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Effect of Long-term Fertilizer Experiment on Yield, Economics and Soil Fertility of a Vertisol under Soybean–Wheat Cropping System

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Abstract

The field study was conducted under the 50-year-old All India Coordinated Research Project on Long Term Fertilizer Experiment in a Vertisol at Jawaharlal Nehru Krishi Vishwavidyalaya, Jabalpur, Madhya Pradesh (India) during 2021–22 to assess the productivity, soil fertility, and economics of a soybean–wheat cropping system. The experiment comprised eight treatments arranged in a randomized block design with four replications. The results indicated that the 100% NPK+5 t FYM ha^{-1} treatment produced the highest grain yield of soybean (2080 kg ha^{-1}) and wheat (6150 kg ha^{-1}); however, the lowest grain yield of soybean (825 kg ha^{-1}) and wheat (1460 kg ha^{-1}) was produced by the control plot. There were no significant differences in soil reaction (pH), and EC was noticed due to different treatments of fertilizers, either alone or in conjunction with organic manure. The soil organic carbon content had increased significantly from its initial value of 5.7 g kg^{-1} to attain a maximum value of 8.9 g kg^{-1} in the treatment comprised of 100% NPK along with organic manure. Further, the conjoint application of a balanced dose of inorganic fertilizers with organic manure resulted in superior post-harvest soil nutrient availability (N, P, K) compared to other treatment combinations. Economic analysis revealed the highest net returns (₹ 144,229 ha^{-1}) and cost of cultivation (₹ 72,416 ha^{-1}) under the integrated nutrient management treatment practices, yielding a favorable benefit–cost ratio (1.99) for the cropping system. Thus, the study confirms that the combined use of inorganic fertilizers with farmyard manure enhances system productivity and sustains the soil fertility of a Vertisol.

Keywords: LTFE, soybean-wheat cropping system, economics, vertisol

1. Introduction

The application of fertilizer in India is a challenging issue, and it can be not easy to find an appropriate balance between assuring environmental sustainability and enhancing crop productivity. To overcome these issues, proper nutrient management plays an important role, which involves the use of organic manures with inorganic fertilizers to supplement part of the essential plant nutrients required by various cropping systems, thereby fulfilling the nutrient gap (Dwivedi et al., 2019). Hence, the Indian Council of Agricultural Research, New Delhi, launched the "All India Coordinated Research Project on Long Term Fertilizer Experiments (AICRP-LTFE)" in September 1970 at 11 centers to analyze the impact of fertilizers on soil quality, crop productivity, and sustainability. The same experiment was started in 1972 at the Research Farm, Department of Soil Science and Agricultural Chemistry, Jawaharlal Nehru Krishi Vishwa Vidyalaya, Jabalpur (Madhya Pradesh), India, with a soybean-wheat-maize cropping system in a Vertisol. The soybean (*Glycine max* L.)–wheat (*Triticum aestivum* L.) cropping system is one of the most prominent and productive sequences practiced on Vertisols of the Vindhyan Plateau and vast regions of central and western India, including a substantial area of Madhya Pradesh. Long-term fertilizer experiments in this system have generated valuable insights into how sustained applications of different nutrient sources influence crop productivity and soil health under intensive cultivation (Patel et al. 2018 and Bagde et al. 2023). Previous findings indicate that while integrated nutrient management-particularly the combined use of inorganic fertilizers with farmyard manure (FYM)-enhances soil fertility, nutrient-use efficiency, and yield sustainability, the imbalanced fertilization, such as sole N or NP application, fails to maintain productivity over extended periods (Tiwari et al., 2024). Moreover, nutrient availability in Vertisols is governed not only by inherent soil properties but also by strategic nutrient management practices, as a large fraction of applied nutrients becomes fixed and only a small proportion remains plant-available (Thakur et al., 2021, and Sarvade et al., 2025). Organic amendments like FYM act as reservoirs of essential elements and, when applied in conjunction with chemical fertilizers, improve crop yields and reduce dependence on costly external inputs (Birla et al., 2015; Bairwa et al., 2021, and Thakur et al., 2022). Integration of inorganic fertilizers with organic manures will not only sustain the crop production but also will be effective in improving soil health and enhancing the nutrient use efficiency. In view of declining productivity levels, increasingly greater emphasis is now being given on the integrated nutrient supply system, which may play a significant role in sustaining soil quality (Meshram et al., 2018 and Thakur et al., 2025a). Sustainable crop productivity and soil health are central to ensuring food security in intensively cultivated agroecosystems. Among the various soil types, Vertisols occupy a significant area of the soybean–wheat growing regions of central India and are characterized by high clay content, shrink–swell behavior, and inherent nutrient constraints. Continuous cultivation of the soybean–wheat cropping system, coupled with the long-term and often imbalanced use of chemical fertilizers, has raised serious concerns regarding yield stagnation, declining soil fertility, and reduced economic returns. Long-Term Fertilizer Experiments (LTFE) provide a unique and scientifically robust platform to evaluate the cumulative effects of different nutrient management practices on crop productivity, profitability, and soil nutrient dynamics over time. Understanding the long-term impact of integrated and balanced fertilization on yield performance, economics, and soil fertility parameters is essential for developing sustainable nutrient management strategies in Vertisols. Therefore, the present study was undertaken to assess the effect of long-term fertilizer application on crop yield, economic viability, and soil fertility status under the soybean–wheat cropping system in a Vertisol.

