RESEARCH ARTICLE
Performance of chickpea (Cicer arietinum L.) in maize-chickpea sequence under various integrated nutrient modules in a Vertisol of Central India

Chetan Kumar Dotaniya1, Brij Lal Lakaria2*, Yogesh Sharma1, Bharat Prakash Meena3, Satish Bhagwat Rao Aher4, Abhay Omprakash Shirale1, Priya Gurav Pandurang5, Mohan Lal Dotaniya4*, Ashis Kumar Biswas2, Ashok Kumar Patra2, Shish Ram Yadav1, Madan Lal Reager5, Ramesh Chandra Sanwal1, Rajesh Kumar Doutaniya5*, Manju Lata6

1 Department of Soil Science & Agricultural Chemistry, Swami Keshwanand Rajasthan Agricultural University, Bikaner, India, 2 Division of Soil Chemistry & Fertility, ICAR- Indian Institute of Soil Science, Nabibagh, Bhopal, India, 3 ICMR-National Institute for Research in Environmental Health, Bhauri, Bhopal, India, 4 Crop Production Unit, ICAR- Directorate of Rapeseed-Mustard Research, Sewar, Bharatpur, India, 5 Department of Agronomy, Sri Karan Narendra Agriculture University, Jobner, Jaipur, Rajasthan, India, 6 Rajasthan University, Jaipur, India

* lakaria2001@gmail.com (BLL); rajeshkumardoutaniya@gmail.com (RKD); mohan30682@gmail.com (MLD)

Abstract

Present investigation was conducted at the Research Farm of Indian Institute of Soil Science, Bhopal during 2017–18 and 2018–19 to study the performance of chickpea crop under various nutrient management modules in a Vertisol. The field experiment was set up in a randomized block design with three replications of twelve different INM modules. During the rabi seasons of 2017–18 and 2018–19, the chickpea (cv. JG-315) was grown with a set of treatments. The crop’s performance was evaluated in terms of growth, yield (grain and straw), nutritional content, and nutrient uptake under different treatments. At crop harvest, the physico-chemical characteristics of the soil were also evaluated. Finally, the relationship between the numerous examined parameters was determined. The results showed that integrated nutrient management modules had a positive impact on chickpea crop performance and productivity when compared to using only inorganic fertilizer. The INM modules dramatically increased soil organic carbon and improved soil health in terms of physical and chemical qualities, in addition to higher crop performance. Among the various modules, (1) application of 75% STCR dose + FYM @ 5t ha⁻¹ to maize followed by 100% P only to chickpea and (2) application of FYM @ 20t ha⁻¹ to maize followed by FYM @ 5t ha⁻¹ to chickpea increased the productivity and nutrient uptake in chickpea, improved soil physico-chemical properties and reflected as viable technique in improving soil nutrient availability on sustainable basis.
Introduction

As a result of rapid urbanization and industrialization, India is facing a dire predicament in which the number of mouths to feed will continue to rise at an alarming rate while available agricultural land area remains inelastic, if not declining. As a result, adopting intense cropping is unavoidable in order to increase food grain output. Second, because of the quick visual impacts of nitrogenous fertilizer on plants and the higher expense of phosphatic and potassic fertilizers, most farmers prefer to apply solely nitrogenous fertilizer to crops, resulting in an imbalance of nutrient consumption and nutrient depletion from the soil. High crop yields can be maintained by judicious application of manures and fertilizers. Crop rotation with cereals and legumes, as well as organic manure addition and optimal N P K application to the soil system, are crucial for crop yield and soil health [1, 2]. Maize-chickpea rotation is an important cropping sequence of India [3]. Maize is an important cereal crop in the global agricultural economy, serving as both human food and animal feed. Maize, after sugar cane, is the most demanding crop in this cropping sequence, requiring both micro and macro nutrients throughout its growing period to achieve high growth and yield potentials.

Long-term sustainability concerns are rising in agriculture as a result of over- and under-application of fertilizers, as well as inadequate resource management, which is causing soil health to deteriorate and crop production to decline [4–6]. The most obvious notion for regulating and maintaining soil health and crop productivity is the integrated use of organic and inorganic sources of nutrients [7, 8]. Integrated nutrient management is one of the most important components towards enhancing crop production and sustaining soil fertility [4, 5, 9]. Due to application of P fertilizers during crop production, a huge amount of P converts into unavailable forms and is fixed into the soil [10]. The use of locally available organic residues (OR), i.e. bagasse, press mud and rice straw can be a cheaper technology to mobilize unavailable P in situ [11]. The addition of organic material increased the amount of food available to microorganisms, allowing for faster breakdown. The presence of sugar in organic wastes promotes decomposition and increases the release of low molecular organic acids into the soil [8, 12]. Application of sugarcane industries by-products reduces the RDF and improves organic matter of soil during the crop production [13]. Chickpea is a popular pulse crop farmed and consumed throughout the world, particularly in Afro-Asian countries. It is also one of the major pulse crops cultivated and consumed in India. Chickpea recorded a highest ever production of 11.23 Mt at a record productivity level of 1063 kg ha\(^{-1}\) in an area of 10.56 M ha. In India, among 7 major chickpea producing states MP ranks 4.60 Mt and contribute more than 40 per cent of total chickpea production in India. Keeping in view the above the present study was undertaken to study the performance of chickpea under various INM modules.

Materials and methods

Experiment site

A field experiment was conducted at the research farm of the ICAR-Indian Institute of Soil Science, Bhopal. Geographically, the ICAR-IISS lies between 23°18’ N latitude and 77°24’ E longitudes. The elevation above mean sea level is 485 m. The climate of study site is sub-humid and in characterized by cool and dry winters, hot summer and humid monsoon with a mean annual rainfall of 1146 mm 75–80% of which is received during June to September.

Experiment details

The Chickpea (JG-315) was grown with 70 kg ha\(^{-1}\) seed rate with row to row and plant to plant spacing of 30cm X 10 cm in a Vertisol at the research farm of the Indian Institute of Soil Science with 15 different treatments (Table 1). The general recommended dose (GRD) of...
fertilizer application for chickpea was 20-60-20 kg N, P₂O₅ and K₂O, respectively. The plot size of the experiment was 20 X 5 sq meters.

