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INTEGRATED NUTRIENT MANAGEMENT STRATEGIES IMPROVE CHICKPEA (*CICER ARIETINUM L.*) GROWTH, YIELD, NUTRIENT AVAILABILITY, AND SOIL BIOLOGICAL PROPERTIES IN THE DEGRADED LANDSCAPE OF BUNDELKHAND REGION

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ABSTRACT

Achieving optimal yields in chickpea is multi-challenging in the Bundelkhand region due to land degradation, poor soil fertility, scant irrigation facility, and frequent droughts. This study aimed to evaluate the effect of integrated use of organic and inorganic fertilizers on chickpea growth, yield, nutrient availability in soil, and soil biological properties through a field experiment conducted at Rani Lakshmi Bai Central Agricultural University, Jhansi, Uttar Pradesh during *Rabi* season 2022-23. The field experiment was laid in a randomized complete block design with nine treatments replicated thrice *viz*, control (T1), 100% RDF (T2), 75% RDF (T3), 100% RDF + 5 t ha^{-1} FYM (T4), 75% RDF + 5 t ha^{-1} FYM (T5), 100% RDF + 5 t ha^{-1} vermicompost (T6), 75% RDF + 5 t ha^{-1} vermicompost (T7), 100% RDN through FYM (T8) and 100% RDN through vermicompost (T9). Observations on soil properties were recorded at flowering and harvesting stage of the crop. Grain and stover **y**ield and availability of N, P, K, and S were significantly higher in T6 followed by T4. Highest bacteria and fungi population, and dehydrogenase activity were observed in T4 (49.0 and 57.0 CFU g^{-1} soil, and 12.4 µg TPF g^{-1} day^{-1}) followed by T6 (47.3 and 54.9 CFU g^{-1} soil, and 12.1 µg TPF g^{-1} day^{-1}) at flowering but a reverse trend was observed between T6 (35.2 and 35.5 CFU g^{-1} soil, and 8.2 µg TPF g^{-1} day^{-1}) and T4 (34.3 and 34.1 CFU g^{-1} soil, and 7.9 µg TPF g^{-1} day^{-1}) at harvesting, respectively. In contrast, highest actinomycetes population was recorded in T6 (44.5 and 82.8 CFU g^{-1} soil) followed by T4 (42.2 and 77.8 CFU g^{-1} soil) both at flowering and harvesting, respectively. It was concluded that inclusion of organic manures in RDF remains key for maximizing chickpea production and sustaining the soil fertility and health in Bundelkhand region.

***Keywords* :** Colony forming unit; INM; land degradation; soil fertility; pulse crop.

Introduction

With the erratic rainfall patterns and limited access to irrigation facilities, the Bundelkhand region of central India is characterized by water scarcity, poor soil conditions, low soil organic carbon (SOC) content, periodic droughts and crop failures as well as high production risks (Singh *et al.*, 2022; Yadav *et al.*, 2024). Agriculture in this region is historically under invested and climate vulnerable, which makes the farming community ethically poor with uncertain livelihood (Sah *et al.*, 2024). Owing to the multifaceted constraints, the cropping intensity of this region (145%) is lower against the mean cropping intensity of Uttar Pradesh (159%) and Madhya Pradesh (155%).

Pulses comprise a major stake of the cultivated crops in the *Bundelkhand* region since it possesses a high adaptability of wide range of environmental conditions. This region is often termed as the 'Pulse Bowl' of Uttar Pradesh as it considerably contributes to total state pulse production including chickpea (Sah *et al.,* 2024). Chickpea (*Cicer arietinum* L.) encompasses a special importance to the rural economy of this region as well as human dietary requirements (Yadav *et al.*, 2023; Yadav *et al.*, 2024). Except irrigation, chickpea is managed by minimum use of external inputs like fertilizers, manures etc. In fact, fertilizer use in Bundelkhand region was reported to be lowest (56.6 kg ha^{-1}) as compared Uttar Pradesh state average (152 kg ha^{-1}) (Pandey and Reddy, 2012). Consequently, chickpea productivity in the region is severely limited (Gupta *et al.*, 2014). Nevertheless, this low input pulse crop plays key role in shaping physical, chemical and biological properties of the soil (Ozlu *et al.,* 2019). For example, it increases soil fertility by fixing atmospheric N, meeting 80% of the plant's N requirements through symbiotic nitrogen fixation up to 140 kg N ha^{-1} (Wolde-Meskel *et al.*, 2018).

Given low chickpea productivity in the region, it warrants for adaptive management practices to limit the rate of nutrient mining and returning the nutrients to the soil for sustaining the crop productivity (Paramesh *et al.,* 2023). Integrated nutrient management (INM) that combines organic manures with synthetic fertilizers offers such adaptive management to support soil health, ensure nutrient recycling, sustain long-term agricultural productivity, and limit soil degradation (Swapna *et al.*, 2020; Thakur *et al.*, 2023). This practice also showed potential to improve soil fertility (Kishor *et al.,* 2024) and enhance microbial biomass and diversity by facilitating atmospheric CO_2 sequestration in soil (Datta *et al.*, 2025), a key mechanism to restore the degraded lands and to offset global warming. Partial replacement chemical fertilizers with organic manures can increase microbial growth, enzymatic activities, and improve soil quality over time (Liu *et al.*, 2009). Apart from slowly releasing the nutrients to the plants (Singh *et al.*, 2014; Kumari and Kumar, 2024), organic manures can also enhance population and diversity of soil microorganisms, which leads to improved soil health and plant productivity (Chakraborty *et al.*, 2011). Despite the multifaceted benefits of INM, challenges remain to elucidate the complexities between fertilizers, organic manures, soil microbes, and nutrient cycling across various agroecosystems including the Bundelkhand region.

