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Impact of Farming Practices on Soybean Yield, Quality and Nutrient Uptake in Inceptisols

Kiran Patil [a,b++*], Dharmendrakumar Phalke [a,b#], Sandesh Deshmukh [a,b†], Abhay Patil [a,b#], Deepak Sawale [a,b#], Avinash Gosavi [a,b#], Lochana Kotangale [a,b++] and Ajinkya Mandake [a,b‡]

[a] *Division of Soil Science, College of Agriculture, Pune (MS), India.*
[b] *Mahatma Phule Krishi Vidyapeeth, Rahuri, India.*

Authors' contributions

This work was carried out in collaboration among all authors. All authors read and approved the final manuscript.

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ABSTRACT

Soil structure, nutrient use efficiency, microbial activity, and environmental sustainability can all be enhanced by conventional farming, standard package of techniques, organic farming, climate resilient farming, zero budget natural farming, etc. A field experiment was conducted at the College of Agriculture, Pune during the kharif season of 2024 to evaluate the effects of various agricultural

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++ *M.Sc. (Agriculture) Student;*
# *Associate Professor of Soil Science;*
† *Senior Research Assistant;*
‡ *Assistant Professor of Chemistry;*
**Corresponding author: E-mail: kiranpatil28025@gmail.com;*

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methods on soybean output, nutrient absorption, and quality. Five treatments—conventional farming, standard package of practices, organic farming, zero budget natural farming, and climate resilient farming—and four replications were included in the Randomized Block Design study. According to the results, climate resilient farming continuously performed better than other treatments, recording noticeably greater yields of grain (31.03 q ha^{-1}) and straw (37.57 q ha^{-1}). This approach significantly improved quality attributes, especially protein (40.98%) and oil content (20.39%). Nitrogen, phosphorus, and potassium levels of 195.88, 51.04, and 89.36 kg ha^{-1}, respectively, led to the maximum uptake of major nutrients. Iron, manganese, zinc, and copper micronutrient absorption was also noticeably better. These findings show that climate resilient farming provides a sustainable substitute for traditional systems by improving productivity, nutrient use efficiency, and seed quality. The study highlights its potential as a successful tactic to enhance soybean performance in the face of shifting climate circumstances.

Keywords: Soybean; yield; nutrient uptake; oil; protein; climate resilient farming.

1. INTRODUCTION

Soybean (*Glycine max* L.) is a very important oilseed and protein crop that is prized for both its high protein content and its ability to improve soil fertility through biological nitrogen fixation. Numerous agronomic management techniques, including as crop rotation, fertilization, irrigation, tillage, and pest control, have a significant impact on its productivity. In order to maximize soil health, nutrient availability, and water-use efficiency—all of which are important factors that determine crop output and sustainability—these measures are essential. Soybeans are now a crucial part of crop diversification plans in emerging nations like India, especially in areas with nutrient-sensitive soils like Inceptisols.

These are young, moderately developed soils that respond very well to suitable management measures because they have fluctuating fertility levels and little horizon differentiation (Anbhazhagan et al., 2024, Masto et al., 2007). Nonetheless, a number of soil-related issues, such as degradation, a decrease in the amount of organic matter, and ineffective nutrient cycling, have been brought on by the prolonged dependence on conventional farming methods, which are typified by high tillage, monocropping, and the heavy use of synthetic inputs. These problems raise significant environmental concerns in addition to compromising crop output.Relatively young soils known as inceptisols have low fertility and a high rate of deterioration. Soil structure, nutrient use efficiency, microbial activity, and environmental sustainability can all be enhanced by conventional farming, standard package of techniques, organic farming, climate resilient farming, zero budget natural farming, etc. In a delicate inceptisol ecosystem with a changing climate, integrating various agricultural methods is essential to enhancing soybean output and quality while preserving soil health (Pendke et al., 2025).

Alternative farming systems, particularly organic and natural farming, which are based on agro-ecological principles, are becoming more and more popular as a reaction to these issues. Systems like Rishi-Krishi Tantra and Zero Budget Natural Farming (ZBNF) place a strong emphasis on promoting biodiversity, recycling on-farm organic matter, increasing soil microbial activity, and using as few external inputs as possible (Ramesh et al., 2009). These methods have been acknowledged for their capacity to improve resilience to climatic stresses like droughts, floods, and irregular rainfall patterns, as well as to restore soil health and lower production costs (Conley & Santini, 2007). However, these systems are frequently criticized for having lower initial yields and increased labor requirements, especially when switching from traditional to alternative techniques.