**Experimental soil**

The soil of experimental site is classified as Vertisol (*Typic Haplusterts*) with smectite as the dominant clay mineral. Vertisols are churning heavy clay soils with a high proportion of swelling clays. These soils form deep wide cracks during summer season. The soil of the experimental site is clayey in texture with 25.2, 18 and 56.8 per cent of sand, silt and clay, respectively. The soil was medium in soil organic carbon (0.53%), low in available N (68.8 mg kg⁻¹), medium in available P (12.8 mg kg⁻¹) and high in available K (237 mg kg⁻¹). The soil was normal in reaction (pH 7.76) and electrical conductivity (EC) was 0.48 dS m⁻¹.

**Crop performance, nutrient concentration and uptake**

The performance of the chickpea crop was evaluated by monitoring the growth and yield parameters viz., plant height, seed index (100 seed), seed yield and straw yield. The plant samples were collected at harvest stage and thoroughly washed with distilled water, dried at room temperature for 24 hours; oven dried at 65°C till constant weight. The samples were ground to a homogenous powder using grinding machine. The samples were digested in H₂SO₄ and diacid (HNO₃: HClO₄ at 9:4 ratio) for estimation of N and; P and K, respectively [14]. The N, P and K in digest were determined by modified Kjeldhal method, vanadomolybdate phosphoric yellow colour method and flame photometer method, respectively [15]. The uptake of the nutrients was calculated from the concentration and respective seed/straw yield. The total uptake was calculated by combining straw and seed uptake.

**Soil sampling, processing and analysis**

Soil samples were collected from 0-15 cm depth after harvest of *rabi* season each year and were homogenized. Visible litter and roots were picked out from collected soil samples. The
soil samples were air-dried at room temperature, ground and sieved through 2 mm sieve. The processed soil was stored in air tight plastic containers for further analysis of different properties. The soil pH was measured in soil water suspension (1:2.5 ratio) using pH meter [15]. The soil water suspension used for pH estimation was kept for one hour, the electrical conductivity (dS m\(^{-1}\)) was measured in the supernatant using electrical conductivity meter after standardizing the instrument with 0.01 M KCl. The soil organic carbon content (%) in soil samples was determined in soil using the wet oxidation methods [16]. Available nitrogen content in soil was estimated by alkaline permanganate method [17] in which a known quantity of soil was reacted with 0.32% alkaline KMNO\(_4\) and 2.5% NaOH in a Kjeldhal flask and the contents were distilled. The liberated ammonia was absorbed in boric acid containing mixed indicator and N was estimated by titrating the distillate against standard sulphuric acid till bluish green colour changed to original color boric acid. The available phosphorus was determined using Olsen’s method (0.5 N NaHCO\(_3\) with pH 8.5). The phosphorus content extract was determined by ascorbic acid method [18]. The soil available potassium was extracted from the soil using neutral normal ammonium acetate in soil solution (ratio 1:5) and the K in extract was recorded using flame photometer [19].

**Statistical analysis**

The experiment comprised with twelve treatments laid out in a randomized block design (RBD) with three replications. All the measurements are the mean value of three separate replicates. Data was subjected to an analysis of variance. The mean values were grouped for comparisons and the least significant differences among them were calculated at \( P < 0.05 \) confidence level using ANNOVA statistics as outlined by [20].

**Results**

**Growth and yield of chickpea**

During the experimental period, the performance of the chickpea crop was measured in terms of growth and yield parameters, grain yield, and biomass. The plant height of chickpea was recorded at 30 DAS, 60 DAS and 90 DAS, respectively during the study years \( \text{viz}., 2017–18 \) and 2018–19 (Table 2). The results revealed that the plant height of chickpea recorded at periodic interval during the study period found significantly higher under the treatment receiving FYM@ 20 t ha\(^{-1}\) (T\(_{11}\)) and the treatment receiving STCR recommended dose of fertilizers (T\(_3\)) as compared to the other treatments. The seed index of chickpea found significantly influenced under the integrated nutrient application (Table 3). The pooled data of two years indicated highest seed index under the treatment receiving FYM@ 20 t ha\(^{-1}\) followed by the treatment with STCR recommended dose of fertilizers. The grain yield of chickpea ranged 1.37–2.39 t ha\(^{-1}\), 1.05–2.15 t ha\(^{-1}\) and 1.21–2.27 t ha\(^{-1}\) during 2017–18, 2018–19 and pooled of two years, respectively. The average grain yield of chickpea across the treatments was found 1.97 t ha\(^{-1}\), 1.66 t ha\(^{-1}\) and 1.81 t ha\(^{-1}\) during 2017–18, 2018–19 and pooled of two years, respectively. The pooled data indicated that the treatment receiving FYM @ 5t ha\(^{-1}\) (T\(_{11}\)) recorded highest grain yield (2.27 t ha\(^{-1}\)) and found statistically significant over rest of the treatments.

**Nutrient accumulation in chickpea seed and straw**

The chickpea grain N concentration ranged 2.67–2.96%, 2.64–2.90% and 2.65–2.93% during 2017–18, 2018–19 and pooled of two years, respectively. Similarly, the average chickpea grain N concentration across the treatments was found 2.79% during the study period. The chickpea grain P concentration ranged 0.40–0.49%, 0.41–0.50% and 0.41–0.50% during 2017–18, 2018–
and pooled of two years, respectively (Table 4). Similarly, the average chickpea grain P concentration across the treatments was found 0.44% and 0.45% during 2017–18 and 2018–19, respectively. The chickpea grain K concentration ranged 1.01–1.14%, 1.05–1.15% and 1.03–1.14% during 2017–18, 2018–19 and pooled of two years, respectively. Similarly, the average chickpea grain K concentration across the treatments was found 1.10%, 1.12% and 1.11% during 2017–18, 2018–19 and pooled of two years, respectively. The chickpea stover N concentration ranged 0.52–0.68%, 0.55–0.73% and 0.54–0.71% during 2017–18, 2018–19 and pooled of two years, respectively. Similarly, the average chickpea stover N concentration across the treatments was found 0.63%, 0.67% and 0.65% during 2017–18, 2018–19 and pooled of two years.

