



Long-term effect of manuring-fertilization on nutrients availability and yield under rice (*Oryza sativa*)-lentil (*Lens culinaris*) system

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ABSTRACT

Soil health degradation is a major threat in agricultural sustainability specially under rainfed agriculture. The purpose of this study was to assess the impact of long-term fertilization and manuring on soil organic carbon, nutrient status, uptake and yield trends under a rainfed rice (*Oryza sativa* L.)-lentil (*Lens culinaris* L.) cropping system situated at Agriculture Research Farm of Banaras Hindu University, Varanasi, Uttar Pradesh. Soil samples were collected in 2019 and 2021 after harvesting of rainy (*kharif*) season rice from 34 years old long-term experiment with rice-lentil cropping system of dry sub-humid region of India and analysed for various pools of SOC, nutrients availability, uptake and yield attributes. Results showed that 50% NPK+FYM treatment significantly influenced soil organic carbon pools and improved macronutrients (Nitrogen, Phosphorus, Potassium), microbial biomass carbon and dehydrogenase activity in soil as compared to the control. In addition, the integrated application of farmyard manure and inorganic fertilizers significantly enhanced the nutrient uptake, productivity of rice and lentil, and maintained the nutrient balance in the soil. Therefore, the balanced use of inorganic fertilizer along with organic manure may be recommended for maintaining soil health and crop productivity under subtropical India.

Keywords: LTFE, Nutrient availability, Nutrient uptake, Yield

Modern agriculture depends on the application of fertilizer to provide vital nutrients to crops and contribute to sustainable agricultural production (Shakoor *et al.* 2020). It is well known that the use of inorganic fertilizers can be beneficial in the short term for high yields but, it might deteriorate the physio-chemical and biological attributes of soil, which can negatively impact productivity and soil health in the long run (Bose *et al.* 2021). Organic manures improve the soil organic carbon (SOC) and perform the function of increasing soil organic matter (SOM) content, cation exchange capacity (CEC), enhancing soil physical, chemical and biological properties (Lal 1997). Application of farmyard manure not only enhanced crop productivity but also improved soil fertility and is positively related to soil C accumulation (Sharma *et al.* 2018). Several long-term experiments have been conducted to determine the effect of fertilization and manuring on nutrient dynamics and to evaluate the overall assessment of fertilization. Furthermore, long-term fertilizer experiments offer better opportunities to examine crop productivity, soil quality as well as identify factors that affect these changes to evaluate agricultural

sustainability (Rasmussen *et al.* 1998). But very few studies have been carried out on soil health parameters and crop productivity under a long term rainfed rice-based system in India. Our hypothesis was that imbalanced fertilization, low moisture content under rainfed rice (*Oryza sativa* L.)-lentil (*Lens culinaris* L.) cropping system might have differential impacts on various physical, chemical and biological attributes of soil and crop yield. Therefore, present investigation was undertaken with the objective to study the long-term impact of manuring and fertilization on SOC dynamics, nutrient availability, uptake and crop yield. The novelty of this work lies in the identification of the best management practices for maintaining soil health and crop productivity under long-term rainfed rice-lentil system of dry sub-humid India.

MATERIALS AND METHODS

Experimental site description: The long-term fertilizer experiment (LTFE) was conducted in the All India Co-ordinated Research Project for Dryland Agriculture, established at Agriculture Research Farm of Banaras Hindu University, Varanasi (25°18'0" N, 83°03'0" E and 128.93 m amsl) which was initiated in 1985 with rice (NDR-97)-lentil (HUL-57) cropping system. The soil found at the study site belongs to the Inceptisol order. This region is characterized by a dry tropical climate with strong variations

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in seasonal temperature and precipitation. It receives an average annual rainfall of 1100 mm each year, which is 80% due to the southwest monsoon between June and September and the potential evapotranspiration is about 1500 mm. The maximum temperature in May–June can reach up to 37.9°C, while the minimum drops to 8.9°C from December–January. The mean relative humidity is about 68% which rises to 86% during wet season and goes down to 33% during dry season. Rice (NDR-97) was grown in the rainy (*kharij*) season (July 1st week every year) followed by lentil (HUL-57) in the winter (*rabi*) season (last week of October–November 1st week). The experiment was laid out in randomized complete block design and the whole field was divided into three blocks each representing a replication (net plot size 10 m × 9 m). Soil samples were collected from selected six treatments, viz. T₁, control (no fertilizer, no manure); T₂, 100% RDF (Recommended doses of fertilizers) of NPK (Nitrogen:Phosphorus:Potassium) (80:40:30 kg/ha); T₃, 50% RDF of NPK (40:20:15 kg/ha); T₄, 50% FYM (40 kg/ha N through farmyard manure); T₅, 100% FYM (80 kg/ha N through farmyard manure) and; T₆, 50% NPK + FYM (40:20:15 kg/ha + 40 kg/ha N through farmyard manure). The N, P and K were applied through urea, diammonium phosphate (DAP) and muriate of potash (MOP) respectively.

