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Impact of Integrated Nutrient Management on Soil Properties under Long-Term Fertilizer Experiment in Vertisol

Chandini Pradhan [a], Amlan Kumar Ghosh [a*], B. K. Dixit [b], Somya Kumari Bhadani [a] and Satya Narayana Pradhan [a]

[a] Department of Soil Science and Agricultural Chemistry, Soil Technology and Carbon Sequestration Laboratory, Institute of Agricultural Sciences, Banaras Hindu University, Varanasi 221005, India.
[b] Department of Soil Science, College of Agriculture, Jawahar Nehru Krishi Viswa Vidyalaya, Jabalpur, Madhya Pradesh, 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

Aims: To study the effect of continuous fertilization on soil properties and soil carbon stock, in a long-term experiment under a wheat-soybean cropping system in Vertisol.

Study Design: The experiment was laid in a Randomized block design and consisted of three replications and nine treatments.

Place and Duration of Study: Soil samples were collected during April 2022 following the harvest of Wheat from the on-going long-term fertilizer experiment at Jawahar Nehru Krishi Viswa Vidyalaya, Jabalpur, Madhya Pradesh, India

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**Corresponding author: E-mail: amlankumar@yahoo.com;*

Methodology: The soil samples were collected from two depths (0-15 and 15-30cm) and were analyzed for properties such as pH, electrical conductivity, available N, available P and available K using standard procedures.

Results: The results indicated that out of all the treatments continued application of 100% NPK+ Farm yard manure had a significant effect ($P<0.05$) on all the parameters. This treatment had the highest value for in both 0-15 and 15-30 cm: SOC%(0.79% and 0.73%), available N(319.3 kg ha^{-1} , 275.00), available P(40.11 kg ha^{-1}, 37.85 kg ha^{-1}), available K (326.33 kg ha^{-1}, 302.9 kg ha^{-1}).

Conclusion: Continued application of both 100%NPK along with FYM has a significant positive impact on the build-up of nutrients in the soil. This indicates that integrated application of nutrition assures productivity soil in the long.

Keywords: Chemical fertilizers; integrated nutrient management; long-term fertilizer experiment; Vertisol.

1. INTRODUCTION

The future of agriculture is tainted with scarcity of land and shortage of water; while being burdened with the responsibility of feeding the expanding population in upcoming years. Under such scenarios, the use of chemical fertilizers and high- yielding varieties serve as rescues by increasing the productivity of crops from limited land resources. However, the continued and non-judicious use of chemical fertilizers over the years may result in serious environmental issues. Relentless use of chemical fertilizers has been reported to damage the physiochemical properties of soil by raising soil acidity, which accelerates the degradation of soil health, productivity, stability, and sustainability [1]. These inorganic fertilizers are also water-soluble, which allows them to percolate into the subsurface layers and change the soil's inherent characteristics [2]. Excess application or unbalanced application of nitrogen may result in eutrophication, contamination of ground water with nitrates and emission of greenhouse gases such as nitrous oxides [3]. The application of phosphate fertilizer over a long period in cultivated land, can be a major source of potentially toxic trace metals like lead, cadmium, and arsenic. These trace elements may build up in soils and move up the food chain [4]. Phosphatic fertilizers like nitrogenous fertilizers when applied to soil over a long period also contribute to eutrophication significantly [5]. Sole application of chemical fertilizers over the years has also been reported to enhance the deficiency of soil organic carbon as well as secondary and micronutrients which have led to a gradual reduction in productivity over years, even after application of fertilizers [6].

Long-term experiments have proved that intensive cropping systems are exhibiting signs of "fatigue," as seen by yields that are stagnant or dropping. One explanation proposed for this yield stagnation is the reduction in the quantity and quality of soil organic matter (SOM) [7]. Thus, an alternative source of nutrient management is necessitated which is efficient enough to fulfill the growing food demand at an affordable cost while maintaining the sustainability of soil by improving the soil organic carbon content. Organic manures have been known to nourish soil health by providing essential nutrients, enriching the soil's organic carbon, improving physical properties and boosting microbial activity since ancient times. Since organic manures are locally available and are made of in-farm products they are cost effective and easily available. But neither organic manure nor chemical fertilization alone can sustain productivity in the long run hence integrated nutrient application turns out to be a promising solution. Numerous studies have been carried out throughout the world to evaluate the impact of integrated nutrient management on soil [8-11]. It has been found that long-term application of integrated nutrients not only promotes soil health but also helps in carbon sequestration by enriching the soil's organic carbon. Integrated application of nutrients has different impacts on different cropping systems, soil type and duration of application.

