



## Soil fertility and nutrient dynamics of chickpea under integrated phosphorus management practices

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### Abstract

A field experiment was conducted during the *rabi* season of 2022–23 at the Agronomy Instructional Farm, Chimanbhai Patel College of Agriculture, Sardarkrushinagar Dantiwada Agricultural University, Sardarkrushinagar, Gujarat, to evaluate the effect of integrated phosphorus management on nutrient dynamics, nutrient uptake and soil fertility status in chickpea (*Cicer arietinum* L.). The experiment was laid out in a factorial randomized block design with four replications comprising three levels of phosphorus (20, 30 and 40 kg P<sub>2</sub>O<sub>5</sub> ha<sup>-1</sup>), two levels of vermicompost (1 and 2 t ha<sup>-1</sup>) and two levels of phosphorus-solubilizing bacteria (PSB) inoculation (without and with PSB @ 5 ml kg<sup>-1</sup> seed). Results revealed that application of 40 kg P<sub>2</sub>O<sub>5</sub> ha<sup>-1</sup> significantly enhanced nitrogen and phosphorus content in seed and stover, nutrient uptake, seed yield and stover yield over 20 kg P<sub>2</sub>O<sub>5</sub> ha<sup>-1</sup> and remained statistically at par with 30 kg P<sub>2</sub>O<sub>5</sub> ha<sup>-1</sup> in most cases. Vermicompost application at 2 t ha<sup>-1</sup> significantly improved nutrient concentration, nutrient uptake and crop productivity compared with 1 t ha<sup>-1</sup>. Seed inoculation with PSB also resulted in significant improvement in nutrient uptake and yield owing to enhanced phosphorus solubilization and nutrient availability. The integrated application of phosphorus, vermicompost and PSB improved post-harvest soil fertility by increasing available nitrogen, available phosphorus, organic carbon content and soil microbial population. Higher nutrient uptake was closely associated with increased seed and stover yields, indicating improved nutrient-use efficiency under integrated nutrient management. The study demonstrated that integrated phosphorus management involving 40 kg P<sub>2</sub>O<sub>5</sub> ha<sup>-1</sup>, vermicompost at 2 t ha<sup>-1</sup> and PSB inoculation effectively enhanced nutrient dynamics, soil fertility and productivity of chickpea under North Gujarat conditions. Therefore, the integrated use of inorganic phosphorus, organic manure and biofertilizer may be recommended as a sustainable nutrient management strategy for chickpea cultivation.

**Keywords:** Chickpea, integrated phosphorus management, vermicompost, phosphorus-solubilizing bacteria, nutrient uptake, soil fertility, organic carbon, microbial population

### Introduction

Chickpea (*Cicer arietinum* L.) is one of the most important grain legumes cultivated worldwide and occupies a prominent position in Indian agriculture. Apart from being a rich source of dietary protein, chickpea plays a significant role in sustaining soil fertility through biological nitrogen fixation and addition of organic residues to the soil. As a leguminous crop, it contributes to the improvement of soil health and forms an important component of sustainable cropping systems, particularly in arid and semi-arid regions. The productivity and sustainability of chickpea cultivation largely depend on balanced nutrient management. Among the essential plant nutrients, phosphorus is considered the second most important nutrient after nitrogen and often acts as a major limiting factor in pulse production. Phosphorus is involved in numerous physiological and biochemical processes including energy transfer, photosynthesis, root development, nodulation, biological nitrogen fixation and seed formation. Adequate phosphorus nutrition enhances root growth and improves the efficiency of nutrient uptake, resulting in better crop performance. However, phosphorus availability in soil is generally low because a substantial

portion of applied phosphorus becomes fixed in insoluble forms and remains unavailable to plants.

The continuous and indiscriminate use of chemical fertilizers without adequate supplementation of organic sources has led to deterioration of soil health, declining nutrient-use efficiency and reduced sustainability of agricultural production systems. Therefore, integrated nutrient management approaches that combine inorganic fertilizers with organic manures and beneficial microorganisms have gained considerable attention for improving nutrient availability and maintaining soil fertility. Such integrated approaches not only enhance crop productivity but also improve soil physical, chemical and biological properties.

Vermicompost is an eco-friendly organic amendment produced through the decomposition of organic wastes by earthworms. It contains appreciable amounts of macro- and micronutrients in readily available forms along with beneficial microorganisms, enzymes and plant growth regulators. Application of vermicompost improves soil structure, aggregation, water-holding capacity, aeration and microbial activity. It also increases organic carbon content

and enhances nutrient retention in soil, thereby contributing to long-term soil fertility and sustainability.