Collection and analysis of soil: Soil and plant samples (grain and straw) were collected randomly from the treated plot. We collected three replicate field moist soil samples from six treatments at 0–15 cm depth after harvesting of rice in October 2019 and 2021. One portion of the soil sample was kept at 4°C to be examined for biological characteristics and for chemical analysis, the soil sample was dried at ambient temperature, powdered and passed through a 2 mm sieve. The soil samples were collected separately for bulk density (BD) (Blake and Hartge 1986). Assessing the chemical parameters of the soil involved soil pH (Page *et al.* 1982), KMnO₄ oxidizable nitrogen (available N) (Subbiah and Asija 1956), soil phosphorus (available P) (Olsen *et al.* 1954), soil potassium (available K) (Hanway and Heidel 1952), soil organic carbon (SOC) (Walkley and Black 1934) and its fractions very labile pool (VLOC), labile pool (LOC), less labile (LLOC) and non-labile (NLOC) of organic carbon was examined by using modified Walkley and Black method (Chan *et al.* 2002).

Active pool, passive pool and lability index were calculated (Mandal *et al.* 2008).

Active pool = Very labile pool + Labile pool

Passive pool = Less labile pool + Non-labile pool

$$\text{Lability index} = \left\{ \left(\frac{\text{C}_{\text{pool I}}}{\text{TOC}} \times 3 \right) + \left(\frac{\text{C}_{\text{pool II}}}{\text{TOC}} \times 2 \right) + \left(\frac{\text{C}_{\text{pool III}}}{\text{TOC}} \times 1 \right) \right\}$$

Dehydrogenase activity (Dick *et al.* 1996) and soil microbial biomass carbon (MBC) (Vance *et al.* 1987) were measured to assess the soil biological characteristics. Triplicate plant samples from each treatment were collected and thoroughly washed with dilute acid and double distilled water as per the standard protocol, dried in an oven at 60°C and ground. Total nitrogen (TN) content in rice straw and grain samples was determined by distillation and subsequent titration with standard acid after acid digestion (Patra *et al.* 2018). After digesting the straw and grain sample in nitric-perchloric acid (3:1) mixture, total phosphorus (TP) was measured spectrophotometrically by vanadomolybdophosphoric yellow colour method (Koenig and Johnson 1942), total potassium (TK) was examined using method of flame-photometer. The nutrient uptake by plant samples were calculated as (Rasool *et al.* 2008):

$$\text{Nutrient uptake (kg/ha)} = \frac{\text{Nutrient content (\%)} \times \text{Yield (kg/ha)}}{100}$$

Equivalent rice yield: Equivalent rice yield (ERY) was calculated as (Ghorai *et al.* 2023):

$$\text{ERY} = \frac{\text{Lentil yield} \times \text{Unit price of lentil}}{\text{Unit price of lentil}} + (\text{Rice yield})$$

Statistical analysis: The treatment means were compared using Duncan's multiple range test (DMRT) at the 95% level of significance (Gomez and Gomez 1984).

RESULTS AND DISCUSSION

Long term impact of manuring and fertilization on soil physico-chemical properties: The bulk density ranged between 1.36 Mg/m³ (50% NPK+FYM) to 1.46 Mg/m³ (control plot) (Table 1). The breakdown of organic matter promotes microbial activity and releases polysaccharides into the soil, which act as a binding agent and enhances

Table 1 Impact of different management practices on physico-chemical and biological soil characteristics (mean of 2019 and 2021)

Treatment	BD (Mg/m ³)	pH	Available N (kg/ha)	Available P (kg/ha)	Available K (kg/ha)	MBC (µg/g)	DHA (µg TPF/g/24 h)
T ₁	1.46a	6.5ab	117b	10.2d	82.0a	273d	31.78b
T ₂	1.42a	6.3ab	184a	34.2ab	101a	395bc	40.22ab
T ₃	1.43a	7.3a	146ab	16.6cd	98.0a	369c	36.76ab
T ₄	1.40a	7.0ab	125ab	25.1bc	86.9a	443ab	48.73ab
T ₅	1.39a	6.6ab	159ab	30abc	89.8a	502a	49.39ab
T ₆	1.36a	6.1b	134ab	41.8a	114a	498a	54.89a

Treatment details are given under Materials and Methods.

soil aggregation, which may account for the decreased soil bulk density in the NPK+FYM treated plot (Bhatt *et al.* 2019).