While the effects of INM on crop productivity are well documented (Dwivedi *et al.*, 2018; Yadav *et al.*, 2024), there have been a lack of scientific understanding how INM may affect the nutrient availability and soil biological properties in the *Bundelkhand* region. We hypothesized that integrated use of inorganic and organic sources of nutrients would improve nutrient availability over their sole applications. The objective was to evaluate the effect of integrated use of organic and inorganic fertilizers on chickpea growth, yield, and nutrient availability in soil as well as soil biological properties. This study would unearth the impact of fertilization regimes and soil amendments on chickpea productivity and soil chemical and biological properties in the drought-hit degraded lands of the Bundelkhand region.

Materials and Methods

Experimental site, climate, and soil

The current study was done during the *rabi* season (November–March) of 2022–23 at a research farm located at the Rani Lakshmi Bai Central Agricultural University, Jhansi (25°51 N; 78°56 E; 227.1 m above mean sea level). The experimental site experiences semi-arid to sub-tropical climate with extreme hot summers and cool winters, with a mean annual precipitation ~900 mm. The average maximum and minimum temperature prevailed during the experimental period was 30.6 and 10.2°C, respectively (Figure 1). The total precipitation received during the experimental period (November, 2022–April, 2023) was 32.9 mm, of which 11.9 mm and 21.0 mm received during January and March, respectively. The total cumulative pan evaporation was 88.9 mm during the entire cropping period. The soil is clay loam in texture (sand: 52.1%, silt: 15.6%, and clay: 32.3%) with a pH 7.4, electrical conductivity 0.23 dS m^{-1}, SOC 3.7 g kg^{-1}, 159.8 kg N ha^{-1}, 11.0 kg P ha^{-1}, 144.1 kg K ha^{-1}, and 19.6 kg S ha^{-1}.

Experimental details

For accomplishment of the objectives, a field experiment was undertaken in a randomized block design (RCBD) with nine treatments replicated thrice viz., control (T1), 100% recommended dose of fertilizer (RDF) (T2), 75% RDF (T3), 100% RDF + 5 t ha^{-1} FYM (T4), 75% RDF + 5 t ha^{-1} FYM (T5), 100% RDF + 5 t ha^{-1} vermicompost (T6), 75% RDF + 5 t ha^{-1}

vermicompost (T7), 100% recommended dose of N (RDN) through FYM (3.44 t ha^{-1}) (T8) and 100% RDN through vermicompost (1.31 t ha^{-1}) (T9). The RDF was 20:60:20:20 kg ha^{-1} N:P:K:S. The required amounts of N, P, K, and S were added basally through diammonium phosphate (DAP), single super phosphate (SSP), muriate of potash (MOP) and bentonite (S-90%) followed by sowing. Elemental composition of FYM and vermicompost was 0.58, 0.12, 0.47, and 0.29%, and 1.52, 0.27, 0.62, and 0.34% of N, P, K, and S, respectively. After the basal application of fertilizers and manures, the sowing of chickpea (*cv.* Pusa Parvati) was done at a seed rate of 80 kg ha^{-1} with a spacing of 30.0×10.0 cm with the help of a seed drill. The plot size was kept at 6×5 m.

Growth parameters

Since it was not possible to study all plants of the population at its successive stage of growth; therefore, five plants were randomly selected in each plot for successive observations on growth parameters like shoot and root weight (on oven-dry basis) and number of nodules $plant^{-1}$ at flowering (67 DAS) and harvesting stage (124 DAS). For nodule count, plants were uprooted carefully and the soil mass adhering roots was washed off with running tap water and total as well as effective root nodules were counted to record the average number of nodules $plant^{-1}$. Afterwards, plant shoots were separated from roots and allowed to dry under shade for few days followed by oven dry (60°C) to constant weight and their dry weights were recorded.

Yield measurements

The harvested produce was threshed to separate grain and stover and then weighed and converted into t ha^{-1} on the basis of a net plot area (2×2 m).

Soil sampling and analyses

Treatment-wise composite soil samples (0–15 cm) were collected for estimation of available nitrogen (N), phosphorus (P), potassium (K), Sulphur (S), microbial colony counts, and dehydrogenase activity at flowering and harvesting stage. A part of the soil was air dried in shade and ground with the help of a porcelain mortar-pestle and sieved to a 2.0 mm sieve and stored for further analysis. For soil biological properties, another part of soil samples was stored in zippered polythene bags at 4ºC till analysis.

Available N was estimated by the alkaline $KMnO_4$ method (Subbiah and Asija, 1956); available P was measured by extracting the samples with 0.5 M $NaHCO_3$ (pH 8.5) and determining P concentration in aliquot calorimetrically using ascorbic acid (Olsen *et al.*, 1954); available K was quantified using 1.0 N NH_4OAc (pH 7) as an extractant followed by measurement by a flame photometer (Schollenberger and Simon, 1945); and available S was extracted using 0.15% $CaCl_2$ solution and measured using a spectrophotometer as per the turbidimetric method (Williams and Steinberg, 1969). Enumeration of soil microbial population (bacteria, fungi, and actinobacteria) was done by serial dilution and pour plate assay. The stock solution was serially diluted up to 10^{-5} and 1 ml of 10^{-3}, 10^{-4} and 10^{-5} dilutions were poured on nutrient agar (Lapage *et al.*, 1970), Martin's Rose Bengal streptomycin agar medium (Subba Rao 1986), and Kenknight and Munaier's agar medium (Wollum, 1982) plates to determine the population count of bacteria, fungi, and actinobacteria, respectively. The agar plates were incubated at 25°C (fungi and actinobacteria, 7 days) and 28°C (bacteria, 2 days) for further growth. Colonies were counted in triplicates of 10^{-3}, 10^{-4} and 10^{-5} dilutions and their averages were multiplied with dilution factor to obtain the bacteria, fungi, and actinobacteria population (colony forming unit, CFU), respectively and expressed as CFU g^{-1} soil. Soil dehydrogenase activity (DHA) was measured using the method of Klein *et al.* (1971).

