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Effect of Nutrient Management Practices on Sustaining Soil Health and Quality of Soybean (*Glycine max* L.) under Rainfed System in Western Himalayas

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ABSTRACT

Background: Soybean cultivation in the rainfed Himalayas is highly vulnerable to rainfall variations and soil health decline. Inadequate nutrient management has resulted in soil degradation and nutrient imbalances, underscoring the need for see-through sustainable practices to maintain soil fertility and productivity in the region.

Methods: The current study was conducted on soil health and quality of soybean (*Glycine max* L.) under rainfed system in Western Himalayas during *kharif* 2023 at CSK HPKV-Hill Agriculture Research and Extension Centre, Bajaura (H.P.). The experimentation contains 8 treatments which are replicated three times using a randomized block design. The soil of the study area was silty clay loam in texture, neutral in reaction with 7.30 g kg^{-1} organic carbon.

Result: The findings indicated that various approaches to nutrient management had dissimilar impressions on the soybean's nutritional quality and soil health. 100% NPK dose along with FYM primes protein and oil content (37.40 and 19.72%) in soyabean. Similar treatment showed maximum uptake of nutrients *viz*., N, P and K (92.58, 12.29 and 54.77 kg ha^{-1}), while Fe, Mn, Cu and Zn (81.79, 45.60, 17.30 and 49.91 g ha^{-1}) in soybean, respectively. Availability of N, P and K was low, medium to high and medium in range under different treatments. The combination of various practices did not show any significant effect on micronutrient concentrations. Correlation studies reported that total nutrient uptake as well as protein and oil content in soybean were found to be increased vis-à-vis increasing availability of nutrients.

Key words: Nutrient management, Soil health, Soyabean, Sustainability.

INTRODUCTION

Agricultural production and sustainability are significantly influenced by soil health, particularly in rainfed ecosystems where soil fertility and water availability are major limiting factors. Known for their rugged landscapes and fragile soils, the Western Himalayas pose significant challenges like erosion, nutrient depletion and declining organic matter, aggravated by unsustainable agricultural practices (Singh *et al.,* 2021). In India soybean [*Glycine max* (L.) Merrill] is a significant pulse as well as oilseed crop. As a legume crop, plays an important role in mountain regions of Great Himalayan ranges contributing to soil fertility through biological nitrogen fixation and improving livelihoods of the farmer community (Patel *et al.,* 2018). *Glycine max* L. is among the most cost-effective and nutrient rich crops, with high protein (36-40%) and oil (20%) content (Raghav *et al.,* 2019), thus, it is used to augment the protein requirement of humans in their diets.

In 2022-23, Himachal Pradesh produced 6.09 metric tonnes of soybeans on 10.75 ha of land, with a productivity of 756 kg ha^{-1} (Department of agriculture, HP, 2023), which is below the optimal productivity of 1600-2000 kg ha^{-1} under rainfed condition (National Food Security Mission, 2018). Steep topography, development of multi nutritional deficiencies brought on by insufficient organic resource recycling and imbalance fertilizer application all contribute to low production (Chaturvedi *et al.,* 2010). Keeping in view the land as a limiting factor, low productivity and importance of the crop, it is the need of the hour to find best nutrient management practices for sustaining soil health and crop yields.

Soybean, with its high protein and oil content, requires a large amount of nutrients (Sharma *et al.,* 2019), therefore exploration of nutrient management options, which can maintain ample nutrient supply required for various metabolic and physiological processes in the plant system. Various researchers had established the fact that neither

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inorganic nor organic amendments alone can maintain adequate availability of nutrients and organic carbon in soil (Kumar *et al.,* 2020). In assurance that the crop's nutritional requirements are satisfied, soil testing as a part of nutrient management aid in recognition of any nutrient deficiencies in the soil, letting farmers to change their fertilizer additions accordingly. Hence, the present investigation entitled "Effect of nutrient management practices on sustaining soil health and quality of soybean (*Glycine max* L.) under rainfed system in Western Himalayas was conducted with the objective to find sustainable nutrient management practices for promoting soyabean production in the Lesser Himalayan ranges.

MATERIALS AND METHODS

The field trial of the experiment was laid down at the experimental farm of CSK HPKV-Hill Agriculture Research and Extension Centre, Bajaura, H.P. (India) during *Kharif* 2023, to undertake soil and crop responses against different nutrient management practices. The study site was situated at 31°50′26″N latitude and 77°10′12″E longitude at an altitude of about 1090 m amsl. The site comes under mid hill sub-humid zone, with an average rainfall of 940-950 mm annually. Meteorological data sets related to the crop season are provided in Fig 1.

