 22.27 kg ha^{-1}. Phosphorus removal by fodder cowpea increased with rising levels of phosphorus fertilization. The highest phosphorus uptake (15.16 kg ha^{-1}) and post-harvest available P (24.78 kg ha^{-1}), were recorded under the combined application of 60 kg P_2O_5 ha^{-1} and 50 kg $ZnSO_4$ ha^{-1} (P_3F_2), resulting in a total available phosphorus pool of 39.94 kg ha^{-1} and a net gain of 42.33 kg ha^{-1}.

In contrast, the unfertilized control (P_0Z_0) recorded the lowest available P and lower depletion, with a net phosphorus loss of 5.90 kg ha^{-1}. The trend clearly indicated that phosphorus application significantly improved phosphorus status in the soil, and that balanced application with zinc further enhanced P retention and availability. Increase in residual soil phosphorus with higher fertilization levels has been reported in recent studies (Kumar *et al*., 2025a; Moreira *et al*., 2025).

Zinc Balance

The balance sheet of available soil Zn at the end of experiment as influenced by the levels of zinc fertilization in fodder cowpea crop was presented in Table 2a.

The initial soil zinc level was 30 kg ha^{-1}. Zinc removal by fodder cowpea increased consistently with increasing levels of zinc fertilization. The maximum zinc uptake (0.46 kg ha^{-1}) and post-harvest available Zn 3.6 kg ha^{-1} were recorded under the application of 50 kg $ZnSO_4$ ha^{-1} combined with 60 kg P_2O_5 ha^{-1} (P_3F_2). This resulted in a total available Zn pool of 4.15 kg ha^{-1} and a net zinc gain of 48.84 kg ha^{-1} over the initial status.

In contrast, the unfertilized control (P_0Z_0) exhibited the lowest available Zn 1.9 kg ha^{-1} and the lowest crop uptake 0.14 mg ha^{-1}, leading to a total Zn availability of only 1.75 kg ha^{-1} and a minimal net gain of 0.4 mg ha^{-1}. These results indicate that zinc application markedly improved Zn uptake and residual soil availability, especially when applied in balanced combination with phosphorus.

This indicates application of higher levels of zinc fertilizer not only improved crop uptake but also increased the residual zinc content in the soil, thereby enhancing nutrient availability for subsequent crops. These results were agreement with Kumawat and Kinchi (2017). Application of zinc fertilizers significantly improved both plant uptake and residual soil zinc status (Oliveira *et al*., 2024; Hemasree *et al.*, 2025).

Correlation

Correlation analysis (Table 3) revealed significant (p= 0.01) positive relationships among plant height, number of branches, number of leaves, leaf area index and dry matter production. These traits were also strongly correlated with green fodder yield (r = 0.949 to 0.956), indicating that better growth leads to higher yield.

Crude protein content was positively correlated with plant height (r = 0.978**) and leaf area index (r = 0.977**), while fibre content showed a strong negative correlation with plant height (r = -0.870**) and protein (r = -0.833**), suggesting improved digestibility with enhanced growth.Positive correlations between growth attributes and yield as well as quality traits have been reported in recent cowpea studies (Kumar *et al*., 2025)

Ash content had positive correlations with growth traits and protein, but negative with fibre, indicating better mineral quality in vigorous plants. Zinc content showed only a moderate positive correlation with fibre (r = 0.643), while flowering and maturity days had no significant association with yield or quality traits. These results are in confirming with Reddy *et al*. (2015).

Table 2 : Balance sheet of available phosphorus (kg ha^{-1}) at the end of season

S. No	Treatments	Initial soil 'P'	Fertilizer applied	Total initial soil P + fertilizer applied (P)	Removal by crop	Actual balance of available soil `P' at the end of crop	Total available `P' (plant + soil)	Net loss or grain
		(1)	(2)	3 (1+2)	(4)	(5)	6 (4+5)	7 (3-6)
1	P_0Z_0	22.27	0	22.27	6.89	9.48	16.37	5.90
2	P_0Z_1	22.27	0	22.27	8.93	10.15	19.08	3.19
3	P_0Z_2	22.27	0	22.27	10.14	10.92	21.06	1.21
4	P_1Z_0	22.27	20	42.27	8.11	10.64	18.76	23.51
5	P_1Z_1	22.27	20	42.27	10.56	14.91	25.47	16.81
6	P_1Z_2	22.27	20	42.27	11.58	17.88	29.46	12.81
7	P_2Z_0	22.27	40	62.27	8.98	13.53	22.51	39.76
8	P_2Z_1	22.27	40	62.27	12.55	20.30	32.86	29.42
9	P_2Z_2	22.27	40	62.27	13.60	22.27	35.87	26.40
10	P_3Z_0	22.27	60	82.27	9.47	14.44	23.91	58.36
11	P_3Z_1	22.27	60	82.27	14.48	21.85	36.32	45.95
12	P_3Z_2	22.27	60	82.27	15.16	24.78	39.94	42.33