Statistical analysis

The experimental data was statistically analyzed using RCBD design as described by Gomez and Gomez, (1984) using an open access OPSTAT software (http://14.139.232.166/opstat/). The overall significance of treatment differences on the measured parameters was assessed using the 'F' test, and the treatment means have been compared using the critical difference (C.D.) at 5% level of significance.

A multiparametric indexing namely geometric mean (GMe) of soil microbial population (CFU) was computed by using the following eq.:

$$GMe = \sqrt[3]{BP \times FP \times AP}$$

where BP, FP, and AP represent CFUs of bacteria, fungi, and actinobacteria observed in treatments, respectively.

Results and Discussion

Plant growth parameters

Results showed that significantly (p<0.05) highest shoot and root dry weight was recorded in T_6 (5.75, 0.85 and 23.30, 2.63 g $plant^{-1}$) followed by T_4 (5.56, 0.82 and 22.18, 2.46 g $plant^{-1}$) at flowering and harvesting, respectively (Table 1). Treatment T_6 and T_4 significantly (p<0.05) increased root dry weight by 88.9 and 82.2%, and 94.8 and 82.2% over the control (T_1) at flowering and harvesting, respectively. Again, these treatments significantly (p<0.05) increased shoot dry weight by 39.9 and 35.3%, and 51.5 and 44.2% over T_1, respectively. It also showed that 100% RDF (T_2) registered a significant (p <0.05) increase in shoot and root dry weight by 25.8 and 46.7%, and 33.6 and 46.7% over T_1 at flowering and harvesting, respectively. The highest root nodulation was recorded in T6 (65.18 and 87.11 plant^{-1}) followed by T4 (61.74 and 78.60 plant^{-1}), which was significantly (p <0.05) higher by 61.2 and 63.7%, and 52.7 and 47.7% over T_1 at flowering and harvesting, respectively (Table 1). 100% RDF registered a significant (p <0.05) increase by 23.2 and 10.8% over T_1 at flowering and harvesting, respectively. On the other hand, treatment T_8 and T_9 although increased dry biomasses and root nodulation over T_1 but remained statistically at par with each other at both growth stages.

Our results showed that highest dry biomasses and root nodulation can be obtained by a combination of 100% RDF with either FYM or vermicompost. This combination provided an optimal blend of nutrients, including essential macronutrients and micronutrients, promoting vigorous root and shoot growth (Prajapat *et al.,* 2016; Swapna *et al.,* 2020). Additionally, the organic components improved soil structure, water retention, nutrient availability, and enhanced nutrient uptake by the plants (Liu *et al.,* 2009; Gudadhe *et al.,* 2015; Ozlu *et al.,* 2019). The symbiotic relationship between leguminous plant and nitrogen-fixing bacteria, fostered by organic amendments, also contributed to increased biomass accumulation which, in turn, promotes beneficial microbial activity, creating a favourable environment for root nodulation (Das *et al.,* 2016). The interaction between inorganic and organic fertilizers may create synergistic effects, optimizing nutrient uptake and utilization by plants, leading to better root nodulation (Wolde-Meskel *et al.,* 2018). Overall, the synergistic effects of inorganic and organic fertilizers led to the observed highest shoot and root dry weight and nodulation in chickpea (Prasad *et al.,* 2005).

Yield

Grain and stover yield were significantly (p<0.05) affected by treatments (Figure 2). The highest grain and stover yield were observed in T_6 (1.8 and 3.5 t ha^{-1}, respectively) followed by T_4 (1.7 and 3.3 t ha^{-1}, respectively). Results further revealed that treatments T_8 and T_9 though increased yields over no fertilization (T_1) but remained statistically at par with each other. Our results clearly showed that integration of recommended fertilizer doses with either vermicompost or FYM enhanced chickpea yields to the greatest extent. The synergistic effects of inorganic and organic fertilizers on improving overall yield in chickpea were previously reported (Das *et al.,* 2016; Thakur *et al.,* 2023; Yadav *et al.,* 2024) and are in line with our findings. Organic amendments are known to improve water retention, soil fertility, and counts of beneficial microorganisms, which probably contributed to enhanced plant vigor and reproductive performance (Prajapat *et al.,* 2016; Paramesh *et al.,* 2023). Nevertheless, the non-significant increase of yield in organically amended treatments (T_8 and T_9) over the control suggests that yield enhancement can merely be achieved with suboptimal nutrient supply.