The chickpea stover P concentration ranged 0.11–0.14%, 0.10–0.15% and 0.10–0.14% during 2017–18, 2018–19 and pooled of two years, respectively. Similarly, the average chickpea stover P concentration across the treatments was found 0.13%, 0.14% and 0.13% during 2017–18, 2018–19 and pooled of two years.

### Table 2. Plant height of chickpea at different growth stages under various INM modules.

| Treatments | Plant Height (cm) | 30 DAS | 60 DAS | 90 DAS |
|------------|-------------------|--------|--------|--------|
|            | 2017–18 | 2018–19 | Pooled | 2017–18 | 2018–19 | Pooled | 2017–18 | 2018–19 | Pooled |
| T1         | 11.2    | 13.1    | 12.2   | 31.8    | 33.6    | 32.7   | 45.7    | 48.1    | 46.9    |
| T2         | 12.4    | 14.3    | 13.3   | 34.9    | 36.8    | 35.9   | 52.6    | 54.7    | 53.6    |
| T3         | 13.4    | 15.7    | 14.5   | 36.3    | 38.1    | 37.2   | 57.0    | 63.7    | 60.4    |
| T4         | 12.6    | 14.2    | 13.4   | 33.9    | 35.7    | 34.8   | 51.3    | 54.7    | 53.0    |
| T5         | 12.8    | 14.6    | 13.7   | 34.7    | 36.6    | 35.7   | 51.4    | 57.3    | 54.4    |
| T6         | 11.8    | 13.6    | 12.7   | 33.6    | 35.4    | 34.5   | 50.9    | 54.3    | 52.6    |
| T7         | 12.2    | 14.1    | 13.1   | 33.8    | 35.6    | 34.7   | 49.1    | 55.1    | 52.1    |
| T8         | 11.6    | 13.4    | 12.5   | 33.7    | 35.5    | 34.6   | 48.9    | 54.8    | 51.8    |
| T9         | 12.1    | 14.0    | 13.1   | 33.0    | 34.9    | 34.0   | 49.7    | 53.3    | 51.5    |
| T10        | 12.2    | 14.1    | 13.2   | 35.6    | 37.3    | 36.5   | 54.2    | 59.2    | 56.7    |
| T11        | 13.6    | 17.5    | 15.6   | 40.6    | 42.5    | 41.5   | 59.6    | 69.2    | 64.4    |
| T12        | 12.9    | 15.1    | 14.0   | 34.8    | 37.3    | 36.1   | 51.0    | 59.8    | 55.4    |
| SEm±       | 0.49    | 0.31    | 0.38   | 1.10    | 1.02    | 1.06   | 2.94    | 1.81    | 1.79    |
| CD (p = 0.05) | 1.44    | 0.91    | 1.10   | 3.23    | 2.98    | 3.09   | 8.64    | 5.31    | 5.23    |

### Table 3. Chickpea seed index, seed and straw yield.

| Treatments | Seed Index (g 100 seed⁻¹) | 2017–18 | 2018–19 | Pooled |
|------------|---------------------------|--------|--------|--------|
|            | 2017–18 | 2018–19 | Pooled | 2017–18 | 2018–19 | Pooled |
| T1         | 12.47   | 12.70   | 12.58  | 1.37    | 1.05    | 1.21   |
| T2         | 13.70   | 13.80   | 13.75  | 2.02    | 1.58    | 1.80   |
| T3         | 13.93   | 14.13   | 14.03  | 2.03    | 1.66    | 1.85   |
| T4         | 13.23   | 13.23   | 13.23  | 1.77    | 1.42    | 1.60   |
| T5         | 13.43   | 13.30   | 13.37  | 1.89    | 1.70    | 1.80   |
| T6         | 13.33   | 13.07   | 13.20  | 1.95    | 1.87    | 1.91   |
| T7         | 13.40   | 13.57   | 13.48  | 2.22    | 1.59    | 1.91   |
| T8         | 13.27   | 13.33   | 13.30  | 1.74    | 1.23    | 1.48   |
| T9         | 13.17   | 13.27   | 13.22  | 2.10    | 2.00    | 2.05   |
| T10        | 13.47   | 13.47   | 13.47  | 1.83    | 1.66    | 1.74   |
| T11        | 14.33   | 14.93   | 14.63  | 2.39    | 2.15    | 2.27   |
| T12        | 13.57   | 13.53   | 13.55  | 2.28    | 1.97    | 2.12   |
| SEm±       | 0.25    | 0.27    | 0.20   | 0.11    | 0.08    | 0.08   |
| CD (p = 0.05) | 0.72    | 0.78    | 0.58   | 0.31    | 0.23    | 0.22   |

https://doi.org/10.1371/journal.pone.0262652.t002

https://doi.org/10.1371/journal.pone.0262652.t003
P concentration across the treatments was found 0.13% during the study period. The chickpea stover K concentration ranged 1.40–1.49% during the study period 2017–2019. Similarly, the average chickpea stover K concentration across the treatments was found 1.45–1.46%.

**Nutrient uptake**

The chickpea total N uptake ranged 47.72–92.24 kg ha⁻¹, 36.45–89.83 kg ha⁻¹ and 42.09–91.04 kg ha⁻¹ during 2017–18, 2018–19 and pooled of two years, respectively (Fig 1). Similarly, the average chickpea total N uptake across the treatments was found 73.77 kg ha⁻¹, 65.21 kg ha⁻¹ and 69.49 kg ha⁻¹ during 2017–18, 2018–19 and pooled of two years, respectively. The chickpea total P uptake ranged 9.99–20.12 kg ha⁻¹ during the study period.

