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Effect of Phosphorus and Zinc Nutrition on Yield, Nutrient Uptake and Soil Fertility in Fodder Cowpea (*Vigna unguiculata* L.)

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ABSTRACT

Background: Productivity of fodder cowpea (*Vigna unguiculata* L.) in sandy loam soils is often constrained by inadequate phosphorus and zinc availability. Balanced fertilization is essential to enhance nutrient uptake, fodder yield and soil fertility.

Methods: In Andhra Pradesh's Southern Agro-Climatic Zone, a field experiment was carried out during the *rabi* season. The effects of zinc (0, 25 and 50 kg $ZnSO_4$ ha^{-1} as factor-II) and phosphorus (0, 20, 40 and 60 kg P_2O_5 ha^{-1} as factor-I) on nutrient uptake, post-harvest soil nutrient status and cowpea fodder output were investigated using a factorial randomised block design.

Result: Application of 60 kg P_2O_5 ha^{-1} significantly increased nutrient uptake and produced the higher green and dry fodder yields. Zinc application at 50 kg $ZnSO_4$ ha^{-1} significantly enhanced fodder yield and nutrient uptake and was at par with 25 kg $ZnSO_4$ ha^{-1}. Higher nutrient levels reduced residual soil nitrogen and potassium due to increased uptake, while soil phosphorus and zinc status improved. Interaction effects were non-significant. Combined application of 60 kg P_2O_5 ha^{-1} with 25 kg $ZnSO_4$ ha^{-1} was found optimal for fodder cowpea.

Key words: Crop productivity, Fodder, Nutrient uptake, Soil health.

INTRODUCTION

Livestock is an indisputable component of agriculture and is crucial to India's rural economy. The contribution of the livestock sector to the Indian economy is 4.11% of GDP and for about 25.6 % of the total agriculture GDP (Samanta *et al.*, 2023). About 50% of total livestock productivity losses can be attributed to insufficient availability of feed and fodder. About 70-75% of the overall expense of raising livestock, especially milch animals, comes from feed. According to Roy *et al.* (2019), India has a net shortage in concentrated feed ingredients (28.9%), dry crop residue (23.4%) and green fodder (11.24%). Five per cent of India's total gross cultivated land is used for fodder production, a percentage that has stayed relatively stable over the past few decades. The states with the highest livestock productivity are Haryana, Punjab, Gujarat and some areas of Rajasthan, which have more land set aside for the cultivation of green fodder.

Cowpea (*Vigna unguiculata L.*), locally known as Bobbera, Lobia, or Chawli, is primarily cultivated across the northern, southern and central regions of India. In Andhra Pradesh, it is grown in an area of 0.17 lakh hectares with a production of 0.16 lakh tonnes with a productivity of 951 kg ha^{-1} (Season and Crop Report-Andhra Pradesh 2022-23). Cowpea is the most important food and fodder legume and serves as poor man's protein and considered as one of the most ancient human food sources (Lakshman and Dawson, 2022). A popular leguminous forage crop that can withstand drought, fodder cowpea is prized for its quick growth, large output of green biomass and high protein content. It plays a crucial role in supporting livestock nutrition, particularly in arid and semi-arid regions, due to its adaptability to dryland farming systems and its ability to fix atmospheric nitrogen, thereby improving soil health (Dharani *et al.*, 2025).

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Phosphorus (P) is crucial element among the three macronutrients (NPK) that is essential for optimal plant growth and development. It is vital constituent of majority of enzymes and co-enzymes which play an important role in the energy transformation, carbohydrates metabolism and also in respiration (Kumar *et al.*, 2016). Phosphorus is fundamental for cell division and development. Phosphorus fertiliser application also promotes root growth, which improves the availability of water and other nutrients to the plant's growing sections, increasing photosynthetic area and dry matter accumulation. Additionally, phosphorus promotes improved nodulation and the effective operation of nodule bacteria to fix nitrogen, which plants will use during the grain development stage and ultimately result in higher grain yield (Singh *et al.*, 2018).

Zinc (Zn) influences the synthesis of growth hormones and supports reproductive processes in certain plants

(Prasad *et al.,* 2016). Zinc plays an important role in chlorophyll formation, carbohydrate metabolism and protein biosynthesis. Zinc is necessary to activate many enzymes like tryptophan synthetase, superoxide dismutase and dehydrogenases. Zinc deficiency impairs RNA and protein biosynthesis leading to a reduction in plant protein content (Siva and George, 2017). During the growing season, applying zinc fertiliser promotes the growth of roots and shoots, which increases the output of seeds. Zinc fertilization is considered as productive and profitable approach for attaining quality fodder (Rengel, 2001).