Nutrient availability

The results indicated that highest availability of N, P, and K was observed in T_6 (192.7, 14.7, and 165.4, and 199.9, 12.2, and 145.8 kg ha^{-1}) followed by T_4 (189.2, 14.6, and 164.5, and 198.5, 12.2, and 143.2 kg ha^{-1}) both at flowering and harvesting stage (Table 2). However, a varying trend was recorded between T_7 (24.3 and 21.5 kg ha^{-1}) and T_5 (23.5 and 20.8 kg ha^{-1}) for S at both flowering and harvesting stage (Table 2). At flowering, available N, P, and K was significantly (p<0.05) increased by 22.3, 20.1, and 21.8% in T_6 and 20.1, 19.3, and 21.1% in T_4 over the control, respectively. Again, at harvesting, availability of N, P, and K was significantly (p<0.05) increased by 22.9, 30.9, and 16.6% in T_6 and 22.4, 29.9 and 14.5% in T_4 over the control, respectively. On the other side, treatment T_7 and T_5 significantly (p<0.05) increased S availability by 44.4 and 25.0%, and 39.4 and 20.6% over the control (T_1) at flowering and harvesting, respectively. It also showed that 100% RDF (T_2) registered a significant (p<0.05) increase in N, P, K, and S availability by 18.9, 12.2, 18.7, and 34.2%, and 21.2, 28.1, 13.5, and 15.9% at flowering and harvesting over the control, respectively.

Result indicated that highest nutrient availability in the soil was recorded with the combination of 100% (RDF) along with either 5t ha^{-1} of FYM or vermicompost both at flowering and harvesting stage, which could be due to many reasons. Organic fertilizers (FYM or vermicompost) improved soil organic matter content, promoting nutrient retention and release (Xu *et al.,* 2008). They also enhanced beneficial microbial activity, facilitating nutrient mineralization and uptake by the chickpea plants (Liu *et al.,* 2009; Meena and Ram, 2013). The balanced combination of inorganic and organic fertilizers ensured a sustained and comprehensive nutrient supply, and thus optimizing nutrient assimilation (Ozlu *et al.,* 2019). This, in turn, led to increased nutrient availability in the soil, fostering healthier plant growth and higher nutrient uptake, ultimately contributing to improved nutrient availability in chickpea crops (Shinde *et al.*, 2023; Gudadhe *et al.*, 2015). In majority, the non-significant increase of nutrient availability in organically amended treatments (T_8 and T_9) over the control reveals that nutrient availability cannot be enhanced with suboptimal nutrient supply.

Soil biological properties

Highest bacteria and fungi population were observed in T_4 (49.0 and 57.0 CFU g^{-1} soil) followed by T_6 (47.3 and 54.9 CFU g^{-1} soil) at flowering but a reverse trend was observed between T_6 (35.2 and 35.5 CFU g^{-1} soil) and T_4 (34.3 and 34.1 CFU g^{-1} soil) at harvesting (Table 3). In contrast, highest actinomycetes population was recorded in T_6 (44.5 and 82.8 CFU g^{-1} soil) followed by T_4 (42.2 and 77.8 CFU g^{-1} soil) both at flowering and harvesting, which was significantly (p<0.05) higher by 66.8 and 80.0%, and 58.5 and 69.1% over the control (T_1) at flowering and harvesting, respectively (Table 3). At flowering, bacteria and fungi population were significantly (p<0.05) increased by 59.7 and 75.2% in T_4, 54.3 and 68.9% in T_6 over the control, respectively. Again, at harvesting, these bacterial and fungal populations were significantly (p<0.05) increased by 44.7 and 77.5% in T_6, 41.2 and 70.6% in T_4 over the control, respectively. 100% RDF (T_2) registered a significant (p<0.05) increase in the population of bacteria, fungi and actinomycetes by 28.3, 14.2, and 14.3%, and 5.7, 9.1, and 9.2% at flowering and but non-significant at harvesting stage over the control, respectively. The results also revealed that highest GMe of microbial population was recorded in T_6 (49.7 and 47.8) followed by T_4 (48.3 and 44.8) at flowering and harvesting, respectively (Figure 3). At flowering, microbial population increased by 66.6 and 61.9% and at harvesting by 69.8 and 59.2% in T_6 and T_4 over the control, respectively.

Over RDF and control treatments, significantly (p<0.05) highest DHA activity in soil was recorded in T_4 (12.4 µg TPF g^{-1} d^{-1}) followed by T_6 (12.1 µg TPF g^{-1} d^{-1}) at flowering but in T_6 (8.2 µg TPF g^{-1} d^{-1}) followed by T_4 (7.9 µg TPF g^{-1} d^{-1}) at harvesting (Table 3). However, DHA activity remained statistically at par between T_4 and T_6 at both growth stages. Treatment T_4 enhanced DHA activity by 39.7 and 41.7% while T_6 by 37.0 and 46.0% over T_1 at flowering and harvesting, respectively. 100% RDF (T_2) failed to increase DHA activity significantly (p<0.05) as compared to the control treatment at both growth stages.

Result indicated that microbial population (bacteria, fungi, and actinomycetes) and DHA activity was higher under the combination of 100% RDF along with either 5 t ha^{-1} of FYM or vermicompost both at flowering and harvesting stage. Similar observations were also reported by many studies (Verma and Mathur, 2009; Borase *et al.*, 2020). Organic fertilizers (FYM or vermicompost) provided a source of organic matter, fostering a favorable environment for microbial growth and activity (Chakraborty *et al.*, 2011). The increased microbial activity resulted in improved nutrient mineralization and nutrient cycling in the soil, leading to enhanced nutrient availability to the chickpea plants (Singh *et al.*, 2014; Patel *et al.*, 2024). The synergistic effects of inorganic and organic fertilizers positively influenced soil biological activity, leading to the observed higher DHA activity in the soil. This higher dehydrogenase activity indicates enhanced microbial respiration and metabolic processes, contributing to nutrient cycling and nutrient availability in the soil (Channagouda *et al.*, 2014). The result also indicated that actinomycetes population was higher at the harvesting over flowering stage, which remained in contrast to bacteria and fungi population and DHA activity. This might be due to the reduced rhizosphere activity as the chickpea plants advance towards maturity, which reduces the plant growth. Actinomycetes are known to thrive on organic substrates, and as the crop matures and residues accumulate, they provide a favorable environment for actinomycetes' proliferation. The higher actinomycetes population at harvesting indicates their active role in nutrient recycling and decomposition processes, which can have positive implications for soil health and nutrient availability in subsequent cropping cycles (Gudadhe *et al.*, 2015).