Similarly, the average chickpea total P uptake across the treatments was found between 7.53–20.93 and 8.76–20.52 kg ha⁻¹ during 2017–18, 2018–19 and pooled of two years (Fig 2). The chickpea total K uptake ranged 52.7–157.7 kg ha⁻¹, 53.5–137.0 kg ha⁻¹ and 53.1–147.3 kg ha⁻¹ during 2017–18, 2018–19 and pooled of two years, respectively.

![Fig 1. Nitrogen uptake in chickpea under various INM modules.](https://doi.org/10.1371/journal.pone.0262652.g001)
Similarly, the average chickpea total K uptake across the treatments was found 115.0 kg ha$^{-1}$, 104.0 kg ha$^{-1}$ and 109.5 kg ha$^{-1}$ during 2017–18, 2018–19 and pooled of two years, respectively (Fig 3). In general, the uptake of N, P and K in chickpea was found higher under the treatments receiving the integrated nutrient management modules/recommended dose of balanced chemical fertilizers (STCR).

Soil properties under various INM modules

**Soil pH and EC.** The soil pH of the soil ranged 7.83–7.89 and 7.85–7.89 in 0–15 cm and 15–30 cm soil depth respectively. Similarly, the average pH value in 0–15 cm and 15–30 cm was recorded as 7.86 and 7.87, respectively across the various INM treatments under study. Similarly, the EC of the soil ranged 0.22–0.26 dS m$^{-1}$ and 0.23–0.36 dS m$^{-1}$ in 0–15 cm and 15–30 cm soil depth, respectively.

**Soil organic carbon (SOC).** The soil organic carbon ranged 0.60–0.89% and 0.42–0.50% in 0–15 cm and 15–30 cm soil depth, respectively under various treatments under study. Similarly, the average SOC across the different treatments in 0–15 cm and 15–30 cm soil depth was found 0.69% and 0.45%, respectively. The highest SOC (0.89%) was found under the treatment receiving FYM @ 20 t ha$^{-1}$ to maize followed by FYM @ 5 t ha$^{-1}$ to chickpea (T$_{11}$). The
treatments consist of organic manures as full or partial input, i.e. T₅, T₇, T₈, T₉, T₁₀ and T₁₂ showed significantly higher SOC.

Soil available N, P and K. The soil available N concentration in 0–15 cm soil layer ranged 195.9–350.4 kg ha⁻¹, 206.1–337.9 kg ha⁻¹ and 201.0–344.1 kg ha⁻¹ during 2017–18, 2018–19 and pooled of two years, respectively. Similarly, the average soil available N concentration across the treatments was found 282.8 kg ha⁻¹, 266.2 kg ha⁻¹ and 274.5 kg ha⁻¹ during 2017–18, 2018–19 and pooled of two years, respectively. The pooled data of two years with respect to soil available N revealed that the highest value was observed in the treatment T₁₁ (FYM @ 20 t ha⁻¹ to maize followed by FYM @ 5 t ha⁻¹ to chickpea). The soil available P concentration in 0–15 cm soil layer ranged 9.3–31.0 kg ha⁻¹, 8.8–34.2 kg ha⁻¹ and 9.1–32.6 kg ha⁻¹ during 2017–18, 2018–19 and pooled of two years, respectively. Similarly, the average soil available P concentration across the treatments was found 21.8 kg ha⁻¹, 26.0 kg ha⁻¹ and 23.9 kg ha⁻¹ during 2017–18, 2018–19 and pooled of two years, respectively. The soil available P was found highest in the treatment T₁₁ (FYM @ 20 t ha⁻¹ to maize followed by FYM @ 5 t ha⁻¹ to chickpea). The soil available K under various long term INM modules ranged 285.7–416.8 mg kg⁻¹ (Table 5). Similarly, the average soil available K across the treatments under study was found 332.8 mg kg⁻¹. The data revealed that the treatment receiving FYM @ 20 t ha⁻¹ to maize followed by FYM @ 5 t ha⁻¹ (T₁₁) showed highest soil available K (416.8 mg ka⁻¹) and found statistically significant over rest all the treatments under study. The treatment receiving STCR dose (T₃), 75% STCR dose + FYM @ 5 t ha⁻¹ (T₅), 75% STCR dose + maize residue mulching (T₆), 1 t PM + Gly 2 t + maize residue mulching (T₇), 5 t FYM + Gly 2 t + maize residue mulching (T₈) and 75% STCR dose + 20 t FYM once in four years (T₁₁) found statistically at par. Similarly, the treatments T₂ (GRD), T₄ (75% of STCR dose), T₆ (75% of STCR dose + 1 t PM) and T₇ (75% of STCR dose + 5 t VC) were also found statistically similar with respect to the soil available K. The treatment control (T₁) showed lowest value of soil available K (332.8 mg kg⁻¹).

Discussion

Chickpea growth and yield were increased by combining chemical and organic plant nutrients. The treatments receiving integrated nutrient management incorporating the application of chemical fertilisers and manures (T₆, T₇, T₉, and T₁₂) were shown to be either superior or comparable to those receiving only chemical fertiliser. The better performance of crop with

Table 5. The effect of various INM modules on soil properties (0–15 cm) at chickpea harvest.

| Treatment | pH | EC | OC | N   | P   | K          |
|-----------|----|----|----|-----|-----|------------|
| T₁        | 7.83 | 0.22 | 0.60 | 201.0 | 9.1 | 275.8     |
| T₂        | 7.85 | 0.24 | 0.65 | 262.7 | 25.2 | 305.8     |
| T₃        | 7.86 | 0.25 | 0.63 | 315.4 | 30.5 | 377.2     |
| T₄        | 7.85 | 0.23 | 0.61 | 256.4 | 19.5 | 340.2     |
| T₅        | 7.84 | 0.24 | 0.73 | 273.4 | 28.0 | 357.5     |
| T₆        | 7.87 | 0.25 | 0.66 | 261.1 | 25.0 | 340.1     |
| T₇        | 7.88 | 0.26 | 0.69 | 246.3 | 22.8 | 369.3     |
| T₈        | 7.86 | 0.26 | 0.68 | 283.4 | 20.7 | 351.4     |
| T₉        | 7.89 | 0.25 | 0.69 | 281.2 | 19.7 | 351.1     |
| T₁₀       | 7.85 | 0.24 | 0.73 | 286.9 | 24.6 | 341.7     |
| T₁₁       | 7.87 | 0.25 | 0.89 | 344.1 | 32.6 | 430.9     |
| T₁₂       | 7.84 | 0.23 | 0.71 | 282.2 | 29.2 | 363.7     |
| SEm ±     | 0.04 | 0.02 | 0.02 | 12.2  | 1.2  | 20.8      |
| CD        | NS   | NS   | 0.07 | 35.6  | 3.4  | 61.0      |