Thus, an assessment of the impact of integrated nutrient management on a particular soil order under certain nutrient management systems and cropping systems is necessary. Vertisol is one of the most prevalent soil orders in India existing in central India with wheat-soyabean as a common cropping system. The Majority of farmers in these areas cultivate soybeans without using fertilizer since they are aware of the impact the legume has on the wheat crop that follows. Wheat yields are low in this region due to uneven application of NPK fertilizers and almost nonexistent usage of organics, which also degrades soil fertility. Keeping these points under consideration a study was carried out to test the hypothesis that the application of both organic and inorganic fertilizers over the long term has a positive impact on the chemical properties of soil in the long run.

2. MATERIALS AND METHODS

2.1 Site Description

The current study was based on a long-term fertilizer experiment under the aegis of the All India Coordinated Research Project (AICRP on LTFE) which was initiated in the year 1972, in a Vertisol at the agricultural research farm of the Department of Soil Science and Agricultural Chemistry, Jawaharlal Nehru Krishi Vishwa Vidyalaya, Jabalpur, Madhya Pradesh. The experimental site had a semi-arid and subtropical climate with an average yearly rainfall of 1350 mm and had medium-black soil in the Kheri series of the Typic Haplustert (Vertisol) with fine montmorillonite in the hyperthermic family. The initial soil properties at the initiation of the experiment in the year 1972 are given in Table.1. The experiment consists of 10 treatments laid in a randomized block design with four replications. For the present study nine out of ten treatments were selected which are: Control (no fertilization), 50% NPK, 100% NPK,150%NPK, 100% NPK +Zn, 100% NP, 100% N, 100% NPK+FYM, 100%NPK-S. The recommended dose of fertilizers for soybean and wheat (20:80:20 and 120:80:40 kg ha^{-1} respectively). Under 100% NPK treatment, FYM was applied to the soybean crop at a rate of 10 mg ha−1 y−1 on a dry weight basis. On a dry weight basis, FYM on average contained 25% C, 0.95% N, 0.55% P, and 0.71% K. Crops were managed as per the standard recommended agronomic practices. Yield data were obtained after threshing of the mature soybean and wheat crops when they had moisture a content of 7–10%.

Table 1. Initial soil characteristics

Soil Properties	Value
Soil pH (Soil: water 1:2.5)	7.60
Electrical conductivity (1:2.5, ds m^{-1})	0.18
Organic carbon (g kg^{-1})	5.7
Bulk density (Mg m^{-3})	1.30
Available N (kg ha^{-1})	193.0
Available P (kg ha^{-1}) (Olsen)	7.6
Available K (kg ha^{-1})	370.0

2.2 Soil Sampling and Analysis

In the current study soil samples were collected from the surface (0-15 cm) and sub-surface (15-30 cm) from nine different treatments after the harvest of wheat after the 50th cropping cycle of wheat-soybean rotation in the year 2022. For analysis of chemical properties of the soil samples were collected from four random points within each replication and a composite sample was prepared after mixing them. Further the sample size of the mixed composite was reduced to 500g by quartering. The soil samples after collection were air-dried and processed before being subjected to chemical analysis. For determination of bulk density, the soil samples were collected through cylindrical cores. Samples were analyzed for pH (1:2.5 soil: water suspension) [12], electrical conductivity by conductivity meter [12], organic carbon by rapid titration method [13], Available N was estimated by alkaline permanganate method [14] and available P by Olsen's method [15], available potassium by ammonium acetate method [12].

2.3 Statistical Analysis

The data was analyzed using Microsoft Excel 2011 and Analysis of variance (ANOVA) was carried out using SPSS 16.0. Duncan's multiple range test (DMRT) at a 5% level of probability was used to test the significance of differences between treatment means [16].