Phosphorus-solubilizing bacteria (PSB) constitute an important group of beneficial microorganisms capable of transforming insoluble and fixed forms of phosphorus into plant-available forms through the production of organic acids and other metabolites. Inoculation with PSB improves phosphorus availability, nutrient uptake efficiency and root development while reducing dependence on chemical phosphorus fertilizers. The enhanced microbial activity associated with PSB inoculation also contributes to improved nutrient cycling and soil biological health.

Integrated application of phosphorus fertilizer, vermicompost and PSB has the potential to improve nutrient availability, nutrient uptake and nutrient-use efficiency while simultaneously enhancing soil fertility status. Such practices can increase the availability of nitrogen and phosphorus in soil, improve soil organic carbon content and stimulate microbial populations, thereby promoting sustainable chickpea production. Evaluation of these integrated nutrient management strategies is essential for developing efficient and environmentally sound nutrient management practices for pulse-based cropping systems.

Considering the growing concern regarding soil fertility depletion and declining nutrient-use efficiency in agricultural soils, the present investigation was undertaken to assess the effect of integrated phosphorus management involving phosphorus fertilizer, vermicompost and phosphorus-solubilizing bacteria on nutrient content, nutrient uptake, soil fertility status and microbial dynamics in chickpea under North Gujarat conditions.

## Materials and Methods

A field experiment was conducted during the *Rabi* season of 2022–23 at the Agronomy Instructional Farm, Chimanbhai Patel College of Agriculture, Sardarkrushinagar Dantiwada Agricultural University, Sardarkrushinagar, and Gujarat, India. The experimental site is situated at 24°19' N latitude and 72°19' E longitude with an altitude of 154.52 m above mean sea level and falls under the North Gujarat Agro-climatic Zone characterized by semi-arid climatic conditions. The soil of the experimental field was loamy sand in texture, slightly alkaline in reaction (pH 7.5) and non-saline with an electrical conductivity of 0.15 dS m<sup>-1</sup>. The soil contained 0.24 per cent organic carbon, 160.9 kg ha<sup>-1</sup> available nitrogen, 32.75 kg ha<sup>-1</sup> available phosphorus and 286.2 kg ha<sup>-1</sup> available potassium before sowing.

The experiment was laid out in a factorial randomized block design with four replications comprising twelve treatment combinations. The treatments consisted of three phosphorus levels (20, 30 and 40 kg P<sub>2</sub>O<sub>5</sub> ha<sup>-1</sup>), two levels of vermicompost (1 and 2 t ha<sup>-1</sup>) and two levels of phosphorus-solubilizing bacteria (PSB) comprising without inoculation and seed inoculation with PSB @ 5 ml kg<sup>-1</sup> seed. Chickpea variety GJG 3 was sown on 14 November 2022 using a seed rate of 60 kg ha<sup>-1</sup> with a row spacing of 45 cm. Nitrogen was applied uniformly to all treatments through urea at the recommended dose of 20 kg ha<sup>-1</sup>, whereas phosphorus was supplied through single super phosphate according to treatment specifications. Vermicompost was applied in furrows at sowing and PSB inoculation was carried out before sowing in the respective treatments. The crop was grown under recommended agronomic practices and irrigated as required during the crop growth period.

Representative seed and stover samples collected at harvest were oven dried, ground and analysed for nutrient content. Nitrogen content in seed and stover was determined by the modified Kjeldahl method, while phosphorus content was estimated by the vanadomolybdo-phosphoric yellow colour method using a spectrophotometer after wet digestion of plant samples. Nutrient uptake by seed and stover was computed by multiplying nutrient concentration with the respective dry matter yield and expressed as kg ha<sup>-1</sup>. Total nutrient uptake was obtained by summing the uptake through seed and stover.

After harvest of the crop, composite soil samples from each plot were collected from 0–15 cm depth and analysed for available nitrogen, available phosphorus, organic carbon and microbial population using standard laboratory procedures. Available nitrogen was estimated by the alkaline potassium permanganate method, available phosphorus by Olsen's method and organic carbon by Walkley and Black's rapid titration method. The microbial population in soil was determined by the standard serial dilution and spread plate technique and expressed as colony forming units (CFU).