https://doi.org/10.1371/journal.pone.0262652.t005
adequate and balanced chemical fertilizer application has already been documented [21–27]. However, the imbalanced use of chemical fertilizers deteriorating the soil health. Similarly, the supply and cost of the chemical fertilizers limits its access and application. The use of integrated nutrient management hence introduced to substitute the partial chemical fertilizer requirement. The integrated nutrient management modules in present investigation proved at par and even better compared to the sole chemical fertilizer application with respect to the performance of the chickpea crop. Dotaniya et al. [9] reported increased seed and straw yield under the application of integrated nutrient. Similarly Srinivasa et al. [28] also found application of recommended N, P₂O₅ with 40 kg K₂O ha⁻¹ + 6 t of FYM recorded higher grain yield (2266.07 kg ha⁻¹) and straw yield (3814.95 kg ha⁻¹) of foxtail millet in red sandy loam soils.

A long-term application of FYM and inorganic fertilizers that the grain yield and uptake of N, P and K by both crops were higher with the application of FYM and inorganic fertilizer than in control plots. The uptake of N, P and K increased with the application of FYM and N₁₀₀, P₅₀, K₅₀ [29]. Shivran et al. [30] recorded that application of FYM @ 5t ha⁻¹, inorganic P₂O₅ @ 40 kg ha⁻¹ and S @ 20 kg ha⁻¹ resulted significantly higher plant height, branches plant⁻¹, number of pods plant⁻¹, number of seeds plant⁻¹, number of nodules, dry weight of nodules and hence higher seed, straw yield and protein content of soybean during 2008 and 2009.

There were no significant difference observed within 40 and 60 kg P₂O₅ ha⁻¹. Similarly, Balai et al. [31] also reported that N content and uptake in grain increased significantly with increasing levels of phosphorus up to 60 kg ha⁻¹ but N content and uptake in straw increased significantly up to 40 kg P₂O₅ ha⁻¹. P content and uptake by grain and straw was significantly increased by applying increasing level of phosphorus up to 60 and 40 kg P₂O₅ ha⁻¹ in chickpea crop. Asangi et al. [32] reported nitrogen (1.48 and 0.69%), phosphorus (0.44 and 0.26%), potassium (0.63 and 1.97%) in maize grain and stover, respectively. Malvi et al. [33] reported highest maximum N, P, K and S nutrient uptakes in fodder berseem plants under 90 kg K₂O and 40 kg S ha⁻¹ application. The results of present investigation are in good agreement with these findings.

In general, the concentration of N, P and K in chickpea (grain and straw) was found higher under the treatments receiving the integrated nutrient management modules/recommended dose of balanced chemical fertilizers (STCR). Shivran et al. [30] recorded that application of FYM @ 5t ha⁻¹, inorganic P₂O₅ @ 40 kg ha⁻¹ and S @ 20 kg ha⁻¹ resulted significantly higher plant height, branches plant⁻¹, number of pods plant⁻¹, number of seeds plant⁻¹, number of nodules, dry weight of nodules and hence higher seed, straw yield and protein content of soybean during 2008 and 2009. There were no significant difference observed within 40 and 60 kg P₂O₅ ha⁻¹. Balai et al. [31] reported that N content and uptake in grain increased significantly with increasing levels of phosphorus up to 60 kg ha⁻¹ but N content and uptake in straw increased significantly up to 40 kg P₂O₅ ha⁻¹. P content and uptake by grain and straw was significantly increased by applying increasing level of phosphorus up to 60 and 40 kg P₂O₅ ha⁻¹ in chickpea crop. Asangi et al. [32] reported nitrogen (1.48 and 0.69%), phosphorus (0.44 and 0.26%), potassium (0.63 and 1.97%) in maize grain and stover, respectively. Malvi et al. [34] reported highest maximum N, P, K and S contents in berseem plants under 90 kg K₂O and 40 kg S ha⁻¹ application.

The type of organic inputs as well as the physico-chemical qualities of soils has influenced soil attributes. Similarly, the average EC value in 0–15 cm and 15–30 cm was recorded as 0.24 dS m⁻¹ and 0.28 dS m⁻¹, respectively across the various INM treatments under study. Both, pH and soil EC did not reveal any significant change under long term application of the various INM modules [35, 36]. Yadav et al. [37] had also recorded non-significant changes in soil pH and EC with the application of chemical fertilizers and organic manures which may be attributed to the fact that the soil pH is mainly affected by the parent material involved in soil formation and the climatic conditions [4, 17].
Soil organic carbon served as a source of food for soil microbial biomass and moderated plant nutrient dynamics in the soil. Manna et al. [38] also found increase in SOC with the application of FYM alone or in combination with recommended NPK fertilizers over absolute control and sole NPK fertilizer application [2, 39, 40]. The results of this study are in close agreement with these findings. The higher C accumulation in the Vertisol may be attributed to their high silt+clay content which increase the C stabilization capacity [41]. The findings of [42–46] with respect to the soil organic carbon are in line with the results of present investigation.