The soil pH varied between 6.1 under 50% NPK+FYM treatment to 7.3 under 50% NPK treatment. A slight decrease in soil pH is seen in the NPK+FYM plot. This is because combined fertilization adjusts the C:N ratio of the soil, which increases microbial diversity, accelerates organic matter degradation, produces organic acid and stimulates soil enzymatic activity (Wen *et al.* 2018).

Long term impact of manuring and fertilization on soil macronutrients:

A plant's nutrition would not be complete without nitrogen. The significantly highest available nitrogen was recorded in 100% NPK (184 kg/ha) treatment over control (117 kg/ha) (Table 1). This could be because NPK instantly enhanced the amount of easily accessible nitrogen, but organic manure took longer time to mineralize (Qin *et al.* 2015, Ryan *et al.* 2003). Moreover, build-up of organic matter is low under rainfed condition due to poor crop growth under low moisture condition and high rate of oxidation of organic matter (Rao *et al.* 2017). The available phosphorus content varied between 10.2–41.8 kg/ha. The highest concentration of available phosphorus was recorded in the 50% NPK+FYM treatment because addition of farmyard manure produces organic acid as it breaks down and solubilizes phosphorus in the soil (Urkurkar *et al.* 2010). The highest and lowest value of available K content was obtained in 50% NPK+FYM (114 kg/ha) treatment and control (82.0 kg/ha) treatment. During decomposition, organic manure causes insoluble K compounds to become soluble, as well as increase cation exchange capacity resulting in higher soil K concentrations (Bose *et al.* 2021).

Long term impact of manuring and fertilization on soil organic carbon pools and lability index: At the surface layer (Fig 1), 50% NPK (86.6%) and 100% NPK (81.3%) treatments had considerably higher amounts of carbon in the active pool and carbon content in the passive pool was maximum in treatments 50% NPK+FYM (37.4%) and 100% FYM (36.6%). The highest lability index (LI) was in 50% NPK (2.61) over 50% NPK+FYM (1.94) treatments at the surface layer. Active carbon pool and lability index were higher in the surface layer due to the addition of plant residues and root biomass was higher in the surface layer which supplies readily mineralizable and hydrolyzable carbon resulting in stimulating the microbial activity (Kaur *et al.* 2008, Venkatesh *et al.* 2013). The NPK+FYM treatment increases the passive pool carbon or recalcitrant carbon and the lowest lability index may be due to the formation of a biochemical complex with organic matter that resists the microbial decomposition, resulting in higher soil carbon accumulation (Mandal *et al.* 2008, Yan *et al.* 2012).

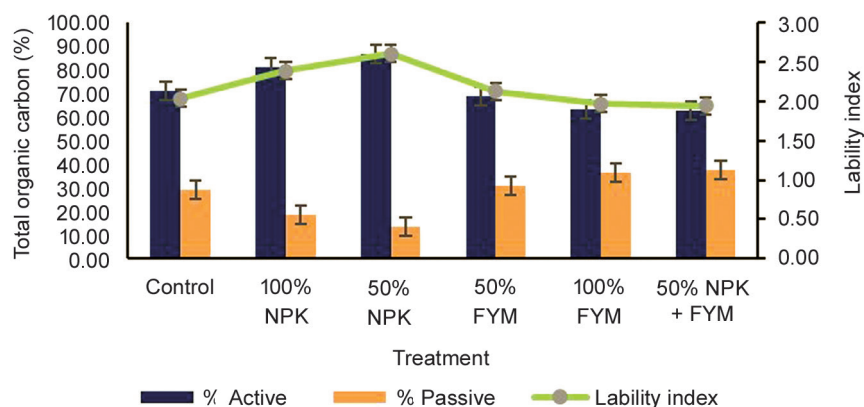


Fig 1 Impact of different management practices on soil organic pools and lability index (mean of 2019 and 2021).

Long term impact of manuring and fertilization on microbial biomass carbon and dehydrogenase activity in the soil: Microbial biomass carbon is a labile fraction of SOC which has a direct role in nutrient cycling. The MBC ranged from 273–502 µg/g (Table 1). As a result, the control plot caused nutrient depletion due to its unfavourable environment for microbial activity, whereas a higher value may be associated with enrichment of carbon via plant residues and FYM, which creates a conducive environment for microbial growth and results in an increase in MBC over the control (Srinivasarao *et al.* 2018). The results showed that the maximum value of DHA was with 50% NPK+FYM (54.89 µg TPF/g/24 h) treatment than control (31.78 µg TPF/g/24 h) treatment. The reason for this is that the FYM treatment increased biological activity and stabilization of extracellular enzymes through humic compounds complexation (Bhattacharyya *et al.* 2008).