Table 2a : Balance sheet of available zinc (g ha^{-1}) at the end of the season

S. No	Treatments	Initial soil 'Zn'	Fertilizer applied	Total initial soil P + fertilizer applied (Zn)	Removal by crop	Actual balance of available soil `Zn' at the end of crop	Total available `Zn' (plant + soil)	Net loss or grain
		(1)	(2)	3 (1+2)	(4)	(5)	6 (4+5)	7 (3-6)
1	P_0Z_0	3	0	3	0.14	1.75	1.89	1.10
2	P_0Z_1	3	25	28	0.15	1.99	2.14	25.85
3	P_0Z_2	3	50	53	0.18	2.16	2.34	50.65
4	P_1Z_0	3	0	3	0.20	2.06	2.25	0.74
5	P_1Z_1	3	25	28	0.24	2.50	2.73	25.26
6	P_1Z_2	3	50	53	0.24	2.52	2.77	50.22
7	P_2Z_0	3	0	3	0.28	2.36	2.64	0.35
8	P_2Z_1	3	25	28	0.31	2.91	3.21	24.78
9	P_2Z_2	3	50	53	0.33	3.22	3.55	49.44
10	P_3Z_0	3	0	3	0.35	2.76	3.12	-0.12
11	P_3Z_1	3	25	28	0.42	3.51	3.92	24.07
12	P_3Z_2	3	50	53	0.46	3.66	4.11	48.88

Table 3 : Correlation matrix between growth parameters, quality parameters and green fodder yield of fodder cowpea

		X1	X2	X3	X4	X5	X6	X7	X8	X9	X10	X11	X12	X13
X1	Plant height	1												
X2	No. of branches	0.979^{**}	1											
X3	No. of leaves	0.994^{**}	0.986^{**}	1										
X4	Leaf to stem ratio	0.992^{**}	0.964^{**}	0.982^{**}	1									
X5	Leaf area index	0.994^{**}	0.981^{**}	0.995^{**}	0.991^{**}	1								
X6	DMP (kg ha^{-1})	0.985^{**}	0.992^{**}	0.991^{**}	0.973^{**}	0.988^{**}	1							
X7	50 % flowering	0.491^{NS}	0.540^{NS}	0.480^{NS}	0.477^{NS}	0.500^{NS}	0.538^{NS}	1						
X8	Days to maturity	0.534^{NS}	0.603^{*}	0.560^{NS}	0.484^{NS}	0.566^{NS}	0.600^{*}	0.861^{**}	1					
X9	Protein	0.978^{**}	0.956^{**}	0.976^{**}	0.981^{**}	0.977^{**}	0.949^{**}	0.406^{NS}	0.464^{NS}	1				
X10	Fibre	-0.870^{**}	-0.886^{**}	-0.855^{**}	-0.847^{**}	-0.860^{**}	-0.869^{**}	-0.475^{NS}	-0.527^{NS}	-0.833^{**}	1			
X11	Ash	0.962^{**}	0.933^{**}	0.952^{**}	0.953^{**}	0.963^{**}	0.944^{**}	0.480^{NS}	0.561^{NS}	0.934^{**}	-0.876^{**}	1		
X12	Zinc	-0.489^{NS}	-0.546^{NS}	-0.494^{NS}	-0.451^{NS}	-0.487^{NS}	-0.574^{NS}	-0.260^{NS}	-0.351^{NS}	-0.362^{NS}	0.643^{*}	-0.547^{NS}	1	

Conclusion

The study concluded that combined application of 60 kg P_2O_5 $ha^-$with 25 kg $ZnSO_4$ ha^{-1} significantly improved growth, green fodder yield, quality, and nutrient use efficiency of fodder cowpea. Moderate fertilizer levels enhanced agronomic efficiency and nutrient recovery, while higher doses reduced efficiency due to nutrient fixation and luxury consumption. Balanced fertilization also increased residual soil phosphorus and zinc, indicating its economic viability and sustainability for sandy loam soils of southern Andhra Pradesh.

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