The soil available N was positively impacted by the various long-term INM modules. This was probably due to the mineralization of N from added organic manure (FYM) [47]. Upon addition of organic matter, the available nutrient status of soil increases considerably due to mineralization from soil as well as its own nutrient contents [37]. The higher N content under INM application are in conformity with the finding of who reported increase in soil available N due to FYM application [48]. Similarly, it was also found that higher soil available N under the sole/combined application of organic manures [49, 50]. The influence of various long-term INM modules significantly influenced the soil available P as the values showed treatment wise variation. The increased availability of P in soil upon organic application is mainly attributed to the release of inorganic P from added organics, inhibition of P adsorption by organic molecules released from the organics, a rise in soil pH during decomposition and complexation of soluble Al^{3+} and Fe by organic molecules [20, 51]. Aziz et al. [49] reported maximum soil N and P contents after a maize harvest for FYM whereas the minimum N and P contents were found for the treatments with the application of inorganic NPK fertilizer. Kong et al. [52] found that availability of soil N, P and K was considerably decline under control and the treatment that received only chemical fertilizers. This indicates that decreasing N, P and K availability in soil could be a threat to long-term sustainability of crop productivity and soil health [53] Furthermore, Yang et al. [54] observed that integration of FYM with 75% NPK of SCTR improved the SOC content in surface soil over the initial value or unfertilized plots. A similar trend was observed for P and K availability in soil system, indicating that significantly build up the Olsen P in surface soil with continuous used of FYM (20 Mg ha^{-1}) and integration of 75% NPK along with FYM as compared to rest of INM practices. Many researchers have indicated that the application of organic and inorganic substracts during crop production has a significant impact on accessible macronutrients in soil [7, 55, 56].

**Conclusion**

The integrated nutrient management modules positively influenced the performance and productivity of chickpea crop as compared to the sole inorganic fertilizer application. Besides the superior crop performance, the INM modules significantly enhanced soil organic carbon and improved soil health in terms of soil physical and chemical properties. Among the various modules, (1) application of 75% STCR dose + FYM @ 5t ha^{-1} to maize followed by 100% P only to chickpea and (2) application of FYM @ 20t ha^{-1} to maize followed by FYM @ 5t ha^{-1} to chickpea increased the productivity and nutrient uptake in chickpea, improved soil physico-chemical properties and reflected as viable technique in improving soil nutrient availability on sustainable basis.

**Acknowledgments**

The authors are thankful to the Director, ICAR-Indian Institute of Soil Science, Bhopal and Vice Chancellor, Swami Keshwanand Rajasthan Agricultural University, Bikaner for providing the research opportunity and for extending every kind of support during the study.
Author Contributions

Conceptualization: Chetan Kumar Dotaniya, Brij Lal Lakaria, Yogesh Sharma, Mohan Lal Dotaniya.

Data curation: Bharat Prakash Meena, Shish Ram Yadav.

Formal analysis: Bharat Prakash Meena, Satish Bhagwatrao Aher, Mohan Lal Dotaniya, Shish Ram Yadav, Ramesh Chandra Sanwal, Rajesh Kumar Doutaniya.

Investigation: Chetan Kumar Dotaniya, Brij Lal Lakaria.

Methodology: Abhay Omprakash Shirale, Priya Gurav Pandurang, Rajesh Kumar Doutaniya.

Project administration: Brij Lal Lakaria, Ashis Kumar Biswas, Ashok Kumar Patra.

Resources: Abhay Omprakash Shirale.

Software: Satish Bhagwatrao Aher, Shish Ram Yadav.

Supervision: Yogesh Sharma, Abhay Omprakash Shirale, Ashis Kumar Biswas, Ashok Kumar Patra.

Validation: Satish Bhagwatrao Aher, Madan Lal Reager.

Visualization: Priya Gurav Pandurang.

Writing – original draft: Chetan Kumar Dotaniya, Mohan Lal Dotaniya, Madan Lal Reager, Ramesh Chandra Sanwal, Rajesh Kumar Doutaniya, Manju Lata.

Writing – review & editing: Mohan Lal Dotaniya, Madan Lal Reager, Ramesh Chandra Sanwal, Manju Lata.

References

1. Sharma AR, Behera UK. Recycling of legume residues for nitrogen economy and higher productivity in maize (Zea mays)–wheat (Triticum aestivum) cropping system. Nutrient Cycling in Agroecosystems. 2009; 83(3):197–210.

2. Meena BP, Jha P, Ramesh K, Biswas AK, Elanchezhian R, Das H, et al. Agronomic management based on multi-split topdressing increases grain yield and nitrogen use efficiency in rainfed maize in Vertisols of India. Journal of Plant Nutrition. 2021; https://doi.org/10.1080/01904167.2021.1998529.

3. Dotaniya CK, Lakaria BL, Sharma Y, Biswas AK, Meena BP, Yadav SR, et al. Physiological parameter of maize as influenced by INM modules under maize-chickpea sequence in a Vertisol of Central India. International Journal of Current Microbiology and Applied Sciences. 2020; 9(09): 2745–2753.

4. Lakaria BL, Jha P, Biswas AK. Soil carbon dynamics under long term use of organic manures. In: Singh AB, Reddy SK, Mannan MC and Subba Rao A. (Eds.), Recycling organic wastes for soil health and productivity. Agrotech Publishing Academy Udaipur, Rajasthan, India. 2011; 83–93.

5. Mazumdar SP, Kundu DK, Ghosh D, Saha AR, Majumdar B, Ghorai AK. Effect of long-term application of inorganic fertilizers and organic manure on yield, potassium uptake and distribution of potassium fractions in the new gangetic alluvial soil under jute-rice-wheat cropping system. International Journal of Agriculture and Food Science Technology. 2014; 5(4): 297–306.

6. Smith JL, Doran JW. Measurement and use of pH and electrical conductivity for soil quality analysis. In: Doran JW and Jones AJ, Eds., Methods for assessing soil quality, Soil Science Society of America Journal SSSA Madison. 1996; pp. 49.

7. Meena BP, Biswas AK, Singh M, Chaudhary RS, Singh AB, Das H, et al. Long-term sustaining crop productivity and soil health in maize–chickpea system through integrated nutrient management practices in Vertisols of central India. Field Crops Research. 2019; 232:62–76.