The research area soil had a silt clay loam texture and a neutral reaction of around 6.5. Soils have organic C content of 7.30 g kg^{-1}, medium in available N and K (252 and 159 kg ha^{-1}), while rich in available P (26.60 kg ha^{-1}) and micronutrients *viz.*, Fe, Mn, Zn and Cu (14.60, 15.30, 2.30 and 0.78 mg kg^{-1}) (Table 1) were sufficient.

A randomized block design was used to set up the experiment, which included eight treatments (Table 2), replicated three times. Soybean (variety-palam soya) was taken as the test crop. The recommended dose for the test crop is 120 kg N, 60 kg P_2O_5 and 40 kg K_2O ha^{-1}. Following the soybean harvest, soil samples were taken from each plot at a depth of 0-0.15 m.

After being air dried and crushed using a wooden pestle and mortar, sieved (2 mm) and placed in plastic bags for examination. The pH and EC of the soil was determined in pH/EC meter using a (1:2) soil:water suspension (Richards 1954). Organic Carbon (OC) was calculated using the rapid titration (Walkley and Black 1934), available N was determined using alkaline permanganate method (Subbiah and Asija 1956), available P was determined using colorimetric method (Olsen *et al.* 1954), available K was determined using flame photometric method (Jackson, 1973), available Fe, Mn, Cu and Zn was determined using atomic absorption spectrophotometry (Jackson, 1973) (Table 3). Grain and stover samples were collected from each plot during harvest and oven-dried at 60±5°C, sieved (1 mm) for analysis. For P and K estimation, samples were digested in a di-acid mixture (HNO_3:$HClO_4$, 4:1) following Piper (1966) procedures. Separate digestion

Table 1: Physical and chemical properties of the soil prior to the trial.

Properties		Value
Distribution of soil separates (%)	Sand	20.20
	Silt	48.60
	Clay	30.60
Soil texture		Silty clay loam
OC (g kg^{-1})		7.30
pH		6.50
EC (dS m^{-1})		0.20
Available macronutrients		**kg ha^{-1}**
N		252
P		26.60
K		159
Micronutrients		**mg kg^{-1}**
Fe		14.60
Mn		15.30
Cu		0.78
Zn		2.30

Table 2: Treatment details.

	Treatments
T_1	Absolute control
T_2	FYM (10 t ha^{-1})
T_3	Natural farming practices (NFP)
T_4	25% NPK + 75% FYM based N
T_5	50% NPK + 50% FYM based N
T_6	75% NPK + 25% FYM based N
T_7	100% NPK + FYM (5 t ha^{-1})
T_8	FYM + biofertilizers

The FYM applied contained 62% moisture and its average nutrient content was 0.65, 0.23 and 0.50% N, P and K, respectively. Biofertilizers was added in T_8 *viz., Rhizobium* and PSB.

*100% NPK = Recommended dose of fertilizers (RDF), Phosphate solubilizing bacteria (PSB).

*Natural farming methods include pre-treated seeds with *beejamrit* for 30 minutes, applying 500 kg ha^{-1} of *ghanjeevamrit* and 500 litres ha^{-1} of *jeevamrit* once a month and applying 10% jeevamrit sprays at 28-day intervals during crop development. Mulching with agricultural leftovers at a rate of 5 t ha^{-1}. Approximately 60 days following the grain filling and seeding stages, 12.5 litres of fermented butter milk is sprayed over the field.

Table 3: Methods employed for plant studies.

Parameter	Method	Reference
N	Micro-Kjeldahl	Jackson (1973)
P	Colorimetry	Jackson (1973)
K	Flame photometry	Black (1965)
Micronutrients (Fe, Mn, Cu, Zn)	Atomic absorption spectrophotometry	Jackson (1973)
Oil content	Soxhlet extraction	A.O.A.C (1970)

for N estimation was performed using a digestion mixture (potassium sulfate, copper sulfate, mercuric oxide and selenium powder) as per Jackson (1973).

Protein (%)

Protein content (%) = N content × 6.25 (Jones 1941)

Nutrient uptake analysis

Nutrient uptake (kg ha^{-1}) = Nutrient content (%) × Yield (q ha^{-1})

Total uptake = Seed uptake + Straw uptake

Statistical analysis

A statistical analysis was performed on the data attained from examination of the plant and soil characteristics. The data were interpreted using the randomized block design analysis of variance approach. Using Rstudio 4.4.2, the correlation coefficient was calculated to determine the relationship between soil characteristics and nutrient uptake in seed and straw. The usual approach outlined by Gomez and Gomez (1984) was used to perform statistical analysis.