MATERIALS AND METHODS

A field study was carried out in the dryland farm of S.V. Agricultural College, Tirupati, during the *Rabi* season of 2024-2025. The experimental soil had a sandy loam texture, a neutral pH of 7.0, low levels of organic carbon (0.27%) and available nitrogen (230 kg ha^{-1}), medium levels of available phosphorus (22.7 kg ha^{-1}), available potassium (235 kg ha^{-1}) and available zinc (1.5 mg/kg). Using a factorial idea with four levels of factor-I and three levels of factor-II, the experiment was set up in a randomised block design and duplicated three times. The treatments consist of three zinc levels- 0 kg $ZnSO_4$ ha^{-1} (Z0), 25 kg $ZnSO_4$ ha^{-1} (Z1) and 50 kg $ZnSO_4$ ha^{-1} (Z2)-and four phosphorus levels-0 kg P_2O_5 ha^{-1} (P0), 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). The fodder cowpea test variety used in this experiment was MFC-09, which was obtained from the Mandya Research Station in Karnataka, India.

All treatments received the standard dose of 25 kg N and 20 kg K_2O ha^{-1} and P_2O_5 was administered in accordance with the treatments. 50% of the nitrogen was applied as basal and the remaining 50% at 30 DAS. At the time of seeding, the full basal dose of potassium and phosphorus was applied. Zinc sulphate (20 kg ha^{-1}) was applied to the soil at 10 DAS in accordance with the treatments. The plants were cut close to the ground at the 50% flowering stage in order to harvest the crop for use as green feed (Dharani, 2025). The initial soil sample collected from the experimental field was analyzed for its physico-chemical properties. The soil was sandy loam in texture, comprising 71.2% sand, 10.4% silt and 18.4% clay, as determined by the Bouyoucos hydrometer method of Piper (1950). The soil was neutral in reaction with a pH of 7.0 and had low soluble salt content with an EC of 0.30 dS m^{-1} at 25°C. A glass electrode pH meter was used to measure the pH of the soil and a conductivity bridge was used to assess EC using the Jackson (1973) method. According to Walkley and Black (1934) wet digestion method, the soil's organic carbon concentration was 0.27%. According to Subbiah and Asija (1956) alkaline potassium permanganate technique, the soil's available nitrogen status was poor (168 kg ha^{-1}). According to Olsen's approach described by Olsen *et al.* (1954), the soil had a medium amount of accessible phosphorus (22.27 kg ha^{-1}). Available potassium content was 235 kg ha^{-1} and was determined using a flame photometer following the procedure of Jackson (1973). The available zinc content of the soil was 1.5 mg/kg and was estimated using DTPA extractant by AAS method as described by Tandon (1993).

Statistical analysis

The analysis of variance method recommended by Panse and Sukhatme (1985) was used to statistically assess the data collected on nutrient intake, post-harvest soil nutrient status and fodder cowpea production during the experiment. The "F" value at the five per cent probability level was used to test for statistical significance. If the "F" value was determined to be significant, the crucial difference (CD) was calculated at the five per cent probability level and the results were provided. "NS" was used to indicate treatment differences that were not statistically significant.

RESULTS AND DISCUSSION

Nutrient uptake at harvest

The uptake of nutrients by fodder cowpea at harvest was significantly influenced by phosphorus and zinc levels (Table 1). However, the interaction effect between phosphorus and zinc was found to be non-significant.

Nitrogen uptake

As phosphorus levels , nitrogen intake dramatically increased. The maximum uptake was recorded with 60 kg P_2O_5 ha^{-1} (92.6 kg ha^{-1}), followed by 40 kg P_2O_5 ha^{-1} (87.6 kg ha^{-1}) and 20 kg P_2O_5 ha^{-1} (78.4 kg ha^{-1}), while the control recorded the lowest value (63.1 kg ha^{-1}). The per cent increase over control was 24.2%, 38.8% and 46.8%, respectively. The enhanced nitrogen uptake with higher phosphorus levels can be attributed to improved root growth, nodulation and biological nitrogen fixation, supported by adequate energy supply in the form of ATP. Phosphorus plays a key role in symbiotic activity and nitrogen metabolism, resulting in greater nitrogen assimilation and translocation within the plant. Similar findings were reported, who observed significant improvement in nitrogen uptake of cowpea with increased phosphorus application.