8. Lakaria BL, Patne M, Jha P, Biswas AK. Soil organic carbon pools and indices under different land use systems in Vertisols of Central India. Journal of the Indian Society of Soil Science. 2012b; 60(2): 125–131.
9. Dotaniya CK, Niranjan RK, Kumar U, Lata M, Regar KL, Doutaniya RK, et al. Quality, yield and nutrient uptake of fenugreek as influenced by integrated nutrient management. International Journal of Plant & Soil Science. 2019; 29(3): 1–7.

10. Dotaniya ML, Datta SC, Biswas DR, Meena BP. Effect of solution phosphorus concentration on the exudation of oxalate ions by wheat (Triticum aestivum L.). Proceedings of the National Academy of Sciences, India, Section B: Biological Sciences. 2013; 83: 305–309.

11. Dotaniya ML. Role of bagasse and press mud in phosphorus dynamics. Lap Lambert Academic Publisher, Germany. 2014; 1st ed. ISBN 13: 978-3-659-49076-7. https://doi.org/10.1007/s10661-013-3593-5 PMID: 24415062

12. Dotaniya ML. Crop residue management in rice-wheat cropping system. First Edition, Lap Lambert Academic Publisher, Germany. 2012; pp. 116. ISBN 978-3-659-29388-7.

13. Dotaniya ML, Datta SC, Biswas DR, Dotaniya CK, Meena BL, Rajendran S, et al. Use of sugarcane industrial byproducts for improving sugarcane productivity and soil health—a review. International Journal Recycling Organic Waste. 2016; https://doi.org/10.1007/s40093-016-0132-8

14. Chapman HD, Pratt PE. Method of analysis for soil, plant and water. University of California. USA 1961.

15. Jackson ML. Soil chemical analysis (Edn. 2) Prentice Hall of India Pvt. Ltd., New Delhi. 1973; Pp. 69–182.

16. Walkley A, Black IA. Rapid titration method for organic carbon of soils. Soil Science. 1934; 37: 29–32.

17. Subbiah BV, Asija GL. A rapid procedure for the estimation of available nitrogen in soil. Current Science. 1956; 25: 259–261.

18. Watanabe FS, Olsen SR. Test of an ascorbic acid method for determining phosphorus in water and NaHCO₃ extracts from soil. Soil Science Society of America Proceedings. 1965; 29: 677–678.

19. Hanway JJ, Heidal HS. Soil analysis methods as used in Iowa state college soil testing laboratory. Iowa State College of Agriculture Bulletin. 1952; 57: 1–13.

20. Gomez KA, Gomez A. Statistical procedures for agricultural research (2nd edition), John wiley and sons, New York. 1983; 1–680.

21. Dharwe DS, Dixit HC, Dotaniya CK, Doutaniya RK, Mohbe S, Tarwariya MK. Effect of phosphorus and sulphur on yield attributes, nutrient content and nutrient uptake of green gram in Bundelkhand soil. International Journal of Current Research. 2019; 11(11): 8225–8229.

22. Dharwe DS, Dixit HC, Dotaniya CK, Mohbe S, Doutaniya RK, Jamara P. Influences of phosphorus and sulphur on yield attributes of summer green gram (Vigna radiata L.). Journal of Pharmacognosy and Phytochemistry. 2018; 7(2): 147–149.

23. Meena BP, Kumar A, Lal B, Sinha NK, Tiwari PK, Dotaniya ML, et al. Soil microbial, chemical properties and crop productivity as affected by organic manure application in popcorn (Zea maya L. var. everta). African Journal of Microbiology Research. 2015; 9(21): 1402–1408.

24. Sawarkar SD, Khamparia NK, Thakur R, Dewda MS, Singh M. Effect of long-term application of inorganic fertilizers and organic manure on yield, potassium uptake and profile distribution of potassium fractions in Vertisol under soybean-wheat cropping system. Journal of the Indian Society of Soil Science. 2013; 61(2): 94–98.

25. Singh AK, Kushwaha HS. An evaluation of chick pea (Cicer arietinum) crop yield through nutrient management in dry land condition of Bundelkhand, (UP), India. International Journal of Current Microbiology and Applied Sciences. 2018; 7(5): 254–258.

26. Thakur NS. Productivity and economic viability of maize (Zea maya) based cropping system under rainfed condition. Research on Crops. 2003; 4(3): 305–309.

27. Dotaniya CK, Lakaria BL, Aher SB, Subhash, Mohbe S, Doutaniya RK. Critical role of potassium in crop production. Agriculture and & Food: E-Newsletter. 2020; Article ID: 31429, pp-89–92.

28. Srinivasa DK, Chikkaramappa T, Basavaraja PK, Sukanya TS, Murali K, Chamegowda TC. Status of different forms of potassium under foxtail millet crop as influenced by graded levels of potassium in Alfisols of Chikkaballapur region, Karnataka. International Journal of Chemical Studies. 2019; 7(3): 3435–3441.

29. Rasool SS, Rehana K, Hira GS. Soil organic carbon and physical properties as affected by long-term application of FYM and inorganic fertilizers in maize-wheat system. Soil and Tillage Research. 2008; 101(1–2):31–36.