RESULTS AND DISCUSSION

Nutrient uptake

Significant variations in nutrient uptake characteristics were reported owing to nutrient management strategies used (Table 4 and 5). In 100% NPK + FYM treated plots, total N uptake rose significantly from 31.72 kg ha^{-1} (control) to 92.58 kg ha^{-1}. The incorporation of similar treatment resulted in the highest total P and K uptake with 296.4 and 182% increase above control. Besides, NFP (T_3) and FYM + biofertilizers (T_8) treatments increased the plant P uptake by 82.90 and 114.8% and K uptake by 67.45 and 75.59%, respectively. As per the results it has been observed that N, P and K uptake showed increasing trend with raising fertilizer application along with FYM, synergy of inorganic and organic inputs fostered better root development, nutrient efficiency (Saket *et al.,* 2014), as FYM improves soil porosity and structure (Sharma *et al.,* 2016), enabling more efficient absorption of essential nutrients (Sawarkar *et al.,* 2014). FYM + biofertilizers combination outperformed

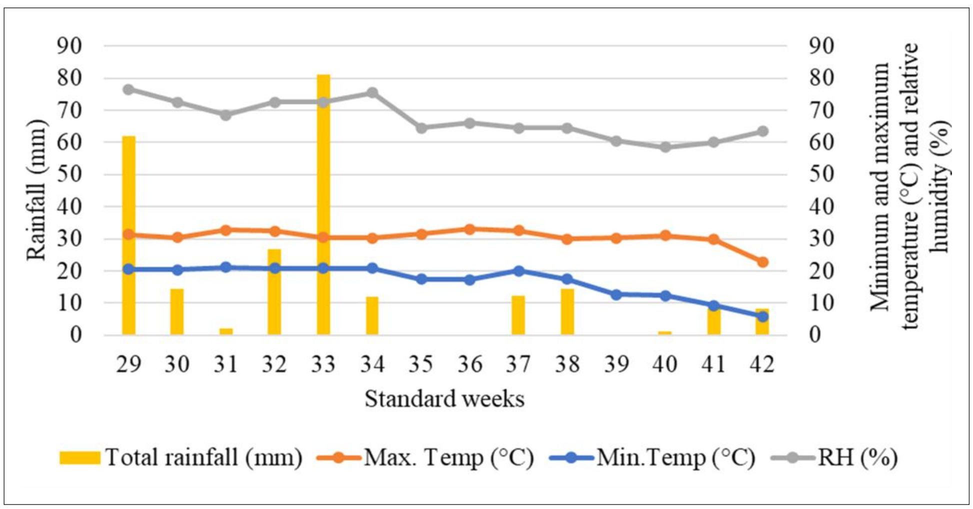


Fig 1: Mean weekly climate data of Bajaura (H.P.) for the year 2023.

Table 4: Effect of nutrient management practices on macronutrient uptake (kg ha^{-1}) in soyabean.

Treatments	Nitrogen (N)			Phosphorus (P)			Pottasium (K)		
	Seed	Straw	Total	Seed	Straw	Total	Seed	Straw	Total
T_1	20.74	10.99	31.72	1.69	1.41	3.10	5.41	14.01	19.42
T_2	31.51	17.83	49.35	2.75	2.37	5.12	8.20	22.87	31.07
T_3	33.30	18.74	52.04	3.06	2.61	5.67	8.87	23.65	32.52
T_4	39.99	23.82	63.81	3.98	3.58	7.57	10.32	30.12	40.45
T_5	49.46	26.42	75.88	4.94	4.43	9.37	12.27	33.06	45.33
T_6	52.37	29.33	81.70	5.40	5.08	10.47	13.07	37.18	50.25
T_7	59.95	32.63	92.58	6.49	5.80	12.29	14.81	39.96	54.77
T_8	35.82	19.36	55.18	3.72	2.94	6.66	9.24	24.86	34.10
CD ($p \leq 0.05$)	7.83	8.68	6.65	0.59	0.61	0.92	1.82	2.03	2.36

the NPF in N and P uptake owing to addition of *Rhizobium* and PSB which facilitates the nitrogen fixation in soyabean and solubilization of P (Girma *et al.,* 2017).