The necessity for scientific analysis to ascertain if various farming systems can preserve or increase crop output while maintaining environmental sustainability is highlighted by this trade-off.

This need is become much more urgent by climate change. Global warming, which has been fueled by rising greenhouse gas emissions since the industrial revolution, is expected to increase temperatures by 1.4°C to 5.8°C. This will also drastically change the distribution of rainfall, increase the frequency of extreme weather events, and change the dynamics of weeds, pests, and diseases. Food security, rural livelihoods, and agricultural production are all seriously threatened by these developments. It becomes crucial in this situation to assess how well various farming methods operate in various agro-ecological settings.

According to recent data, India produced about 12.58 million tonnes of soybeans during the 2023–24 Kharif season, with an average yield of 1,063 kg/ha, grown on 11.83 million hectares. With productivity ranging from 946 to 1,115 kg/ha, Madhya Pradesh (5.54 million tonnes), Maharashtra (5.01 million tonnes), and Rajasthan (1.05 million tonnes) are the main soybean-producing states. However, a decrease in soybean acreage has been documented in a number of places as farmers switch to more lucrative or less climate-sensitive crops as a result of unpredictable rainfall and falling market prices. To help establish sustainable and climate-resilient agricultural practices, the current study intends to evaluate the effects of conventional, organic, and natural farming systems on soybean production, quality, and nutrient uptake in Inceptisol soils. As an alternative to conventional farming, alternative farming systems like organic and natural farming (like ZBNF and Rishi-Krishi Tantra) improve soybean yield, quality, and nutrient uptake in Inceptisol soils by improving soil health, nutrient use efficiency, and climate resilience in the face of changing environmental conditions.

2. MATERIALS AND METHODS

The field experiment comprised following treatments.

1) **Conventional Farming practice (T_1):** Basal dose of 10:26:26 N, P_2O_5 and K_2O kg ha^{-1}@250 kg ha^{-1}, Two foliar sprays of 19:19:19 @ 2 % at 21 and 35 DAS.
2) **Standard package of practices (T_2):** RDF (50:75:45 kg ha^{-1} N, P_2O_5, and K_2O), Application of FYM @ 10 t ha^{-1} (Basal application), Seed treatment of biofertilizers. *viz.,* Rhizobium + Phosphate solubilizing bacteria+ Potash solubilizing bacteria consortium @ 25 ml kg^{-1} ofseeds.
3) **Organic farming practice (T_3):** Basal application of FYM @10 t ha^{-1}, Vermicompost @ 3.5 t ha^{-1} and Phosphate rich organic manure (PROM) @ 200 kg ha^{-1}, Seed treatment of biofertilizers *viz.,* Rhizobium + Phosphate solubilizing bacteria + Potash solubilizing bacteria consortium @ 25 ml kg-1 of seeds.
4) **Zero budget natural farming practice (T_4):** Soil application of Ghanjeevamritha @ 2000 kg ha^{-1} during sowing, Mixed cropping system broadcasting of jowar and maize @ 12 kg ha^{-1}, Seed treatment of Beejamrit and drying of seeds in shade, After sowing mulching of crop residues of previous crop, After sowing application of 500 L ha^{-1} Jeevamritha with first two irrigations, Foliar sprays of Jeevamritha (12.5 L ha^{-1} Jeevamritha + 250 L of water at 21 DAS, 19 L ha^{-1} Jeevamritha + 300 L of water at 45 DAS, 25 L ha^{-1} Jeevamritha + 375 L of water at 65 DAS, 37.5 L ha^{-1} Jeevamritha + 375 L of water at 80 DAS), 7.5 L ha^{-1} Sour Buttermilk + 250 L of water at 90 DAS.
5) **Climate resilient farming (T_5):** Sowing of soybean on BBF (Broad Bed Furrow), Application of chemical fertilizers as per STCRC target 35 qt ha^{-1}, Basal application of FYM@10 t ha^{-1}, Seed treatment of biofertilizers viz., Rhizobium + Phosphate solubilizing bacteria + Potash solubilizing bacteria consortium @ 25 ml kg^{-1} of seeds, Mulching of weed/crop residues.