Correlation studies

The results indicated that grain and stover yield positively and significantly correlated with soil nutrient availability, microbial population, and DHA activity (Figure 4). Nevertheless, the observed correlations were relatively stronger between grain yield and available N (r=0.95; p <0.01), P (r=0.97; p<0.01), K (r=0.94; p <0.01), S (r=0.88; p <0.01), and bacteria population (r=0.92; p <0.01) over others. The strongest correlation was observed between fungi and DHA (r=0.99; p <0.001) in this study. In contrast, available S was non-significantly correlated with fungi (r=0.66) and actinomycetes (r=0.54) population, respectively. Again, DHA was non-significantly correlated with available K (r=0.65) and S (r=0.62).

Higher nutrient availability in the soil promotes better plant growth and development, leading to increased stover and grain yield. A positive correlation between yield and nutrients availability suggests that chickpea plants have efficient mechanisms for taking up the applied nutrients from the soil (Guler *et al.*, 2001). An active and healthy root system can access and absorb nutrients, resulting in improved crop performance and higher yields. The presence of a thriving microbial population can contribute to improved soil fertility. Microorganisms play a vital role in nutrient cycling, decomposition of organic matter, and releasing nutrients in forms that plants can readily absorb. As a result, the crops can benefit from the increased nutrient availability in the soil (Islam *et al.*, 2011). These relationships highlight the importance of maintaining a balanced nutrient supply and fostering a healthy soil microbiome to support optimal crop productivity in agricultural systems.

Conclusions

The combination of inorganic and organic fertilizers created a balanced and nutrient-rich soil, promoting the proliferation of beneficial soil microorganisms, ultimately contributing to higher microbial population in the soil and supporting healthier and more productive chickpea crops in drought-prone *Bundelkhand* region. Therefore, it is concluded that inclusion of organic manures in RDF remains key for maximizing chickpea production and sustaining the soil fertility and health in this region. Future research on long-term INM experiments on pulses in *Bundelkhand* region is warranted for the development sustainable production systems.

Table 1 : Effect of different nutrient management practices on plant growth parameters at flowering and harvesting stages of chickpea

Treatments	**Shoot dry weight (g plant^{-1})**	**Root dry weight (g plant^{-1})**	**Number of nodules plant^{-1}**	**Shoot dry weight (g plant^{-1})**	**Root dry weight (g plant^{-1})**	**Number of nodules plant^{-1}**
	Flowering			Harvesting		
T_1	4.11	0.45	40.43	15.38	1.35	53.20
T_2	5.17	0.66	49.82	20.54	1.98	58.96
T_3	5.03	0.62	44.40	19.86	1.86	54.68
T_4	5.56	0.82	61.74	22.18	2.46	78.60
T_5	5.42	0.75	54.90	21.49	2.25	68.47
T_6	5.75	0.85	65.18	23.30	2.63	87.11
T_7	5.40	0.76	57.28	21.85	2.28	71.06
T_8	4.64	0.49	42.07	18.41	1.62	55.88
T_9	4.38	0.54	45.67	17.00	1.47	50.85
SEm±	0.23	0.02	4.5	3.14	0.82	7.16
CD (p<0.05)	0.51	0.05	6.28	2.78	0.55	6.27
C.V.	5.84	7.34	8.1	8.63	2.73	9.44

Table 2 : Effect of different nutrient management practices on nutrient availability in soil at flowering and harvesting stages of chickpea

Treatments	**N**	**P**	**K**	**S**	**N**	**P**	**K**	**S**
	Flowering				**Harvesting**			
T_1	157.5	12.2	135.7	16.8	162.1	9.3	124.9	17.2
T_2	187.3	13.7	161.2	22.6	196.5	12.0	141.9	20.0
T_3	173.7	12.8	157.9	21.5	182.2	11.2	134.0	19.1
T_4	189.2	14.6	164.5	22.8	198.5	12.2	143.2	20.2
T_5	183.9	13.3	161.6	23.5	192.9	11.6	140.6	20.8
T_6	192.7	14.7	165.4	23.2	199.9	12.2	145.8	20.5
T_7	183.9	13.9	163.3	24.3	193.6	12.1	142.1	21.5
T_8	172.7	12.5	145.8	17.4	183.8	11.2	126.8	17.4
T_9	175.5	12.7	140.9	18.7	184.3	11.0	125.8	17.5
SEm±	4.2	0.4	2.7	0.8	4.0	0.3	5.0	0.6
CD (p<0.05)	12.4	1.3	8.2	2.3	11.9	1.0	14.9	1.9
C.V.	4.0	5.7	3.1	6.3	3.7	5.3	6.4	5.7

All units are expressed in kg ha^{-1}

Table 3 : Effect of different nutrient managements practices on microbial population (CFU) and dehydrogenase activity (DHA) at flowering and harvesting stage of chickpea