Long term impact of manuring and fertilization on nutrient uptake by grain and straw: It was shown that 50% NPK+FYM treatment had significantly higher N, P and K uptake than control treatment (Table 2). As a result, the amount of N, P and K absorbed by grain varied from 10.9–22.5 kg/ha, 2.9–6.19 kg/ha and 1.79–4.08 kg/ha

Table 2 Impact of different management practices on nutrient uptake (mean of 2019 and 2021)

Treatment	Nutrient Uptake					
	N (kg/ha)		P (kg/ha)		K (kg/ha)	
	Grain	Straw	Grain	Straw	Grain	Straw
T ₁	10.9e	16.1d	2.9c	5.39c	1.79f	19.9f
T ₂	18.4c	25.3b	5.0b	8.08b	2.37d	33.2c
T ₃	12.9d	20.8c	3.4c	5.65c	2.01e	29.1d
T ₄	11.6de	21.7c	3.3c	5.67c	2.73c	28.3e
T ₅	20.5b	32.5a	5.2ab	10.8a	3.78b	51.5b
T ₆	22.5a	34.9a	6.19a	12.4a	4.08a	55.1a

Treatment details are given under Materials and Methods.

respectively. The uptakes of N, P and K by straw were considerably greater in 50% NPK+FYM (34.9 kg/ha, 12.4 kg/ha and 55.1 kg/ha) than control (16.1 kg/ha, 5.39 kg/ha and 19.9 kg/ha) treatment. The use of farmyard manure in combination with NPK fertilizer significantly increased nutrient absorption in plants and soil nutrient balance. According to Arulmozhiselvan *et al.* (2013), crops absorbed nutrients more readily when organic sources of nutrients were used, which may be because the breakdown of organic manure chelated nutrients and solubilized native nutrients.

Long term impact of manuring and fertilization on crop yield and equivalent rice yield: Crop production is a good indication of the soil's fertility. Among the treatments, the maximum yield of rice and lentil was 50% NPK+FYM (2038 kg/ha and 965 kg/ha) treatment, whereas the control had the lowest yield (1211 and 585 kg/ha) (Fig 2). According to Yadav *et al.* (2017), use of organic manure either alone or in conjunction with chemical fertilizer supplies all the nutrients including micro and macro in soil which creates a favourable environment for better growth and activity of microorganisms, enhances mineralization of nutrients and increased crop yield due to more absorption and utilization of nutrients leading to overall improvement in crop yield and soil health. It was reported that using organic and inorganic fertilizers together yielded the maximum equivalent rice yield (4506 kg/ha) whereas control contributed the least (2707 kg/ha). Results have shown that balanced fertilization not only increases crop yield but also enhances nutrients in soil (Xue *et al.* 2014).

The application of FYM along with NPK fertilizer in the rainfed rice-lentil cropping system sustained the crop productivity and improved the soil fertility. The recommended doses of fertilizers along with organic manure play a vital role in improving soil organic carbon and its labile fractions in soil and maintain positive balance of N, P and K, thereby enhancing availability of nutrients in soil, improving soil quality and ensuring sustainable yield for a long period of time. Continuous cropping with NPK fertilizer or without fertilizer was insufficient to maintain nutrient balance in soil, therefore, a higher level of organic manure was required to maintain adequate supply of nutrients in the soil. The addition of FYM in optimum quantity improved the physical, chemical and biological properties of the soil. From the study it can be concluded that application of FYM along with NPK fertilizer had a significant impact on nutrient availability, uptake and yield of rice. Therefore, this management practice (50% NPK+FYM) may be recommended for proper nutrient supply, maintaining soil health and strengthening crop productivity under rainfed rice-based system of dry sub-humid India.

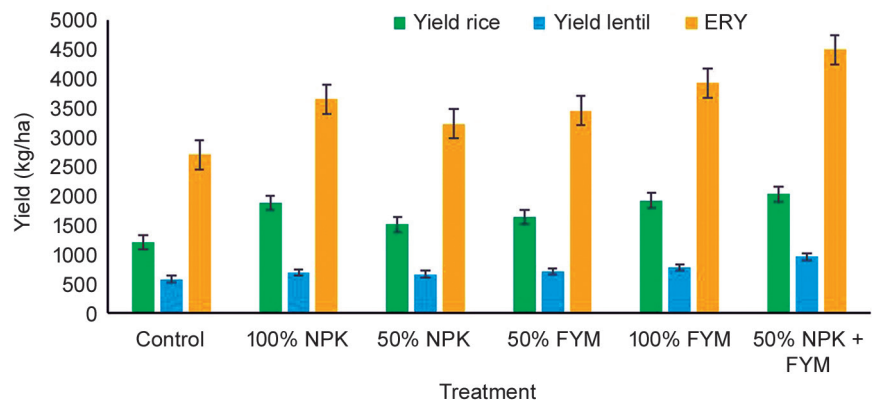


Fig 2 Impact of different management practices on yield and equivalent rice yield (mean of 2019 and 2021).

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