Zinc fertilization also significantly influenced nitrogen uptake. Application of 50 kg $ZnSO_4$ ha^{-1} recorded the highest uptake (84.2 kg ha^{-1}) which was statistically at par with 25 kg $ZnSO_4$ ha^{-1} (80.9 kg ha^{-1}). The increase over control was 6.3% and 10.6%, with only 4.1% increase over recommended level. Zinc enhances nitrogen uptake through its role in enzyme activation, protein synthesis and auxin metabolism, thereby improving nitrogen assimilation and plant growth. Similar results were reported by Pandey *et al.* (2019) in cluster bean.

Phosphors uptake

Phosphorus uptake was significantly influenced by graded levels of phosphorus and zinc fertilization. Application of 60 kg P_2O_5 ha^{-1} recorded the highest uptake (13.0 kg ha^{-1}), which was significantly superior to 40 kg P_2O_5 ha^{-1} (11.7 kg ha^{-1}), 20 kg P_2O_5 ha^{-1} (10.1 kg ha^{-1}) and control (P_0: 8.7 kg ha^{-1}). The per cent increase over control was 16.1, 34.5 and 49.4% respectively, while P_3 showed 11.1% higher uptake over the recommended level (P_2). The increased uptake may be attributed to enhanced phosphorus availability, improved root proliferation and higher phosphatase activity, facilitating efficient nutrient absorption. These findings are consistent with those of Nadeem *et al.* (2017) in cowpea and Rani *et al.* (2016) in mungbean.

Zinc application also significantly improved phosphorus uptake. Application of 50 kg $ZnSO_4$ ha^{-1} (Z_2) recorded the highest uptake (12.6 kg ha^{-1}), followed by Z1 (11.6 kg ha^{-1}) and Z0 (8.4 kg ha^{-1}), with per cent increases of 38.1 and 50.0% over control. Zinc plays a vital role in root development and enzymatic activity, which can indirectly enhance phosphorus acquisition from the soil. These findings corroborate in cowpea and Manisha *et al.* (2021) in fodder cowpea crop in cowpea.

Potassium uptake

Potassium uptake in fodder cowpea was significantly influenced by phosphorus and zinc application, while their interaction was non-significant. Application of 60 kg P_2O_5 ha^{-1} (P_3) recorded the highest uptake (28.4 kg ha^{-1}), followed by P_2 (24.5 kg ha^{-1}) and P_1 (20.6 kg ha^{-1}), whereas control (P_0) recorded the lowest (17.3 kg ha^{-1}). The per cent increase over control was 19.1, 41.6 and 64.2%, respectively. The increased uptake may be attributed to enhanced root growth and nutrient absorption. Zinc application at 50 kg $ZnSO_4$ ha^{-1} (Z_2) recorded higher uptake (25.7 kg ha^{-1}), which was at par with Z_1 (23.8 kg ha^{-1}). These findings are in agreed with in cowpea and crop.

Zinc uptake

As $ZnSO_4$ treatment levels rose, zinc uptake dramatically increased. Zinc uptake was significantly highest at 50 kg $ZnSO_4$ ha^{-1} (311 g ha^{-1}) and lowest at control (219 g ha^{-1}). Zinc uptake increased by 12.2% and 8.1%, respectively, at 50 kg $ZnSO_4$ ha^{-1} compared to control and 25 kg $ZnSO_4$ ha^{-1}. Phosphorus application showed an increasing trend in zinc uptake, with 60 kg P_2O_5 ha^{-1} showing the highest zinc uptake (393 g ha^{-1}) and control showing the lowest (156 g ha^{-1}). These results are consistent with cowpea research by Neeraj *et al.* (2022). Growing green fodder and dry matter output are the reasons for the increase in zinc uptake with phosphorus application. Zinc absorption rises to 60 kg P_2O_5 ha^{-1}. This could be because observed that phosphorus inhibits the translocation of zinc from the root to the above-ground section of the plant, negatively affecting the zinc content in the plant