2. Materials and Methods

The field experiment was carried out during 2021–22 after 50 cropping cycles of soybean-wheat in a Vertisol. The study was conducted under the All India Coordinated Research Project on Long-Term Fertilizer Experiment at the Department of Soil Science and Agricultural Chemistry, Jawaharlal Nehru Krishi Vishwavidyalaya, Jabalpur, Madhya Pradesh, India, which was commenced in 1972. The experimental site is positioned at 23°10'' N latitude and 79°57'' E longitude and located at 393 meters above sea level. The soils of the experimental field belong to montmorillonitic hyperthermic having 56.8% clay content (Kheri series) of the *Typic Haplustert* family (Vertisol). At the start of the experiment, basic properties of surface soil (0-15 cm depth) had a pH of 7.6, EC 0.18 dS m^{-1} (1:2.5 soil: water ratio), and organic carbon 5.7 g kg^{-1}. The soil available N, P, and K were 193, 7.6, and 370 kg ha^{-1}, respectively.

The long-term fertilizer experiment was laid out for 10 treatments with four replications at the Research Farm. It was arranged in a randomized block design. The size of individual plots was 17×10.8 m^2 (183.6 m^2). The spacing between the replications is 2.0 m, which is separated by a permanent bund, while the spacing between the treatments is 1.0 m. However, only eight treatments were used for the present investigation, *i.e.,* T_1=50% NPK, T_2=100% NPK, T_3=150% NPK, T_4=100% NP, T_5=100% N, T_6=100% NPK+FYM, T_7=100% NPK (–S), and T_8=Control.

The crops soybean and wheat were grown in rotation, and the recommended fertilizer applications (100% NPK) for these crops were 20:80:20 and 120:80:40 kg ha^{-1}, respectively. The sources of N, P, and K were single super phosphate (SSP) and muriate of potash, respectively. In sulphur-free treatment, *i.e.,* 100% NPK(-S), the diammonium phosphate (DAP) was used instead of SSP as a source of P. The application of organic manure @ 5 t FYM ha^{-1} $year^{-1}$ is being practiced only to the soybean crop during the *kharif* season. Soybean (variety JS 9752) was sown as rainfed during the *kharif* season, and wheat (variety GW 366) was sown under irrigated conditions during the *rabi* season. The wheat was irrigated 3–4 times at critical phases of crop expansion. Suitable control measures were kept during insect/pest attacks and disease infestations. After the maturity of soybean and wheat crops having 07–10% moisture content, both the crops were harvested and threshed out for recording yield data. The economics was calculated on the basis of prevailing market prices of different inputs and outputs (Thakur et al., 2025a).

The surface soil samples (0–15 cm) were collected after 50 cropping cycles of soybean-wheat during 2021–22 from various treatments. The soil samples were analyzed for different parameters by following standard procedures for soil pH and EC (Jackson, 1973), organic carbon (Walkley and Black, 1934), available nitrogen (Subbaiah and Asija, 1956), available phosphorus (Olsen et al., 1954), and available potassium (Muhr et al., 1965). The data generated on soil analysis and grain yields of both crops were statistically analyzed to describe appropriate implications as per the standard method described by Panse and Sukhatme (1970).