The data generated from nutrient content, nutrient uptake and post-harvest soil fertility parameters were subjected to analysis of variance appropriate to the factorial randomized block design. The significance of treatment effects was tested using the F-test and treatment means were compared using the critical difference (CD) test at the 5 per cent level of significance following the procedure described by Panse and Sukhatme (1985).

## Results and Discussion

### Nitrogen content in seed and stover

Nitrogen content in seed and stover was significantly influenced by integrated phosphorus management practices. Application of higher levels of phosphorus resulted in increased nitrogen concentration in both seed and stover. The highest nitrogen content was recorded under application of 40 kg P<sub>2</sub>O<sub>5</sub> ha<sup>-1</sup>, which remained statistically comparable with 30 kg P<sub>2</sub>O<sub>5</sub> ha<sup>-1</sup> and significantly superior to 20 kg P<sub>2</sub>O<sub>5</sub> ha<sup>-1</sup>. The increase in nitrogen concentration under higher phosphorus nutrition may be attributed to enhanced nodulation and biological nitrogen fixation. Phosphorus is essential for ATP synthesis and energy transfer, which are required for efficient functioning of nitrogen-fixing bacteria and subsequent accumulation of nitrogen in plant tissues.

Application of vermicompost at the higher level significantly enhanced nitrogen content in seed and stover. Vermicompost acts as a source of readily available nutrients and promotes microbial activity in the rhizosphere, resulting in improved nutrient absorption and translocation. Similarly, PSB inoculation significantly increased nitrogen content over the uninoculated treatment. Increased phosphorus availability through microbial solubilization improves root growth and biological nitrogen fixation, thereby increasing nitrogen accumulation in plant tissues.

### Phosphorus content in seed and stover

Phosphorus content in seed and stover increased significantly with increasing phosphorus levels. Application of 40 kg P<sub>2</sub>O<sub>5</sub> ha<sup>-1</sup> recorded the highest phosphorus concentration in plant tissues. The increase may be attributed to greater availability of phosphorus in the root zone and enhanced absorption by the crop. Adequate

phosphorus nutrition improves root proliferation and nutrient uptake efficiency, resulting in greater accumulation of phosphorus in seed and stover.

Application of vermicompost significantly enhanced phosphorus content in plant tissues. Organic acids produced during decomposition of organic matter reduce phosphorus fixation and increase its availability to plants. In addition, vermicompost stimulates microbial activity that contributes to nutrient mineralization and phosphorus release. PSB inoculation also significantly improved phosphorus concentration owing to its ability to solubilize insoluble phosphorus compounds and make them available for plant uptake.

#### **Nitrogen uptake**

Nitrogen uptake by seed, stover and total crop was significantly influenced by phosphorus levels, vermicompost application and PSB inoculation. Application of higher phosphorus levels recorded significantly greater nitrogen uptake compared with lower phosphorus levels. The increase in nitrogen uptake was associated with higher nitrogen concentration and greater seed and stover yields obtained under improved phosphorus nutrition. Enhanced nodulation and biological nitrogen fixation under adequate phosphorus supply also contributed to increased nitrogen acquisition by the crop.

Vermicompost application significantly increased nitrogen uptake over the lower dose. Improved nutrient availability, better root growth and enhanced microbial activity under vermicompost application facilitated greater nutrient absorption and utilization. Similarly, PSB inoculation significantly enhanced nitrogen uptake owing to improved phosphorus availability, which stimulated root development and nitrogen fixation. Increased crop biomass and seed production under integrated nutrient management further contributed to higher nitrogen uptake.

#### **Phosphorus uptake**

Phosphorus uptake by seed, stover and total crop increased significantly with increasing levels of phosphorus application. The highest phosphorus uptake was recorded under 40 kg P<sub>2</sub>O<sub>5</sub> ha<sup>-1</sup>. Increased uptake was mainly attributed to greater phosphorus concentration in plant tissues coupled with higher seed and stover yields. Improved root development and nutrient absorption capacity under adequate phosphorus nutrition facilitated greater uptake of phosphorus.

Application of vermicompost significantly increased phosphorus uptake due to enhanced phosphorus availability and reduced fixation losses. Organic matter decomposition improves nutrient mobility and facilitates phosphorus absorption by plant roots. PSB inoculation also significantly increased phosphorus uptake through solubilization of fixed forms of phosphorus present in the soil. The combined effect of increased phosphorus availability and enhanced crop growth resulted in greater phosphorus accumulation in seed and stover.