Available soil nutrient status

Available soil nitrogen

After harvest of the crop, soil samples were analyzed for available nutrient status (Table 2). The available nitrogen content in soil decreased significantly with increasing phosphorus levels. The highest available nitrogen was recorded under P_0 (191 kg ha^{-1}), followed by P_1 (183 kg ha^{-1}), P_2 (168 kg ha^{-1}) and P_3 (145 kg ha^{-1}). Among zinc levels, control (Z_0) recorded the highest available nitrogen (181 kg ha^{-1}), while the lowest was recorded under 25 kg ha^{-1} $ZnSO_4$ (Z_2) (163 kg ha^{-1}), which was on par with Z_1 (169 kg ha^{-1}). These findings are agreed with Mobeena *et al.* (2020) in fodder cowpea. The reduction in residual soil nitrogen with higher phosphorus and zinc levels may be due to greater crop growth and higher nitrogen uptake under improved nutrient availability. Similar findings were reported Arvind *et al.* (2020) in fodder maize under zinc management practices, where higher nutrient supply enhanced crop growth and nutrient removal from soil.

Available phosphorus in soil increased significantly with increasing phosphorus levels. The highest available phosphorus was recorded under P_3 (20.4 kg ha^{-1}), followed by P_2 (17.9 kg ha^{-1}), P1 (14.5 kg ha^{-1}) and P_0 (10.2 kg ha^{-1}). Similarly, among zinc levels, the highest available phosphorus was observed under Z_2 (18.7 kg ha^{-1}), followed

Table 1: Nutrient uptake of fodder cowpea as influenced by phosphorus and zinc levels.

Treatments	Nitrogen uptake (kg ha^{-1})	Phosphorus uptake (kg ha^{-1})	Potassium uptake (kg ha^{-1})	Zinc uptake (g ha^{-1})
Phosphorus levels				
P_0 - 0 kg ha^{-1}	63.1	8.7	17.3	156
P_1 - 20 kg ha^{-1}	78.4	10.1	20.6	239
P_2 - 40 kg ha^{-1}	87.6	11.7	24.5	307
P_3 - 60 kg ha^{-1}	92.6	13.0	28.4	393
SEm±	1.75	0.37	1.05	12.9
CD (P=0.05)	5.1	1.1	3.1	38
Zinc levels				
Z_0 - 0 kg ha^{-1}	76.1	8.4	18.7	219
Z_1 - 25 kg ha^{-1}	80.9	11.6	23.8	285
Z_2 - 50 kg ha^{-1}	84.2	12.6	25.7	311
SEm±	1.51	0.32	0.91	11.2
CD (P=0.05)	4.4	0.9	2.7	32

Table 2: Phosphorus and zinc levels' effects on the post-harvest soil nutrient status of fodder cowpea.

Treatments	Available N (kg ha^{-1})	Available P (kg ha^{-1})	Available K (kg ha^{-1})	Available Zn (kg ha^{-1})
Phosphorus levels				
P_0 - 0 kg ha^{-1}	191	10.2	238	2.0
P_1 - 20 kg ha^{-1}	183	14.5	225	2.4
P_2 - 40 kg ha^{-1}	168	17.9	207	2.8
P_3 - 60 kg ha^{-1}	145	20.4	195	3.3
SEm±	4.2	0.82	6.7	0.16
CD (P=0.05)	12	2.4	20	0.4
Zinc levels				
Z_0 - 0 kg ha^{-1}	181	10.0	228	2.2
Z_1 - 25 kg ha^{-1}	169	17.2	215	2.7
Z_2 - 50 kg ha^{-1}	163	18.7	201	2.9
SEm±	3.6	0.71	5.8	0.14
CD (P=0.05)	11	2.1	17	0.3

by Z_1 (17.2 kg ha^{-1}), while the lowest was recorded under Z_0 (10.0 kg ha^{-1}). The increase in available phosphorus with higher phosphorus application may be attributed to the direct addition of phosphorus to the soil and its relatively low mobility, resulting in residual accumulation. Similar observations were reported in cowpea and *kabuli* chickpea (Siva and George, 2017) under phosphorus and zinc fertilization.

Available potassium in soil decreased significantly with increasing phosphorus levels. The highest potassium status was recorded under P_0 (238 kg ha^{-1}), while the lowest was observed under P_3 (195 kg ha^{-1}). Among zinc levels, Z_0 recorded higher potassium availability (228 kg ha^{-1}), whereas Z_2 recorded the lowest value (201 kg ha^{-1}). The reduction in potassium availability may be due to increased crop uptake under higher phosphorus and zinc application, as potassium plays a major role in growth, enzyme activation and water regulation in plants. Similar results were reported by Samanta *et al.* (2023) in fodder berseem where higher nutrient levels enhanced biomass production and nutrient uptake, thereby reducing residual soil potassium.