3. Results and Discussion

3.1. Crop productivity

The data pertaining to the grain yields of soybean and wheat have been presented in Table 1. The data indicated that the highest grain yield of soybean (2080 kg ha^{-1}) and wheat (6150 kg ha^{-1}) were obtained in the treatment receiving an optimal

Table 1: Effect of different treatments on crop productivity of soybean–wheat cropping system during 2021–22

Treatments	Grain yields ($t\ ha^{-1}$)		Per cent response over control	
	Soybean	Wheat	Soybean	Wheat
50% NPK	1363	4208	65.2	188.2
100% NPK	1686	5265	104.4	260.6
150% NPK	2010	6038	143.6	313.6
100% NP	1488	4170	80.4	185.6
100 % N	960	1850	16.4	26.7
100% NPK+FYM	2080	6150	152.1	321.2
100% NPK (-S)	1540	4590	86.7	214.4
Control	825	1460	-	-
CD (*p*=0.05)	283	796	-	-

dose of NPK with organic manure (100% NPK+FYM), and the lowest yield of soybean (825 kg ha^{-1}) and wheat (1460 kg ha^{-1}) were recorded in the control plot. The results of fifty cycles of long-term fertilizer experiment indicated that the application of 100% N alone had increased the yield by 16.4% and 26.7% for soybean and wheat, respectively, over the control. Continuous application of N alone resulted increase in yield over control, but the response exhibited a declining trend with time due to imbalanced use of nutrients (Gupta et al., 2019, and Tiwari et al., 2024). Further, the supplementation of P and K with N, *i.e.,* 100% NPK, was found to increase the soybean and wheat yields by 13.3% and 26.3%, respectively. These findings clearly indicated that the highest crop response in terms of yield was found with balanced fertilization. Balanced fertilization is the key to efficient fertilizer utilization for sustaining high yields. Similar findings were also reported by Sawarkar et al. (2010).

3.2. Basic soil properties

3.2.1. Soil pH, EC, and organic carbon

There was no significant difference in soil reaction (pH), and EC was noticed due to different treatments of fertilizers and manure (Table 2). The soil organic carbon content had increased significantly from its initial value of 5.7 g kg^{-1} to attain a maximum value of 8.9 g kg^{-1} in the treatment comprised of 100% NPK along with organic manure. This could be ascribed due to the annual addition of FYM at the rate of 5 t ha^{-1} during the period of experimentation (Thakur and Sawarkar, 2009). Further, increasing levels of fertilizer application helped in increasing the soil organic carbon content due to increased contribution from the biomass, as it was also observed that with increasing levels of fertilizer application, the crop yields was increased. Thakur et al. (2010) and Patel et al. (2018) observed that the conjoint use of fertilizers with FYM built up organic carbon content in soil. Thahur and Sawrakar (2009) also found that the conjoint use of inorganic fertilizers with FYM sustained soil health and crop productivity.

Table 2: Effect of different treatments on soil fertility status at 0–15 cm soil depth during 2021–22

Treatments	Soil pH	Soil EC (dS m^{-1})	Organic carbon (g kg^{-1})	Available nutrients (kg ha^{-1})		
				N	P	K
50% NPK	7.54	0.17	5.8	226	21.6	261
100% NPK	7.56	0.16	7.6	290	33.9	301
150% NPK	7.59	0.18	8.7	330	37.5	321
100% NP	7.54	0.15	6.7	252	27.9	256
100 % N	7.45	0.18	5.2	211	9.9	251
100% NPK+FYM	7.50	0.15	8.9	345	37.1	338
100% NPK (-S)	7.56	0.17	7.2	272	29.6	284
Control	7.51	0.17	4.3	179	8.5	245
CD (*p*=0.05)	NS	NS	0.71	28.7	2.3	23.7
Initial (1972)	7.6	0.18	5.7	193	7.6	370

3.2.2. Available nitrogen

The data of available nitrogen is presented in Table 2, and it varied from 179 to 345 kg ha^{-1}, with the highest levels recorded under treatments receiving the recommended dose of fertilizers along with 5 t FYM ha^{-1}. This trend corroborates earlier findings (Singh et al., 2012, and Kushwaha et al., 2017), indicating that combining fertilizers with organic manure markedly enhances soil N availability, and that increasing nutrient application rates (as in T_8 and T_3) further elevates available nutrient levels. Moreover, phosphorus applied with nitrogen (100% NP) improved soil N status over nitrogen alone (100% N), while the addition of potassium to NP (100% NPK) resulted in even higher N content. These changes in available nitrogen contents in soil, it could be due to fast nitrogen removal through continuous cropping of soybean and wheat (Thakur et al., 2025a).