#### **Seed yield and stover yield**

Seed yield and stover yield were significantly influenced by integrated phosphorus management practices. Application of higher phosphorus levels resulted in substantial improvement in crop productivity. Increased phosphorus availability promoted root development, nodulation, nutrient

uptake and photosynthetic activity, which ultimately enhanced seed and biomass production. The increase in yield under higher phosphorus levels was closely associated with greater nutrient uptake and improved physiological efficiency of the crop.

Application of vermicompost significantly increased seed and stover yields over the lower level. The beneficial effects of vermicompost may be attributed to improved soil fertility, enhanced nutrient availability, increased microbial activity and better moisture retention. These factors collectively promoted vigorous crop growth and higher biomass accumulation.

Similarly, PSB inoculation significantly increased seed and stover yields compared with uninoculated treatment. Improved phosphorus solubilization and nutrient uptake under PSB inoculation enhances crop growth and productivity. The increase in yield under integrated nutrient management played an important role in increasing total nutrient uptake by the crop.

#### **Available nitrogen in soil after harvest**

Available nitrogen status of soil after harvest was significantly influenced by phosphorus fertilization, vermicompost application and PSB inoculation. Application of higher phosphorus levels resulted in increased residual soil nitrogen compared with lower phosphorus levels. Enhanced nodulation and biological nitrogen fixation under adequate phosphorus nutrition contributed to greater nitrogen addition to the soil through root residues and nodules.

Application of vermicompost significantly increased available soil nitrogen owing to gradual mineralization of organic nitrogen compounds and stimulation of microbial activity. Similarly, PSB inoculation improved residual nitrogen status through enhanced biological nitrogen fixation and improved soil biological processes. The increase in available nitrogen after harvest indicates the beneficial residual effect of integrated nutrient management on soil fertility.

#### **Available phosphorus in soil after harvest**

Available phosphorus content of soil after harvest increased significantly with increasing phosphorus levels. Application of higher phosphorus doses maintained greater residual phosphorus availability in soil. This indicates that phosphorus application not only fulfilled crop requirements but also contributed to the build-up of available phosphorus reserves in the soil.

Application of vermicompost significantly enhanced available soil phosphorus. Organic acids released during decomposition reduced phosphorus fixation and increased nutrient availability. PSB inoculation further improved available phosphorus status by continuously solubilizing fixed phosphorus throughout the crop growth period. The combined effect of phosphorus fertilization, organic manure and microbial inoculation contributed to improvement in residual phosphorus fertility.

#### **Organic carbon content**

Organic carbon content of soil after harvest was significantly influenced by integrated phosphorus management practices. Vermicompost application recorded a marked increase in soil organic carbon due to direct addition of organic matter and enhancement of microbial

biomass. Higher organic carbon content improves soil aggregation, water-holding capacity, nutrient retention and overall soil quality.

Although phosphorus and PSB exerted comparatively smaller effects on soil organic carbon, they indirectly contributed through increased root biomass and crop residue addition. Maintenance of soil organic carbon is essential for sustaining soil productivity and improving long-term soil health.

### Soil microbial population

Soil microbial population was significantly enhanced by application of vermicompost and PSB inoculation.

Vermicompost provides a favourable substrate for microbial growth and supplies energy sources required for microbial multiplication. Increased microbial activity under vermicompost application improved nutrient cycling and soil biological fertility.

PSB inoculation significantly increased microbial population through establishment and proliferation of beneficial microorganisms in the rhizosphere. Higher phosphorus levels also promoted microbial growth indirectly through enhanced root development and root exudation. Increased microbial activity is of considerable importance for maintaining nutrient availability, organic matter decomposition and long-term soil fertility.