The findings of the study also revealed that the application of 100% NPK + FYM resulted in maximum uptake of micronutrients *viz.,* iron, manganese, copper and zinc in seed and straw of soyabean. Grain's Fe uptake varied between 28.93 g ha^{-1} (T_1) to 31.39 g ha^{-1} (T_7). In addition, T_7 had a significantly greater Fe uptake in straw than T_6, T_5, T_4 and T_8. The maximum total Mn uptake was also documented in T_7 (45.60 g ha^{-1}) followed by T_6 (44.94 g ha^{-1}). Copper uptake in grain was also significantly higher in T_7 (4.76 g ha^{-1}) which experienced an increase by 14.98 % over control and was statistically at par with T_6 (4.55 g ha^{-1}) and T_5 (4.33 g ha^{-1}). Further, total Zn uptake ranged from 45.86 g ha^{-1} (T_1) to 49.91 g ha^{-1} (T_7) experiencing an increase of 8.83% over control. It is evident from the results that uptake of micronutrients (Fe, Mn, Cu and Zn) varies slightly under different practices but conjoint use of NPK and FYM significantly outclassed other treatments. The synergistic interaction between FYM and chemical fertilizers optimizes nutrient availability, FYM provides organic acids that enhance micronutrient availability by reducing fixation in soil colloids, (Singh and Gupta, 2015; Gupta *et al.,* 2020) boosting crop micronutrient uptake and yield (Singh *et al.,* 2013).

Soybean quality

The protein content was lowest under control (34.10%) and highest (37.40%) with 100% NPK + FYM, which was statistically comparable to T_6 (36.50%) (Fig 2), showing decrease of 8.82% as compared to treatment T_7. In comparison to T_6 (19.58%), T_5 (19.32%) and T_4 (19.32%), T_7 (19.72%) had significantly higher oil content. In terms of soybean quality, protein and oil content were reported significantly higher under integrative supply of chemical fertilizers and FYM by ensuring adequate N, P and K supply. Moreover, the increased availability of N and P (resulted in better root formation) ultimately led to higher absorption of nitrogen by seeds (Shah *et al.,* 2019). FYM + biofertilizers was higher over NFP, T_2 (FYM alone) and control, owing to that rhizobium and PSB, further enhance soil fertility by fixing atmospheric nitrogen and solubilizing bound phosphorus, ensuring a consistent nutrient supply throughout the growing season (Nagar *et al.,* 2018). The upsurge in oil content with increasing fertilizer doses may be credited to sulfur (incorporated *via* SSP) as a decisive nutrient for oil (Triacylglycerol) content in seeds (Bhattacharjee *et al.,* 2013; Shah *et al.,* 2019).

Soil fertility

Soil pH, a key factor influencing nutrient availability in the soil, was observed to be nearly neutral in the experiment, varied from 6.45 (T_7) to 6.51 (T_1). None of the fertilizer management techniques had a significant effect on soil EC; values between 0.20 and 0.25 dS m^{-1} showed safer limits (<0.8 dS m^{-1}) for plant growth and development

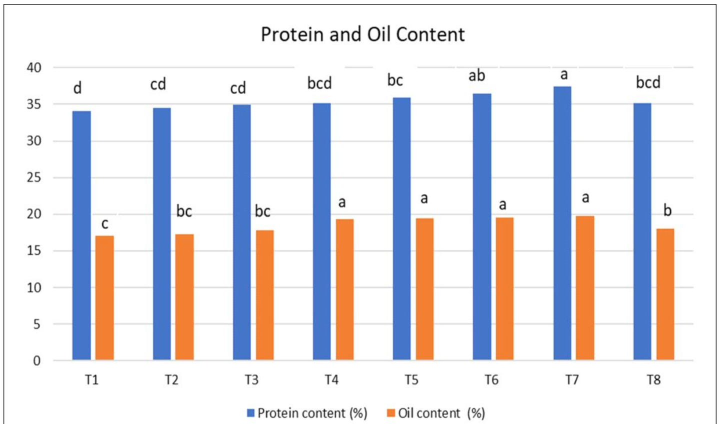
Table 5: Effect of nutrient management practices on micronutrient uptake (g ha^{-1}) in soyabean.