3. RESULTS AND DISCUSSION

3.1 Soil Properties

3.1.1 Soil pH and electrical conductivity

Long-term application of both integrated nutrition as well as chemical fertilizers alone significantly affected the soil pH across both depths. The pH of soil under different nutrient management practices ranged from 7.31 to 7.61 in surface soil while it ranged from 7.35 to 7.66 in sub-surface soil (Table 2). The range of pH found in this study was similar to that reported by Suman et al. [17]. The stability of the soil reaction may have been caused by the high buffering capacity of the clayey soil and the presence of weak salts, such as carbonates or bicarbonates, which upon dissolution release free cations. As a result, the pH of surface and subsurface soils was not significantly affected by the long-term application of integrated nutrients over the years [18]. The lowest pH was observed in 100% N in both layers due to continuous application of urea alone over the years which results in the acidification of soil due to the formation of nitrates. The acidification caused by the sole application of nitrogen has reduced the initial soil pH to a maximum extent as compared to other treatments. The findings also showed that the pH of the soil was slightly lowered at both soil depths upon the addition of FYM and inorganic nutrients. Likewise, Chouvan et al. [19] found that the stabilizing effects of FYM may be the reason for the stability of soil pH when balanced fertilizers were applied in addition to FYM. The electrical conductivity of soil ranged from 0.15 to 0.18 dSm^{-1} in surface soil and 0.14 to 0.18 dSm^{-1} in subsurface layer (Table 2). These findings are in congruence with that of Khandagle et al. [20]. It was observed that the EC values did not exhibit any significant variation which can be attributed to the strong buffering capacity of the soil and the low residual effect of applied inputs [21]. Among the treatments electrical conductivity was highest in 100% NPK + FYM may be due to the rise in base saturation of soil due to the optimum rate of nutrients applied as compared to the control [18].

3.1.2 Soil organic carbon

The soil organic carbon under various nutrient management ranged from 0.43% in control to 0.79% in 100% NPK+FYM treatment in surface soil. In subsurface soil it ranged from 0.40% to 0.73% in control and 100% NPK+FYM respectively (Table 2). A Similar range of organic carbon was reported by [22]. An Increase in soil organic carbon content in 100% FYM +NPK was also reported by Santhy et al. [23] and Singh et al. [8]. It was found that the organic carbon content of surface soil reduced after 50 years of continuous cultivation in control where as its value had considerably increased the most in the case of 100% NPK+FYM followed by 150% NPK and 100% NPK as compared to the initial value. The organic carbon content increased with an increase in fertilizer dose following the sequence 50% NPK<100%NPK<150% NPK. Soil organic carbon content declined with depth, since continuous cultivation enhanced and boosted the decomposition of plant organic residues at the surface level. The highest value of soil organic carbon was observed when organic and inorganic fertilizers were added in combination because it directly added more organic carbon through FYM as compared to inorganic fertilizer alone. Intensive farming with continuous application of fertilizer and FYM treatments results in increased root growth of crops that results in greater residues which may be the cause of this higher SOC content in soil. Consequently, the application of FYM significantly influenced the SOC content of soil [24].

3.1.3 Available nitrogen

The available N in soil under various nutrient management practices are shown in Table 3. The highest amount of available nitrogen was in 100% NPK+FYM while the lowest was in control. Continuous application of integrated nutrients for 50 years resulted in a remarkable increase in the available N content of the soil as compared to the initial value, while reduction of available N was seen in control. The application of inorganic fertilizers also led to the accumulation of available N in the soil as compared to the initial value. The available nitrogen content increased significantly with a rise in fertilizer dose following the sequence 50% NPK<100% N <100% NPK<150% NPK. While the rise in available N content with an increase in fertilizer level is due to obvious reasons, the direct addition of organic matter through FYM may have contributed to the increase in available N under NPK+FYM, facilitating the growth of soil microorganisms and eventually improving the conversion of organically-bound N to mineral form [25]. The Low level of available nitrogen in control or 50% NPK can be attributed to the low input of organic residues as well as fertilizers. Available N content in the subsurface soil layer (15-30 cm) had comparatively lesser value than the surface layer which is attributed to lesser organic matter content and lower microbial actions as compared to the surface soil layer.