**Table 1:** Effect of phosphorus, vermicompost and PSB on N and P content of chickpea

Treatments	N content (%)		P content (%)	
	Seed	Stover	Seed	Stover
A. Levels of phosphorus				
P <sub>1</sub> : 20 kg/ha	3.19	1.30	0.473	0.191
P <sub>2</sub> : 30 kg/ha	3.32	1.32	0.512	0.247
P <sub>3</sub> : 40 kg/ha	3.40	1.36	0.535	0.250
S.Em.±	0.06	0.02	0.008	0.004
C.D. at 5%	NS	NS	0.024	0.012
B. Levels of vermicompost				
V <sub>1</sub> : 1 t/ha	3.25	1.30	0.494	0.223
V <sub>2</sub> : 2 t/ha	3.36	1.35	0.521	0.236
S.Em.±	0.05	0.02	0.007	0.003
C.D. at 5%	NS	NS	0.020	0.010
C. PSB application				
B <sub>0</sub> : Without PSB	3.26	1.32	0.497	0.224
B <sub>1</sub> : With PSB @ 5 ml/kg seed	3.35	1.34	0.517	0.235
S.Em.±	0.05	0.02	0.007	0.003
C.D. at 5%	NS	NS	0.020	0.010
Interactions				
P × V	NS	NS	NS	NS
P × B	NS	NS	NS	NS
V × B	NS	NS	NS	NS
P × V × B	NS	NS	NS	NS
C.V.%	6.99	6.70	6.69	7.39

**Table 2:** Effect of phosphorus, vermicompost and PSB on N and P uptake by chickpea

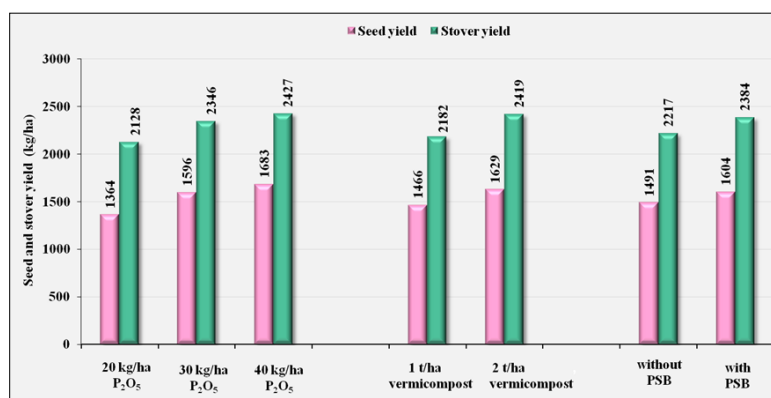
Treatments	N uptake (kg/ha)		P uptake (kg/ha)	
	Seed	Stover	Seed	Stover
A. Levels of phosphorus				
P <sub>1</sub> : 20 kg/ha	43.51	27.70	6.45	4.06
P <sub>2</sub> : 30 kg/ha	52.99	30.97	8.17	5.82
P <sub>3</sub> : 40 kg/ha	57.22	33.03	9.00	6.09
S.Em.±	1.84	1.00	0.25	0.16
C.D. at 5%	5.30	2.88	0.71	0.45
B. Levels of vermicompost				
V <sub>1</sub> : 1 t/ha	47.71	28.45	7.24	4.92
V <sub>2</sub> : 2 t/ha	54.77	32.69	8.50	5.73
S.Em.±	1.51	0.82	0.20	0.13
C.D. at 5%	4.33	2.35	0.58	0.37
C. PSB application				
B <sub>0</sub> : Without PSB	48.72	29.27	7.44	5.01
B <sub>1</sub> : With PSB @ 5 ml/kg seed	53.76	31.87	8.30	5.64
S.Em.±	1.51	0.82	0.20	0.13
C.D. at 5%	4.33	2.35	0.58	0.37
Interactions				
P × V	NS	NS	NS	NS
P × B	NS	NS	NS	NS
V × B	NS	NS	NS	NS
P × V × B	NS	NS	NS	NS
C.V.%	14.39	13.11	12.47	11.83

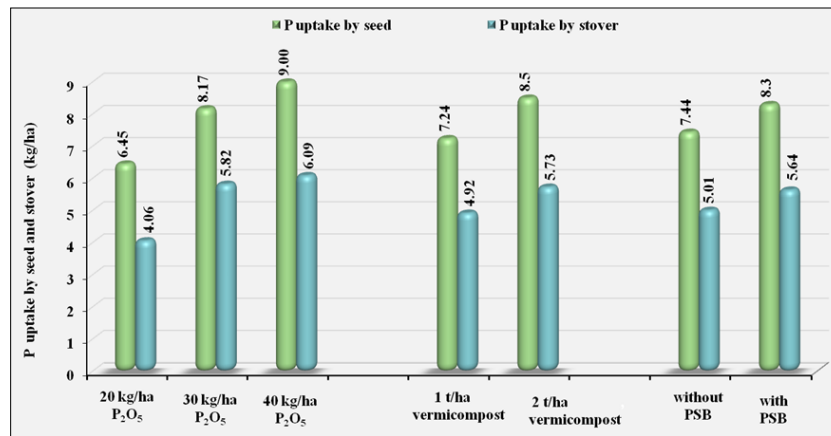
**Table 3:** Effect of phosphorus, vermicompost and PSB on seed yield, stover yield and harvest index of chickpea