Treatments	Bacteria ($\times10^5$) (CFU g^{-1} soil)	Fungi ($\times10^4$) (CFU g^{-1} soil)	Actinomycetes ($\times10^3$) (CFU g^{-1} soil)	DHA (µg TPF g^{-1} d^{-1})	Bacteria ($\times10^5$) (CFU g^{-1} soil)	Fungi ($\times10^4$) (CFU g^{-1} soil)	Actinomycetes ($\times10^3$) (CFU g^{-1} soil)	DHA (µg TPF g^{-1} d^{-1})
	Flowering				Harvesting			
T_1	30.7	32.5	26.7	8.9	24.3	20.0	46.0	5.6
T_2	39.3	37.2	30.5	9.0	25.7	21.8	50.2	5.9
T_3	37.7	32.2	28.5	9.2	26.5	21.5	49.4	5.7
T_4	49.0	57.0	42.2	12.4	34.3	34.1	77.8	7.9
T_5	40.0	47.5	34.9	10.8	30.9	32.8	75.5	7.5
T_6	47.3	54.9	44.5	12.2	35.2	35.5	82.8	8.2
T_7	42.0	48.2	32.8	11.2	31.1	30.6	70.5	7.6
T_8	37.1	37.7	35.1	9.7	27.4	26.2	60.2	6.5
T_9	38.8	36.3	34.1	10.0	28.3	27.8	64.0	6.7
SEm±	0.9	1.1	0.8	0.3	0.5	0.7	1.6	0.2
CD (p<0.05)	2.6	3.4	2.4	0.9	1.5	2.1	4.8	0.5
C.V.	3.7	4.7	4.1	4.9	3.0	4.3	4.3	4.2

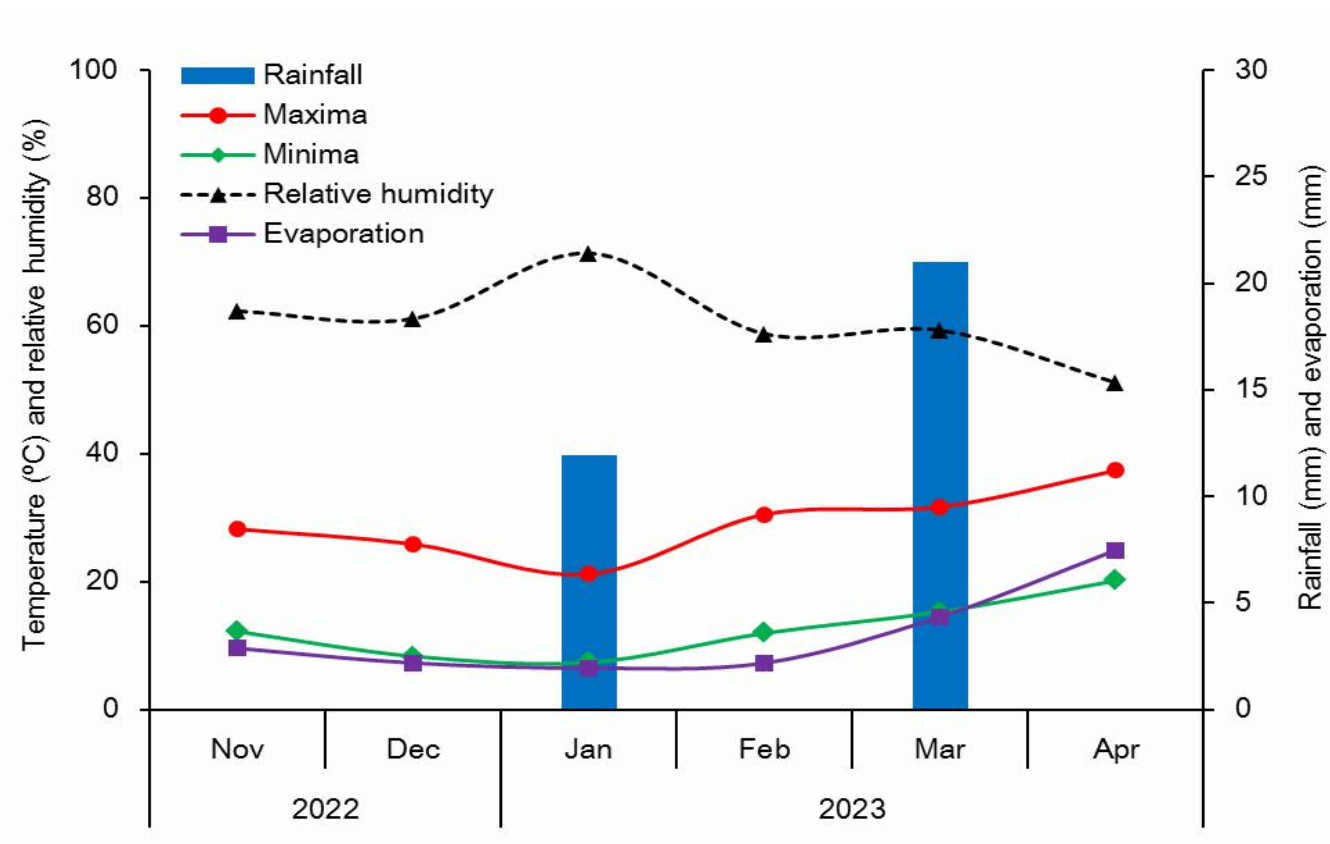

Fig. 1 : Monthly mean of meteorological conditions prevailed during the chickpea cropping season (2022–23).