3.1.4 Available phosphorous

Long-term application of various nutrient management practices had a significant impact on Available P in soil and it varied from 7.45 kg ha^{-1} to 40.11 kg ha^{-1} in surface soil and 6.49 kg ha^{-1} to 37.85 kg ha^{-1} in the subsurface layer (Table 3). The lowest value was seen in the control with no fertilization and the highest in NPK+FYM. As compared to the initial value of available P in the soil (7.6 kg ha^{-1}) there was a significant increase in its amount due to the application of fertilizers and manures over 50 years, with the maximum increase being witnessed in integrated nutrition. Available P was fairly low in treatment where there was application of only 100% N in both the layers and had value at par to control. The significant variation in P content seen across different fertility treatments receiving suboptimal, optimum, and super-optimal nutritional dosages, respectively, indicates increased P build-up. Among various treatments the highest soil P build-up was reported under NPK+ FYM, which was significantly more than 100% NPK. The annual addition of P and the solubilization of native P through increased release of organic acids in FYM-treated plots are responsible for this build-up of P in the soil [26]. The reason behind the increased P accumulation in surface soil as compared to subsurface soil is attributed to the ability of soil to fix applied P and subsequently limit its mobility [27].

3.1.5 Available pottasium

The ammonium acetate extracted K under different nutrient management practices after 50 years ranged from 210 kg ha^{-1} to 326 kg ha^{-1} in surface soil under 100% N and 100% NPK + FYM respectively (Table 3). Similarly in the sub-surface layers it varied from 206 kg ha^{-1} to 302 kg ha^{-1} in `100% N and 100% NPK+FYM respectively. It was lowest for treatments where K was not applied for years like 100% N followed by 100% NP because of mining of the inherent K present in soil [28]. A Similar observation where the K content was in a similar range and followed the same pattern was reported by Khandagle et al. [20]. The K content declined with an increase in the depth of soil. The highest K was found when FYM was added along with mineral fertilizer because FYM directly adds potassium to soil and also aids in the release of K due to the interaction of organic matter with clays [29].

Table 2. pH, electrical conductivity and soil organic carbon under soybean-wheat cropping system in surface (0-15 cm) and subsurface (15-30 cm) under continuous fertilization for 50 years

Treatments	**pH**		**Electrical conductivity (dSm^{-1}) ^{1})**		**Soil organic carbon (%)**	
	0-15 cm	**15-30cm**	**0-15 cm**	**15-30cm**	**0-15 cm**	**15-30cm**
50% NPK	7.42^{b*}±0.03$^{\#}$	7.53^{b*}±0.02$^{\#}$	0.16^{c}±0.00	0.09^{a}±0.01	0.55b±0.00	0.53^{c}±0.03
100% NPK	7.48^{c}±0.04	7.58^{cd}±0.02	0.16^{c}±0.00	0.12^{b}±0.00	0.62^{ab}±0.00	0.58^{cde}±0.04
150% NPK	7.59^{ef}±0.03	7.63^{e}±0.02	0.16^{bc}±0.00	0.08^{a}±0.00	0.70^{b}±0.10	0.65^{e}±0.03
100% NPK+ Zn	7.61^{f}±0.03	7.66^{e}±0.03	0.18^{e}±0.00	0.09^{a}±0.00	0.60^{ab}±0.02	0.58^{cde}±0.08
100% NP	7.38^{b}±0.04	7.42^{b}±0.03	0.16^{c}±0.00	0.08^{a}±0.01	0.57^{a}±0.08	0.54^{ab}±0.04
100% N	7.31^{a}±0.03	7.35^{a}±0.03	0.16a±0.00	0.08^{a}±0.01	0.56^{a}±0.07	0.51^{cd}±0.03
100% NPK+FYM	7.53^{cde}±0.03	7.59^{d}±0.03	0.18f±0.00	0.09^{a}±0.02	0.79^{b}±0.02	0.73^{f}±0.03
100% NPK- S	7.55^{de}±0.02	7.57^{cd}±0.03	0.17^{d}±0.00	0.09^{a}±0.01	0.58^{a}±0.02	0.55^{de}±0.04
Control	7.51^{cd}±0.02	7.55^{cd}±0.02	0.15^{b}±0.00	0.09^{a}±0.01	0.43^{a}±0.08	0.37^{a}±0.03

#Mean ± standard deviation

**Means in a column followed by the same letter do not differ significantly (P< 0.05) by Duncan's multiple range test*

Table 3. Available nutrients (kg ha^{-1}) in surface (0-15 cm) and subsurface (15-30 cm) after 50 years of continuous soybean-wheat cropping system