Treatments	Seed yield (kg/ha)	Stover yield (kg/ha)	Harvest index (%)
A. Levels of phosphorus			
P <sub>1</sub> : 20 kg/ha	1364	2128	39.07
P <sub>2</sub> : 30 kg/ha	1596	2346	40.50
P <sub>3</sub> : 40 kg/ha	1683	2427	41.00
S.Em.±	47.41	70.16	0.95
C.D. at 5%	136	202	NS
B. Levels of vermicompost			
V <sub>1</sub> : 1 t/ha	1466	2182	40.18
V <sub>2</sub> : 2 t/ha	1629	2419	40.21
S.Em.±	38.71	57.28	0.78
C.D. at 5%	111	165	NS
C. PSB application			
B <sub>0</sub> : Without PSB	1491	2217	40.17
B <sub>1</sub> : With PSB @ 5 ml/kg seed	1604	2384	40.22
S.Em.±	38.71	57.28	0.78
C.D. at 5%	111	165	NS
Interactions			
P × V	NS	NS	NS
P × B	NS	NS	NS
V × B	NS	NS	NS
P × V × B	NS	NS	NS
C.V.%	12.25	12.20	9.50

**Table 4:** Effect of phosphorus, vermicompost and PSB on available N, P<sub>2</sub>O<sub>5</sub>, organic carbon and microbial counts in soil after harvest of chickpea

Treatments	Available N (kg/ha)	Available P <sub>2</sub> O <sub>5</sub> (kg/ha)	Organic carbon (%)	Microbial count (cfu × 10 <sup>5</sup> /g soil)
A. Levels of phosphorus				
P <sub>1</sub> : 20 kg/ha	165.47	34.39	0.254	180.9
P <sub>2</sub> : 30 kg/ha	172.86	38.33	0.260	177.9
P <sub>3</sub> : 40 kg/ha	179.58	40.11	0.269	172.1
S.Em.±	3.33	0.67	0.01	3.6
C.D. at 5%	9.59	1.94	NS	NS
B. Levels of vermicompost				
V <sub>1</sub> : 1 t/ha	168.64	36.79	0.257	172.8
V <sub>2</sub> : 2 t/ha	176.63	38.43	0.265	181.2
S.Em.±	2.72	0.55	0.01	2.9
C.D. at 5%	7.83	1.58	NS	8.4
C. PSB application				
B <sub>0</sub> : Without PSB	171.07	36.97	0.259	171.3
B <sub>1</sub> : With PSB @ 5 ml/kg seed	174.20	38.25	0.264	182.6
S.Em.±	2.72	0.55	0.01	2.9
C.D. at 5%	NS	NS	NS	8.4
Interactions				
P × V	NS	NS	NS	NS
P × B	NS	NS	NS	NS
V × B	NS	NS	NS	NS
P × V × B	NS	NS	NS	NS
C.V.%	7.72	7.17	9.46	8.12
Status in soil before sowing of chickpea	160.9	32.75	0.240	145.6

**Fig 1:** Effect of phosphorus, vermicompost and PSB on seed and stover yield of chickpea.



**Fig 2:** Effect of phosphorus, vermicompost and PSB on P uptake by chickpea.

## Conclusion

The results of the present investigation clearly demonstrated that integrated phosphorus management involving phosphorus fertilization, vermicompost application and PSB inoculation significantly improved nutrient concentration, nutrient uptake, crop productivity and post-harvest soil fertility status of chickpea. Enhanced phosphorus availability under integrated nutrient management promoted root growth, nodulation, biological nitrogen fixation and nutrient absorption, resulting in higher seed and stover yields. Simultaneously, improvement in available nitrogen, available phosphorus, organic carbon and microbial population indicated better soil health and sustainability. The findings suggest that integrated use of phosphorus, vermicompost and PSB represents an effective strategy for improving nutrient-use efficiency, sustaining soil fertility and enhancing productivity of chickpea under North Gujarat conditions.

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