Treatments	Iron (Fe)			Manganese (Mn)			Copper (Cu)			Zinc (Zn)		
	Seed	Straw	Total	Seed	Straw	Total	Seed	Straw	Total	Seed	Straw	Total
T_1	28.94	46.82	75.76	12.96	29.49	42.45	4.14	11.16	15.29	13.76	32.44	45.86
T_2	30.35	47.57	77.92	13.20	29.76	42.96	4.21	11.58	15.79	14.28	33.40	47.68
T_3	30.38	47.62	78.00	13.23	30.01	43.24	4.23	11.20	15.43	14.34	33.77	48.11
T_4	30.57	49.97	80.54	13.32	30.30	43.62	4.31	12.14	16.45	14.47	34.26	48.73
T_5	30.87	50.01	80.88	13.67	30.37	44.04	4.43	11.89	16.32	14.52	34.46	48.98
T_6	30.97	50.03	81.00	13.84	31.10	44.94	4.55	12.02	16.57	14.63	34.79	49.42
T_7	31.39	50.40	81.79	14.22	31.39	45.60	4.76	12.54	17.30	14.77	35.14	49.91
T_8	30.05	48.76	78.81	13.24	30.17	43.40	4.26	11.68	15.94	14.38	33.59	47.98
CD (p=0.05)	1.11	2.32	2.60	0.74	1.08	1.06	0.37	0.84	0.95	0.40	1.40	1.16

(Kumar *et al.,* 2020). Soil organic carbon (OC), a CO_2 sink and nutrient regulator, increased by 5.87% with 100% NPK + FYM compared to the control (Table 6). A slight pH decrease under treatments is likely due to soil acidification (Paliwal *et al.,* 2021), from nitrogenous fertilizers, influenced by their type, rate and duration of use. Further, combination of inorganic fertilizers and FYM increases soil OC through increasing biomass production of soybean (Kumar and Meena, 2015), which decompose and contribute to build up of soil OC during crop growth (Thakur *et al.,* 2011; Singh and Bandyopadhyay, 2012). The notable increase in available N under T_8 can be due to *Rhizobium's* (applied as biofertilizer) capacity to fix atmospheric nitrogen enhancing the availability of N to plants and in soil (Saikia *et al.,* 2018; Raklami *et al.,* 2019). Application of 100% NPK + FYM recoded an increase in available P and K by 51.29 and 28.78% with respect to control. The rise in available P and K with inorganic fertilizers and FYM owing to straight nutrient addition and reduced fixation through humus-clay interactions, leading to more availability of nutrients in the soil (Thakur *et al.,* 2011). Correspondingly, available nutrient status rose vis-à-vis higher fertilizer dosages, results from suitable replenishment of nutrients through sources (Hekmat *et al.,* 2019). Availability of iron and manganese in soil varied from 13.02 and 16.09 mg kg^{-1} (T_1) to 14.32 and 17.85 mg kg^{-1} T_3 (NFP). Although, combined application of FYM and NPK led to slight decrease in Fe and Mn compared to initial levels (Table 6). Application of *Jeevamrit* and *Ghanjeevamrit* in NFP increases the solubility of Fe and Mn by boosting the activity of chelating agents (organic acids) during decomposition, preventing their fixation into unavailable forms and making them more accessible for plant uptake, improving soil fertility and crop health (Maqueda *et al.,* 2011; David *et al.,* 2022). The combination of various nutrient management practices did not show any significant increases in Cu and Zn concentration.

Correlation studies

Comprehensive overview of the relationship between variables used in the study, shows that higher nitrogen absorption is strongly linked (r≈0.96) to better protein content, indicating that nitrogen is an essential nutrient for protein synthesis in plants (Almaz *et al.,* 2017). Positive



Graph showing protein and oil content; According to DMRT, treatment means with different alphabetical letters differ substantially.

Fig 2: Effect of nutrient management practices on quality of soyabean.

Table 6: Effect of nutrient management practices on chemical properties, macronutrients (kg ha^{-1}) and micronutrients (mg kg^{-1}) status of soil.