30. Shivran RK, Kumar P, Jat RK, Kumar V, Nilmami P. Effect of integrated nutrient management practices on growth, yield and economics of chickpea in maize chickpea/wheat cropping system. Journal of Pharmacognosy and Phytochemistry. 2017; SP1: 115–118.
31. Balai K, Jajoria M, Verma R, Deewan P, Bairwa SK. Nutrient content, uptake, quality of chickpea and fertility status of soil as influenced by fertilization of phosphorus and zinc. Journal of Pharmacognosy and Phytochemistry. 2017; 6(1): 392–398.
32. Asangi AM, Srinivasamurthy AM, Subbarayappa CT, Bhaskar S. Nutrient content and uptake by maize (Zea mays L.) crop due to application of distillery spent wash RO reject. Journal of Pharmacognosy and Phytochemistry. 2018; 7(1): 1745–1750.
33. Malvi V, Dotaniya CK, Reager ML, Dixit HC, Doutaniya RK, Mohbe S. Effect of potassium and sulphur on yield, quality and nutrient uptake of winter season berseem (Trifolium Alexanderinum L.) in central part of India. Journal of Soils and Crops. 2021; 31(1): 25–31.
34. Lynch MJ, Mulvaney MJ, Hodges SC. Decomposition, nitrogen and carbon mineralization from food and cover crop residues in the central plateau of Haiti. Springer Plus. 2016; 5: 973.
35. Choudhary M, Panday SC, Meena VS, Singh S, Yadav RP, Mahanta D, et al. Long-term effects of organic manure and inorganic fertilization on sustainability and chemical soil quality indicators of soybean-wheat cropping system in the Indian mid-Himalayas. Agriculture, Ecosystems and Environment. 2018; 257: 38–46.
36. Meena BP, Tiwari PK, Dotaniya ML, Shirale AO, Ramesh K. Precision nutrient management techniques for enhancing nutrient use efficiency. In: Advances in nutrient dynamics in soil plant system for improving nutrient use efficiency (Elanchezhan R, Biswas AK, Ramesh K, Patra AK, eds), New India Publishing Agency, New Delhi, India. 2017; pp. 61–74.
37. Yadav KK, Chhipa BR. Effect of FYM, gypsum and iron pyrites on fertility status of soil and yield of wheat irrigated with high RSC water. Journal of the Indian Society of Soil Science. 2007; 55(3): 324–329.
38. Lynch MJ, Mulvaney MJ, Hodges SC. Decomposition, nitrogen and carbon mineralization from food and cover crop residues in the central plateau of Haiti. Springer Plus. 2016; 5: 973.
39. Haynes RJ, Mokolobate MS. Amelioration of Al toxicity and P deficiency in acid soils by additions of organic residues: a critical review of the phenomenon and the mechanisms involved. Nutrient Cycling in Agroecosystems. 2001; 59: 47–63.
40. Lakaria BL, Singh M, Reddy KS, Biswas AK, Jha P, Chaudhary RS, et al. Carbon addition and storage under integrated nutrient management in soybean–wheat cropping sequence in a Vertisol of Central India. National Academy Science Letters. 2012; 35(3):131–137.
41. Six J, Conant RT, Paul EA, Paustian K. Stabilization mechanisms of soil organic matter: Implications for C-saturation of soils. Plant and Soil. 2002; 241: 155–176.
42. Alam MK, Islam MM, Nazmus S, Mirza H. Effect of tillage practices on soil properties and crop productivity in wheat-mungbean-rice cropping system under subtropical climatic conditions. The Scientific World Journal. 2014; https://doi.org/10.1155/2014/437283 PMID: 25197702
43. Lynch MJ, Mulvaney MJ, Hodges SC. Decomposition, nitrogen and carbon mineralization from food and cover crop residues in the central plateau of Haiti. Springer Plus. 2016; 5: 973.
44. Purakayastha TJ, Huggins DR, Smith JL. Carbon sequestration in native prairie, perennial grass, no-tilled and cultivated Palouse silt loam. Soil Science Society of America Journal. 2008; 72(2): 534–540.
45. Singh M, Wanari RH. Potassium responses and requirement of crops grown in Vertisols: Experiences from long term fertilizer experiment. Indian Journal of Fertilizers. 2012; 8(3): 26–32.
46. Dotaniya CK, Yashona DS, Aher SB, Rajput PS, Doutaniya RK, Lata M, et al. Crop performance and soil properties under organic nutrient management. International Journal of Current Microbiology and Applied Sciences. 2020; 9(4): 1055–1065.
47. Drinkwater L, Letourneau DK, Workneh F, Bruggen AV, Shennan C. Fundamental differences between conventional and organic tomato Agro ecosystems in California. Ecological Applications. 1995; 5(4): 1098–1112.
48. Thamaraiselvi P, Lalitha P, Jayanthi P. Preliminary studies on phytochemicals and antimicrobial activity of solvent extracts of Eichhorniacrassipes, Asian Journal of Plant Sciences. 2012; 2: 115–122.
49. Aziz T, Ullah S, Sattar A, Nasim M, Farooq M, Mujtabakh M. Nutrient Availability and Maize (Zea mays) Growth in Soil Amended with Organic Manures. International Journal of Agriculture and Biology. 2010; 12(4): 621–624.
50. Tadesse T, Dechassa N, Wondimu B, Setegn G. Effect of farmyard manure and inorganic fertilizers on the growth, yield and moisture stress tolerance of rain-fed lowland rice. American Journal of Research Communication. 2013; 1(4): 275–301.
51. Iyamuremye F, Dick RP. Organic amendments and phosphorus sorption by soils. Advances in Agronomy. 1996; 56: 139–185.
52. Kong XB, Lal R, Li BG, Li KJ. Crop yield response to soil organic carbon stock over long-term fertilizer management in Huang-Huai-Hai Plains of China. Agricultural Research. 2014; 3: 246–256.
53. Jat RL, Jha P, Dotaniya ML, Lakaria BL, Rashmi I, Meena BP, et al. Carbon and nitrogen mineralization in Vertisol as mediated by type and placement method of residue. Environ Monit Assess. 2018; 190: 439. https://doi.org/10.1007/s10661-018-6785-1 PMID: 29955978

54. Yang J, Gao W, Shunrong R. Long-term effects of combined application of chemical nitrogen with organic materials on crop yields, soil organic carbon and total nitrogen in fluvo-aquic soil. Soil and Tillage Research. 2015; 151: https://doi.org/10.1016/j.still.2015.03.008

55. Elayarajan M, Sathy S, Arulmozhiselvan K. Effect of inorganic fertilizers and organic manures on yield and nutrient uptake by maize hybrid under maize-sunflower cropping sequence in Typic Haplustalf, Karnataka Journal of Agricultural Science. 2015; 28(1): 29–33.

56. Kushwa V, Hati KM, Sinha NK, Singh RK, Mohanty M, Somasundaram J, et al. Long-term conservation tillage effect on soil organic carbon and available phosphorous content in vertisols of central India. Agricultural research. 2016; 5(4): 353–361.