Treatments	**Available N(kg ha^{-1})**		**Available P(kg ha^{-1})**		**Available K(kg ha^{-1})**	
	0-15 cm	**15-30 cm**	**0-15 cm**	**15-30 cm**	**0-15 cm**	**15-30 cm**
50% NPK	221.3^{c}±1.52	193^{bc}±4.72	21.78^{b}±1.49	20.24^{b}±1.55	256.00^{c}±11.00	243.33^{c}±5.50
100% NPK	282.0^{f}±2.00	208^{e}±2.00	33.60^{d}±1.45	30.95^{de}±1.51	286.70^{d}±6.15	265.33^{e}±5.13
150% NPK	309.3^{g}±2.08	251^{f}±3.51	36.98^{e}±2.27	33.55^{e}±1.15	321.00^{e}±9.64	293.00^{f}±6.00
100%NPK+ Zn	264.7^{e}±4.66	205^{e}±4.04	32.40^{cd}±2.10	30.33^{d}±1.93	287.33^{d}±7.76	263.67^{de}±7.09
100% NP	251.7^{d}±2.08	201de±4.72	29.07^{c}±1.39	25.27^{c}±2.23	218.33^{ab}±6.80	210.56^{a}±4.23
100% N	212.3^{b}±2.08	189^{b}±5.50	9.12^{a}±1.60	7.85^{a}±0.46	210.67^{a}±4.16	206.00^{a}±5.56
100% NPK+FYM	319.3^{h}±4.04	275^{g}±5.68	40.11^{e}±1.98	37.85^{f}±3.10	326.33^{e}±5.50	302.96^{g}±2.75
100%NPK-S	264.3^{e}±6.02	198^{cd}±2.51	31.15^{cd}±2.61	29.07^{d}±1.40	285.33^{d}±3.21	255.67^{d}±3.05
Control	191.7^{a}±5.03	154^{a}±3.05	7.45^{a}±1.27	6.49^{a}±0.46	225.67^{b}±5.03	221.00^{b}±5.00

#Mean ± standard deviation

**Means in a column followed by the same letter do not differ significantly (P< 0.05) by Duncan's multiple range test*

4. DISUCSSION

The presented study explores the impact of integrated nutrient management on soil properties, specifically focusing on the long-term fertilizer experiment conducted in Vertisol under a wheat-soybean cropping system. The primary objective is to examine the influence of continuous fertilization on soil properties and soil carbon stock. The study is conducted at Jawahar Nehru Krishi Viswa Vidyalaya in Jabalpur, Madhya Pradesh, India, with soil samples collected in April 2022 following the wheat harvest.

The results highlight that continuous application of 100% NPK (Nitrogen, Phosphorus, Potassium) along with farmyard manure (FYM) has a significant effect on all measured parameters. This treatment demonstrates the highest values for soil organic carbon (SOC), available nitrogen, phosphorus, and potassium at both soil depths (0-15 cm and 15-30 cm).

The conclusion drawn from the study emphasizes the positive impact of integrated application of nutrients, specifically 100% NPK along with FYM, on the accumulation of essential nutrients in the soil [30,31,32]. The findings suggest that this integrated nutrient management approach contributes significantly to the buildup of nutrients in the soil over the long term [33,34]. The study implies that such integrated strategies are crucial for ensuring sustained soil productivity, providing insights into agricultural practices that can enhance crop production in the studied region [35,36,37,38].

Comparatively, when considering studies on soil quality and the influence of agro-environmental factors on crop production in tropical territories of Latin America, one should note that regional variations in soil types [39,40], climate [41,42], and cropping systems may lead to different outcomes [43,44,45]. The scientific relevance of this study lies in its contribution to the understanding of nutrient management practices in Vertisol, which can inform agricultural strategies for improving soil fertility and crop yield in similar agroecological contexts [46,47]. It adds valuable knowledge to the broader scientific discourse on sustainable agriculture and soil management in tropical regions [48,49].

5. CONCLUSION

The application of integrated nutrients for 50 years of continuous cultivation of wheat-soybean in Vertisol had a significant and positive effect on soil carbon stocks as well as the available nutrients. While repeated application of sole chemical fertilizers also had a similar impact on soil, their impact was far less as compared to the integrated nutrient application. Further imbalance application of chemical fertilizers had resulted in unwanted impacts on soil pH, mining of K, lower organic carbon etc. Thus, application of integrated nutrient management is a safe and productive management system in the long run as compared to the application of chemical fertilizer alone.

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COMPETING INTERESTS

Authors have declared that no competing interests exist.

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