Available zinc in soil increased significantly with increasing phosphorus levels and was highest under P_3 (3.3 kg ha^{-1}), followed by P_2 (2.8 kg ha^{-1}), P1 (2.4 kg ha^{-1}) and P_0 (2.0 kg ha^{-1}). Similarly, among zinc levels, the highest available zinc was recorded under Z_2 (2.9 kg ha^{-1}), followed by Z_1 (2.7 kg ha^{-1}) and Z_0 (2.2 kg ha^{-1}). The increase in residual zinc content with higher zinc application may be due to the direct addition of zinc to the soil through $ZnSO_4$. The increase in zinc availability under higher phosphorus levels may indicate a balanced nutrient interaction under the present soil conditions. Similar observations were reported in legumes under different zinc management practices.

Yield

Different amounts of zinc and phosphorus had a substantial impact on cowpea's green and dry fodder yield, but the interaction effect was not significant (Table 3).

Table 3: Impact of varying zinc and phosphorus levels on cowpea fodder yield.

Treatments	Green fodder yield (q ha^{-1})	Dry fodder yield (q ha^{-1})
Phosphorus levels		
P_0- 0 kg ha^{-1}	10.72	3.15
P_1- 20 kg ha^{-1}	13.03	4.70
P_2- 40 kg ha^{-1}	13.68	5.17
P_3- 60 kg ha^{-1}	14.99	6.29
SEm±	0.31	0.15
CD (P=0.05)	0.93	0.44
Zinc levels		
Z_0- 0 kg ha^{-1}	11.14	4.07
Z_1- 25 kg ha^{-1}	13.73	5.13
Z_2- 50 kg ha^{-1}	14.44	5.30
SEm±	0.27	0.13
CD (P=0.05)	0.81	0.38

Phosphorus application has a major impact on the yield of dry and green fodder. Applying 60 kg P_2O_5 ha^{-1} (P_3) resulted in higher green (14.99 q ha^{-1}) and dry fodder (6.29 q ha^{-1}) yields, which were comparable to 20 kg P_2O_5 ha^{-1} (P_1) and followed by 40 kg P_2O_5 ha^{-1} (P2). The control group (P_0) had lower green (10.73 q ha^{-1}) and dry (3.16 q ha^{-1}) yields. greater root development, which results in greater nutrient uptake and utilisation, is responsible for the increase in green and dry fodder output with rising phosphorus levels. Increased plant height, leaf area and number of leaves per plant are probably due to phosphorus's critical role in root development, energy transfer and general plant vigour. These findings were in accordance with the results reported by and Mobeena *et al.* (2020).

In comparison to control (Z_0) and 25 kg $ZnSO_4$ ha^{-1}, which was statistically equivalent to 25 kg $ZnSO_4$ ha^{-1} (Z_1), application of 50 kg $ZnSO_4$ ha^{-1} (Z_2) resulted in substantially higher yields of dry fodder (5.30 kg ha^{-1}) and green cowpeas

(14.45 q ha^{-1}). Yields of dry fodder (4.07 q ha^{-1}) and green (11.14 q ha^{-1}) were significantly lower in the control group (Z_0). The increase in green and dry fodder output after zinc administration can be explained by the various physiological and biochemical functions in plant development. Zinc is a necessary cofactor for proteins and enzymes involved in protein synthesis, nucleic acid metabolism and cell division (Marschner, 1986). Additionally, zinc is necessary for the production of tryptophan, a precursor to indole-3-acetic acid (IAA), which controls plant growth and development, as well as for the metabolism of carbohydrates (Oosterhuis *et al.*, 1996). Additionally, Mohan and Singh (2014), Pandey *et al.* (2019), Manisha (2021) and Dharani *et al.* (2025) have demonstrated positive responses of cowpea production to zinc application.

CONCLUSION

From the present study, it can be concluded that combined application of 60 kg P_2O_5 ha^{-1} along with 25 kg $ZnSO_4$ ha^{-1} was found to be the most effective and economically sustainable nutrient management strategy for maximizing fodder yield and nutrient uptake of fodder cowpea, while maintaining soil fertility of fodder cowpea during the *rabi* season on sandy loam soils of Southern Agro-Climatic Zone of Andhra Pradesh.

Conflict of interest

We wish to confirm that there are known conflicts of interest associated with this publication and there has been no significiant financial support for this work that could have influenced its outcome.

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