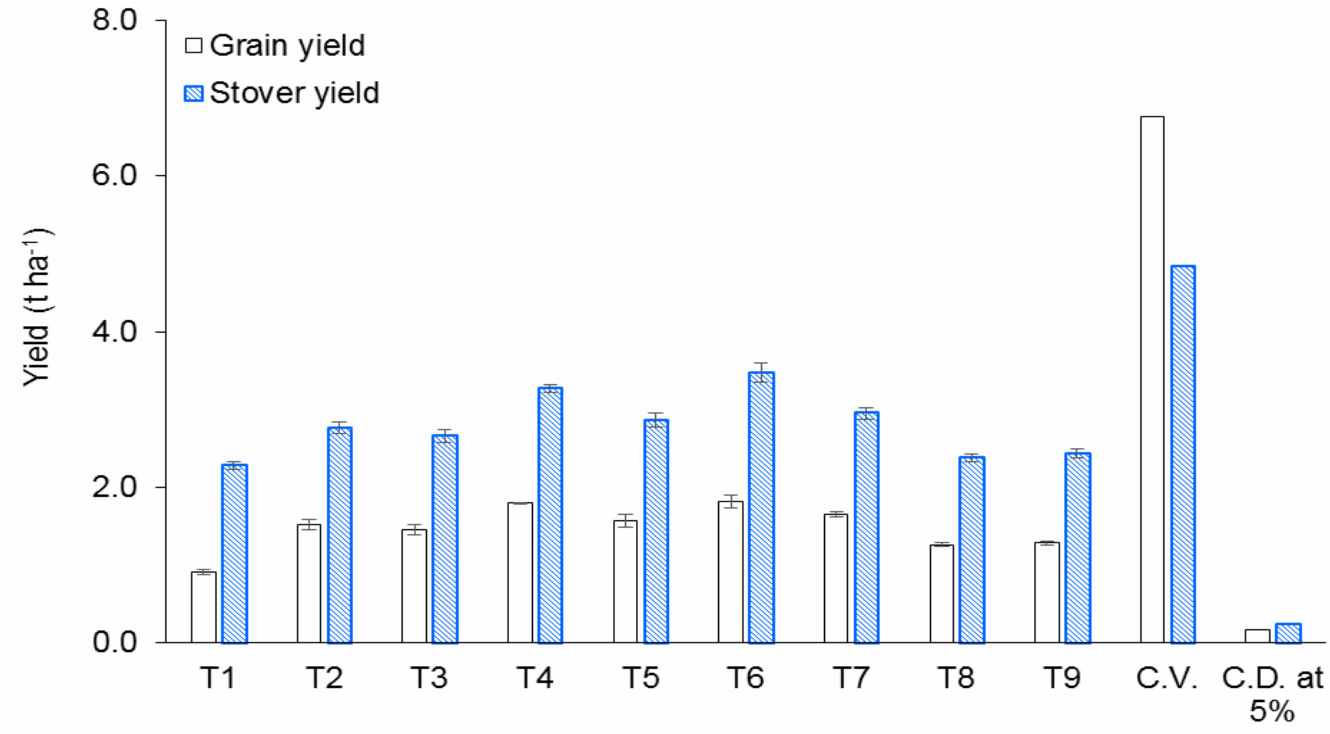

Fig. 2 : Effect of different nutrient management strategies on grain and stover yield of chickpea. Vertical bars on the column indicate standard error (n=3). For grain yield C.D. at 5%=0.17 and for stover yield C.D. at 5%=0.24