Treatments	pH	SOC (g kg^{-1})	EC (dS m^{-1})	N	P	K	Fe	Mn	Cu	Zn
T_1	6.51	7.32	0.20	238	23.20	139	13.02	16.09	0.77	2.28
T_2	6.50	7.55	0.21	249	27.20	167	13.89	17.10	0.78	2.32
T_3	6.49	7.43	0.22	244	28.10	169	14.32	17.85	0.77	2.32
T_4	6.47	7.67	0.22	264	29.80	167	13.91	16.96	0.77	2.31
T_5	6.47	7.60	0.24	262	30.20	168	13.82	16.74	0.78	2.30
T_6	6.46	7.40	0.25	260	32.50	172	13.32	16.68	0.76	2.29
T_7	6.45	7.75	0.25	256	35.10	179	13.87	16.71	0.81	2.33
T_8	6.50	7.50	0.22	269	28.60	174	14.29	17.12	0.80	2.34
CD (p=0.05)	-	0.07	NS	11.02	2.34	9.56	1.16	0.90	NS	NS
Initial value	6.50	7.30	0.20	252	26.70	159	14.60	15.30	0.78	2.30

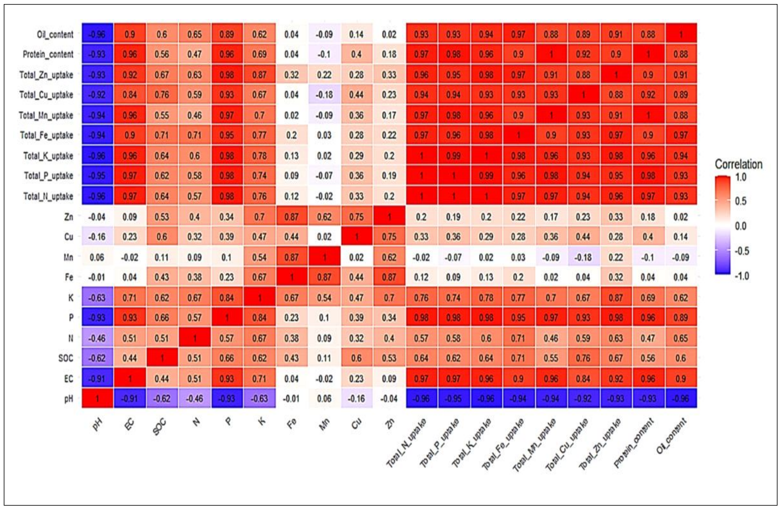


Fig 3: Correlation studies between soil parameters, nutrient uptake and quality of soyabean.

correlations between nutrient uptake and protein/oil content underscore the need for nutrient-rich soils to improve crop superiority (Awasthi *et al.,* 2020). Total P uptake is strongly positively correlated with Total N and K uptake (r≈0.98 and r≈0.99), indicates synergistic relation among N, P and K uptake (Mamia *et al.,* 2018). SOC and nutrients uptake relation highlights that more OC build up support nutrients uptake, likely due to enhanced nutrient availability in organic matter rich soils (Ozlu *et al.,* 2019). pH is negatively correlated with Total N (r≈-0.96), P (r≈-0.94) and K uptake (r ≈-0.93), suggesting that slightly acidic soils favor nutrient uptake, possibly due to increased nutrient solubility (Puli *et al.,* 2016). The strong correlations between N, P and K uptake underscore the importance of balanced fertilization strategies are crucial for optimal crop growth (Chakraborty and Hazari, 2016). Strong correlations of SOC with soil macronutrients (N, P, K) and micronutrients (Fe, Mn, Cu, Zn) show that organic matter is a critical factor for nutrient availability (David *et al.,* 2022) (Fig 3).

CONCLUSION

Results of the study had reported that application of balanced fertilizers (N, P, K) along with FYM had positive impacted on soil OC, nutrient availability, uptake proficiency and quality characteristics of soyabean. When recommended fertiliser dosages were applied in conjunction with FYM, the highest nutrient uptake, protein and oil content was recorded in soybean. This was equivalent to adding 75% inorganic nutrients and 25% FYM-based N. Crop quality is significantly influenced by different nutrient management practices, as seen by trends in oil and protein content. Similar trend was reported for nutrient availability, in contrast available Fe and Mn was significantly higher in natural farming practices. Thus, it can be concluded that application of 100% RDF + FYM and 75% RDF + 25% FYM was comparable with each other and superior over other combinations in term of improving soyabean quality and maintaining soil fertility, indicating possibility of compensating 25% chemical fertilizers by using organic amendments in the region concerning health safety.

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Disclaimers

The views and conclusions expressed in this article are solely those of the authors and do not necessarily represent the views of their affiliated institutions. The authors are responsible for the accuracy and completeness of the information provided, but do not accept any liability for any direct or indirect losses resulting from the use of this content.

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Conflict of interest

No, I declare that the authors have no competing interests (financial and/or non-financial interests) regarding the publication of this article. This manuscript had been finalized under the set guidelines and does not include any unethical matter.

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