A proximate study of a variety of soil amendments, such as farmyard manure (FYM), vermicompost, phosphate-rich organic manure (PROM), Ghanajeevamrit, Jeevamrut, and Beejamrit, was carried out in order to assess the impact of various organic and natural farming inputs on soybean performance. Table 1 summarizes the findings of an analysis of these inputs' chemical composition, which included the macronutrient content, organic carbon, and C:N ratio. These inputs are a variety of microbial formulations and nutrient sources that are frequently utilized in natural and sustainable farming systems. Following crop harvest, representative plant samples were taken from each treatment plot and subjected to chemical analysis in order to evaluate crop quality characteristics and ascertain the nutrient content (nitrogen, phosphorus, potassium, etc.). For each treatment, grain and straw yields were noted. The nutrient concentration in plant tissue was multiplied by the corresponding dry matter yield to determine the amount of nutrients that soybeans absorbed. After that, the data were converted to kilograms per hectare (kg/ha) so that comparisons between treatments could be made. Under Inceptisol soil conditions, this integrated method allowed for a thorough evaluation of the effects of various input treatments on soybean yield, quality, and nutrient absorption capability.

Table 1. Proximate analysis of organic sources of nutrients

Parameters	FYM	Vermicompost	PROM	Jeevamrit	Beejamrit	Ghanajeevamrit
pH	7.49	6.91	7.18	4.92	8.02	7.8
EC(dSm^{-1})	1.66	2.12	1.74	3.22	3.11	2.7
Total C (%)	22.26	30.79	21.06	0.22	0.13	44.54
Total N (%)	0.69	1.48	0.78	0.32	0.16	0.97
Total P (%)	0.39	0.79	14.57	0.09	0.11	0.49
Total K (%)	0.38	0.81	0.37	0.59	0.48	0.99
Total S (%)	0.61	0.45	1.12	-	-	-
Fe($mgkg^{-1}$)	186	35.7	12.70	7.79	18.7	228
Mn($mgkg^{-1}$)	35.7	65.7	0.67	0.98	3.27	39.7
Zn($mgkg^{-1}$)	14.8	18.3	2.69	0.58	12.9	14.6
Cu($mgkg^{-1}$)	4.39	15.2	0.46	0.51	0.49	4.49
C:N ratio	32:1	21:1	24:1	0.7:1	0.8	45.92

3. RESULTS AND DISCUSSION

3.1 Influence of Farming Practices on Yield and Quality of Soybean

3.1.1 Yield of soybean

There was a notable difference in soybean grain production between farming practices (Table 2). Zero budget natural farming (T_4) recorded the lowest production (11.10 q ha^{-1}), whereas climate-resilient farming (T_5) produced the highest yield (31.03 q ha^{-1}). Organic farming produced 13.23 q ha^{-1}, which was lower than other treatments but far higher than zero budget natural farming. Improved crop growth and a balanced nutrient supply are responsible for the increased output under climate-resilient farming. It has been demonstrated that adding organic manures to liquid organic formulations like panchagavya and beejamrit improves growth and yield metrics (Shwetha and Babalad, 2008). Combining organic and inorganic sources, decreasing reliance on chemical fertilizers, increasing soil fertility, and optimizing production and profitability are all ways that integrated nutrient management (INM) maximizes fertilizer use (Selim *et al*., 2020).

3.1.2 Quality of soybean

The amount of protein in soybeans varied greatly depending on the farming practices (Table 2), with climate-resilient farming (T_5) having the highest value (40.98%), which was comparable to the standard package of practices (39.40%), organic farming (38.79%), and conventional farming (38.33%). The protein content of zero budget natural farming (T_4) was much lower (35.83%). Similarly, oil content was lowest (18.32%) with zero budget natural farming approaches and highest under climate-resilient farming (20.39%) and standard package of practices (20.08%). The quality of seeds was significantly impacted by nutrient management; treatments that combined NPK fertilizers with farmyard manure (FYM) and biofertilizers increased the amount of protein and oil, which is in line with research showing that higher nitrogen availability raises the amount of protein in seeds (Chaturvedi *et al*., 2010; Singh and Rai, 2004).

3.1.3 Influence of farming practices on total macronutrients uptake by soybean

Nutrient uptake data analysis revealed statistically significant differences amongst the assessed farming systems (Table 3). The normal package of operations had a nitrogen uptake of 165.32 kg ha^{-1}, while climate-resilient farming had the highest overall nitrogen uptake (195.88 kg ha^{-1}). On the other hand, nitrogen uptake was lower in zero budget natural farming (62.97 kg ha^{-1}). This is because there were fewer external nutrient inputs and the mineralization rates of just natural additions were slower. Phosphorus showed a similar pattern, with climate-resilient farming recording the highest uptake (51.04 kg ha^{-1}), while conventional farming, organic farming, and standard package of practices all showed better values than zero budget natural farming (14.83 kg ha^{-1}). This trend also applied to potassium uptake, with climate-resilient farming achieving 89.36 kg ha^{-1}, conventional package of practices coming in second (74.74 kg ha^{-1}), and zero budget natural farming achieving the lowest (26.16 kg ha^{-1}?). Nutrient priming, particularly with important macro- and micronutrients, dramatically improves seedling vigor, root development, and nutrient absorption, ultimately improving yield performance, according to Ugile *et al*., (2024) investigation into how different nutrient concentrations and uptake in soybean seeds affect crop growth.