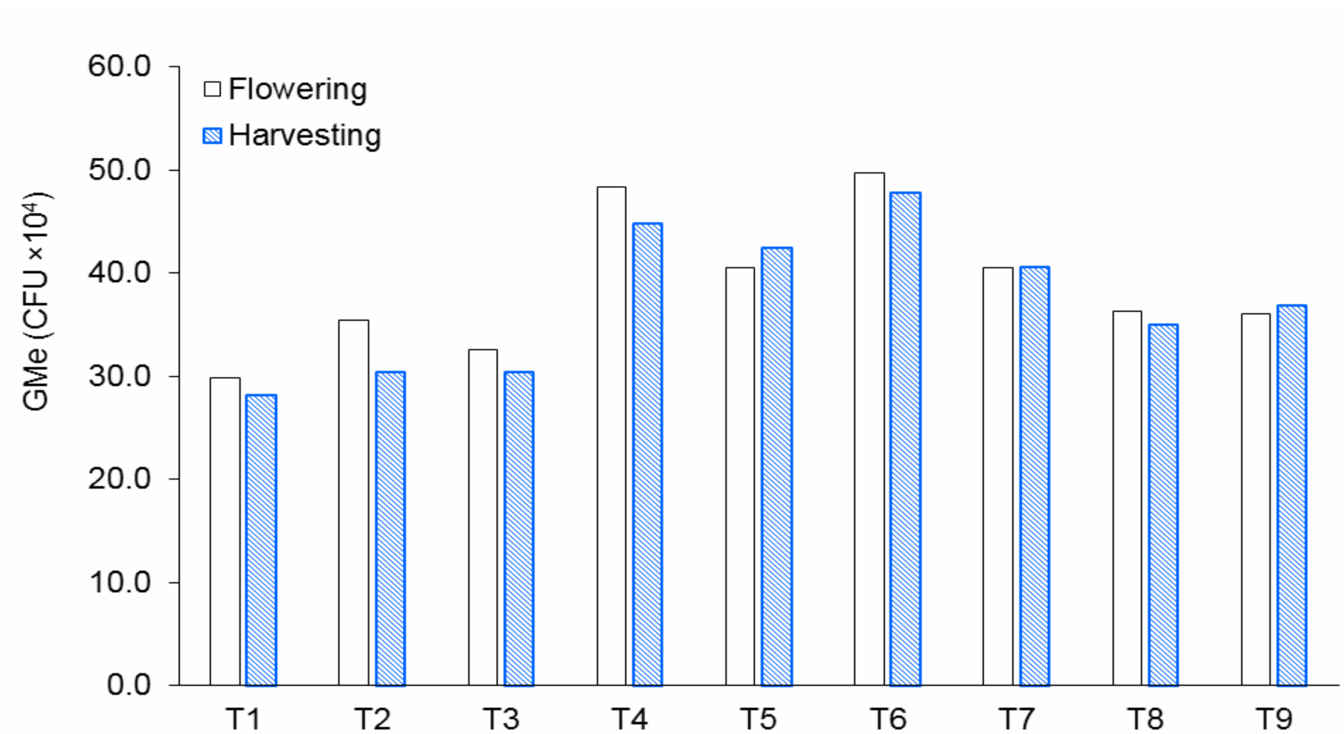

Fig. 3 : Effect of different nutrient managements strategies on the geometric mean of microbial population (CFU) including bacteria, fungi, and actinomycetes

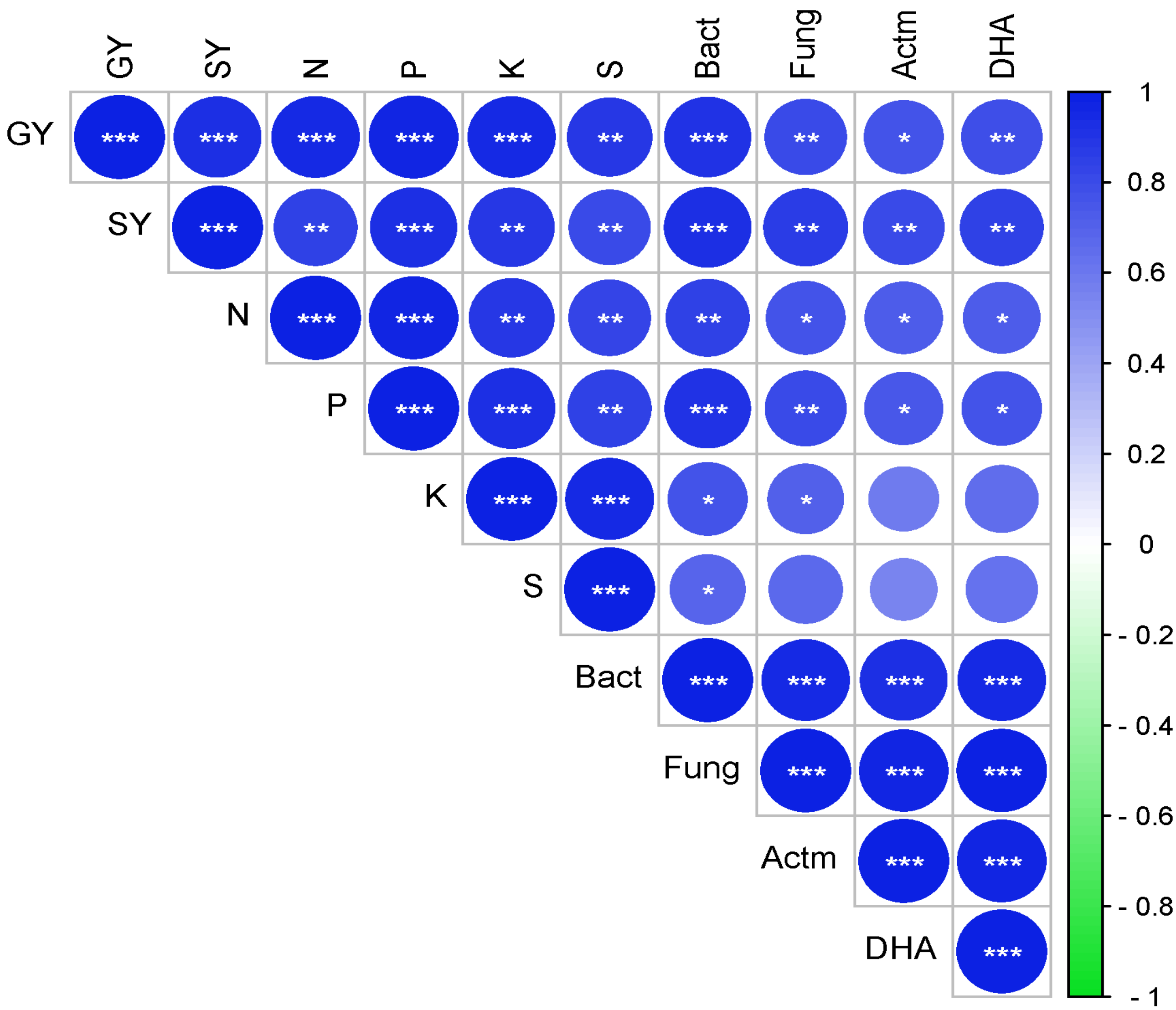

Fig. 4 : Correlogram showing the relationship between the yield and measured soil properties. GY: Grain yield; SY: Stover yield; Bact: Bacteria population (CFU); Fung: Fungi population (CFU); Actm: Actinomycetes population (CFU); DHA: Dehydrogenase enzyme activity. **p*<0.05; ***p* <0.01; ****p*<0.001

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Conflict of interest

The authors declare no known conflict of interests.

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