3.2.3. Available phosphorus

The data on available P contents (Table 2) showed that the imbalanced application of nutrients reduced the available P in soil. The significant decline in available P content was observed in plots without fertilizer application, and 100% N alone plots is due to the removal of phosphorus from the plant when phosphorus is not applied in these treatments. However, 100% NP application significantly increased the availability of phosphorus in the soil compared to 100% N alone application (Khandagle et al., 2020, and Dwivedi et al., 2019). Further, the conjoint use of 100% NPK with FYM resulted in a marked increase in available P status of soil and found the highest value of available P, 37.1 kg ha^{-1} at 0-15 cm soil depth, respectively. Sharma et al. (2021) also pointed out the positive effects of organic matter on the availability of phosphorus in the soil. The results also showed that the highest available P content was in surface soil as compared to sub-surface soils in all treatments. It was also observed that successive increases occurred due to increasing levels of fertilizer application (Bagde et al., 2023).

3.2.4. Available potassium

The data revealed a decline in available soil K from its initial value of 370 to 245–338 kg ha^{-1} after 50 years of continuous cropping (Table 2), indicating substantial depletion of native K reserves. The greatest reduction occurred in the control plot, followed by the 100% N treatment, while the extent of decline diminished with higher levels of NPK application. Long-term use of N or NP alone exerted a depressive effect on soil K availability, likely due to nutrient imbalance and sustained mining of native K pools, which in turn contributed to yield reduction (Sawarkar et al., 2013). In contrast, the highest available K levels were recorded under 100% NPK+FYM and 150% NPK treatments, where organic manure likely reduced K fixation and enhanced K availability through interactions of organic matter with clay, in addition to direct K supplementation (Pathariya et al., 2022). These findings suggest that current K fertilizer recommendations are inadequate and require revision to prevent further declines in soil fertility and crop productivity. The higher K content in 100% NPK plot is due to the high amount of K in this treatment. Therefore, from the findings, it can be concluded that current K recommendations are not sufficient and need to be changed, otherwise production will be decreased unexpectedly in the future (Inwati et al., 2022).

3.3. Economics of soybean–wheat cropping system

The study indicated (Table 3) that the soybean-wheat cropping system incurred the highest cultivation cost under the integrated nutrient management treatment of 100% NPK combined with FYM (₹ 72416 kg ha^{-1}), compared to the lowest cost under the control plot (₹ 47761 kg ha^{-1}). Despite the higher input cost, the same integrated approach yielded the greatest net returns (₹ 144229 kg ha^{-1}), outperforming the control plot (₹ 20014 kg ha^{-1}). Furthermore, the benefit-to-cost ratio was notably superior in the 100% NPK+FYM treatment (1.99) relative to the control (0.42), underscoring the economic advantage of integrating chemical fertilizers with organic and biological inputs. These findings support earlier conclusions reported by Dwivedi et al. (2016), Parihar et al. (2010), Thakur et al. (2023) and Thakur et al. (2025b), highlighting the enhanced profitability and sustainability of such nutrient management strategies.

Table 3: Effect of different treatments on production efficiency and economics of soybean–wheat cropping sequence

Treatments	Cost of cultivation (₹ ha^{-1})			Gross return (₹ ha^{-1})			Net return (₹ ha^{-1})			B:C ratio
	Soybean	Wheat	Total	Soybean	Wheat	Total	Soybean	Wheat	Total	
50% NPK	25471	32531	58002	67095	96250	163345	41624	63719	105343	1.82
100% NPK	28577	36839	65416	78975	115275	194250	50398	78436	128834	1.97
150% NPK	31682	41146	72828	83610	123825	207435	51928	82679	134607	1.85
100% NP	27477	34639	62116	70875	102225	173100	43398	67586	110984	1.79
100 % N	22627	29789	52416	44460	44025	88485	21833	14236	36069	0.69
100% NPK + FYM	35577	36839	72416	89145	127500	216645	53568	90661	144229	1.99
100% NPK (– S)	28164	36279	64444	72900	104925	177825	44736	68646	113381	1.76
Control	19728	28033	47761	36000	31775	67775	16272	3742	20014	0.42

5. Conclusion

Overall, the long-term (50-year) soybean–wheat cropping sequence demonstrated that integrating organic manure with a recommended dose of NPK not only maintained superior crop yields but also enhanced soil fertility, as reflected in substantial increases in soil organic carbon and available N and P; however, the persistent decline in available K suggested ongoing soil mining under continuous cultivation. Thus, it may be concluded that the 100% NPK+5 t FYM ha^{-1} not only enhances crop productivity but also sustains soil fertility.

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