Table 2. Influence of farming practices on yield of soybean

Treat. No.	Farming practices	Grainyield(qha^{-1})	Protein(%)	Oil (%)
T_1	Conventional farmingpractice	20.46	38.33	19.09
T_2	Standard packageof practices	27.08	39.40	20.08
T_3	Organic farming practice	13.23	38.79	19.26
T_4	Zero budget natural farming practice	11.10	35.83	18.32
T_5	Climateresilient farming	31.03	40.98	20.39
	SE(m)±	**0.73**	**1.04**	**0.22**
	CD (0.05)	**2.24**	**3.19**	**0.67**

Table 3. Influence of farming practices on total macronutrients uptake by soybean

Treat. No.	Farming practices	Totaluptakeof macronutrients(kg ha^{-1})		
		N	**P**	**K**
T_1	Conventional farmingpractice	121.00	28.39	49.30
T_2	Standard packageof practices	165.32	43.31	74.74
T_3	Organic farming practice	81.49	20.59	34.38
T_4	Zero budget natural farming practice	62.97	14.83	26.16
T_5	Climateresilient farming	195.88	51.04	89.36
	SE(m)±	**3.66**	**1.10**	**2.37**
	CD (0.05)	**11.28**	**3.40**	**7.31**

Table 4. Influence of farming practices on total micronutrients uptake by soybean

Treat. No.	Farming practices	Total uptake of micronutrients (g ha^{-1})			
		Fe	**Mn**	**Zn**	**Cu**
T_1	Conventional farmingpractice	261.49	150.05	107.14	46.98
T_2	Standard packageof practices	434.97	238.76	205.30	90.02
T_3	Organic farming practice	261.51	148.26	156.43	60.01
T_4	Zero budget natural farming practice	165.77	91.55	65.89	36.33
T_5	Climateresilient farming	553.23	309.49	298.63	124.66
	SE(m)±	**10.46**	**6.83**	**6.56**	**2.90**
	CD (0.05)	**32.24**	**21.04**	**20.20**	**8.93**

3.1.4 Influence of farming practices on total micro nutrients uptake by soybean

There was a notable difference in the intake of micronutrients between farming systems (Table 4). While zero budget natural farming had the lowest absorption of all micronutrients (Fe: 165.77; Mn: 91.55; Zn: 65.89; Cu: 36.33 g ha^{-1}), climate-resilient farming reported the maximum uptake of iron (553.23 g ha^{-1}), manganese (309.49 g ha^{-1}), zinc (298.63 g ha^{-1}), and copper (124.66 g ha^{-1}). The mineralization of organic manures releases micronutrients and organic acids that solubilize otherwise unavailable forms through natural chelation, which is responsible for enhanced micronutrient absorption under integrated nutrition management. When sprayed at the time of sowing, farmyard manure enhances nutrient availability and translocation, increasing accumulation in grain and stover, which in turn increases crop nutritional quality and overall nutrient intake (Potkile *et al*., 2017).

4. CONCLUSION

Among the tested practices, climate resilient farming emerged as the most effective, leading to notable improvements in soybean yield, quality, and nutrient assimilation. This approach achieved the highest grain yield (31.03 q ha^{-1}) along with superior protein (40.98%) and oil content (20.39%). It also enhanced nutrient uptake, with nitrogen, phosphorus, and potassium levels reaching 195.88, 51.04, and 89.36 kg ha^{-1}, respectively. Moreover, greater absorption of micronutrients such as iron (553.23 g ha^{-1}) and zinc (298.63 g ha^{-1}) indicated better soil health and higher productivity under Inceptisol conditions.

DISCLAIMER (ARTIFICIAL INTELLIGENCE)

Auther(s) hereby declare that NO generative AI technologies such as Large Language Models (ChatGPT, COPILOT, etc.) and text-to-image generators have been used during the writing or editing of manuscripts.

COMPETING INTERESTS

Authors have declared that they have no known competing financial interests or non-financial interests or personal relationships that could have appeared to influence the work reported in this paper.

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