



Effect of 67-years of manuring, fertilization and amendments on fractions of soil organic carbon, nutrient dynamics and yield sustainability in an acidic Alfisol

RIAJ RAHAMAN¹, SUNANDA BISWAS^{1*}, PRABHAKAR MAHAPATRA², MAHESH C MEENA¹,
ABIR DEY¹, T K DAS¹, PRIYA SINGH¹ and KALYANI PATIL¹

ICAR-Indian Agricultural Research Institute, New Delhi 110 012, India

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ABSTRACT

Amending a problem soil in addition to nutrient input is crucial for maintaining a healthy and productive soil in the long run. The study aimed at evaluating the long-term impact of manuring and fertilization with or without liming on different soil attributes and crop yield in an acidic Alfisol. Surface soil samples (0–15 cm) were collected from selected 7 treatments, viz. Control; N; FYM; $\frac{1}{2}(N+FYM)+P_{X/2}+K_{Y/2}$; NPK; NPK+L; and $P_{(A-X)}K_{(B-Y)}+FYM+L$ of the Permanent Manurial Trial (PMT) of Birsa Agricultural University, Ranchi, after the harvesting of rainy (*kharif*) maize (*Zea mays* L.) at the 67th crop cycle (2023 and 2024) and assessed for various fractions of soil organic carbon (SOC), available nutrients and yield attributes. The experiment was laid out in a randomized block design (RBD) and replicated thrice. The treatments which received manures either alone or in combination with chemical fertilizers recorded significantly higher amount of all the fractions of SOC, available nitrogen and lower bulk density as compare to the unfertilized plot or treatment with inorganic alone. The study also revealed that, addition of lime helped maintaining an optimum pH level, enhanced microbial activities and nutrient availability in the soil leading to a higher crop yield. Therefore, integrated use of manures and fertilizers in addition to lime for a prolonged period would have significant positive impact on soil health and sustaining its productivity.

Keywords: Acid soil, Available nutrients, Long-term experiment, Soil organic carbon

Chemical fertilizers, one of the key inputs of agriculture, play crucial role in boosting crop productivity by availing essential nutrients to plant. Nevertheless, continuous cropping with indiscriminate and imbalanced use of fertilizers causes deterioration of soil health leading to poor yield in the long run (Gabhane *et al.* 2023). The use of organic manures coupled with fertilizers significantly improves soil health and sustain crop yield by adding organic matter, forming aggregates, retaining water and augmenting microbial activities in soil. Moreover, manures help to alleviate the consequences of climate change by storing carbon in the soil over time (Trivedi *et al.* 2020, Mandal *et al.* 2020). Nutrient availability in soil and activities of microbes highly depends on soil reaction (pH) which is a major concern in acidic soil. Incorporation of lime in acidic soil favours the soil processes, reduces nutrient loss and therefore, increases crop yield significantly (Wang *et al.* 2021).

Long-term fertility experiment reveals the influence of combination of different nutrient sources and their levels on crop yield over the years and helps in finding the best management practices for a particular region (Mahapatra *et al.* 2018). The contribution of long-term fertility experiment to current trends of soil science remains outstanding since its initiation in India and has been used to understand the influence of crop management and fertilization on organic matter content and the rate of carbon sequestration in soil (Ghosh *et al.* 2016). However, the information on effect of integrated use of fertilizers, manures in addition with amendments for a prolonged period on soil health and crop productivity in a problematic acidic soil is insufficient. Hence, an attempt was made through this study to evaluate the effect of 67-years of fertilization, manuring and liming on different pools of soil organic carbon and availability of essential nutrients in soil in relation to crop yield.

MATERIALS AND METHODS

Experimental site: Soil samples were collected from the Permanent Manurial Trial (PMT) of Birsa Agricultural University, Kanke, Ranchi (23°17'N, 85°19'E and 625 m amsl), Jharkhand after harvesting of rainy (*kharif*) maize in October 2023. The site has followed a maize-wheat cropping

¹ICAR-Indian Agricultural Research Institute, New Delhi;

²Birsa Agricultural University, Ranchi, Jharkhand. *Corresponding author email: sunandabiswas13@gmail.com

sequence since its initiation in 1956. The climate of Ranchi is typically tropical with hot (maximum temperature of 42°C) and wet summer, receiving a mean annual rainfall of 1450 mm and enjoys a mild winter (minimum temperature of 15°C). The soil developed in this region is generally acidic, loamy, compact, rich in oxides of iron and poor in organic matter content, calcium and water retention. Toxicity of iron and aluminium, low nutrient availability and restricted microbial activity led to inferior crop yield. The initial soil had a pH of 5.5, organic carbon of 5.2 g/kg and bulk density of 1.45 Mg/m³.

Experimental details: Experiment was conducted in a randomized block design (RBD) comprised of 7 treatments, viz. Control; N; FYM; $\frac{1}{2}(N+FYM)+P_{X/2}+K_{Y/2}$; NPK; NPK+L; and $P_{(A-X)}K_{(B-Y)}+FYM+L$ (Table 1), replicated thrice. Initially the nutrients N, P₂O₅ and K₂O (45:45:45 kg/ha) were added through ammonium sulphate (AS), single super phosphate (SSP) and muriate of potash (MOP), respectively. During 1969 the fertilizer doses were revised to 100:60:60 kg/ha and further modified to 110:90:70 kg/ha for N, P₂O₅ and K₂O, respectively in the year 1976. Besides, ammonium sulphate has been replaced by urea as source of nitrogen since 1994. Farm yard manure (FYM) was applied based on nitrogen content and lime was incorporated in accordance with lime requirement in every 4th year. Crop varieties used during the study was Suwan (Maize) and K 9107 (Wheat).

Soil sampling, processing and analysis: Surface soil samples (0–15 cm) were collected from each replication of the selected seven treatments using an auger after the harvesting of *kharif* maize at the 67th crop cycle. One part of the fresh samples were kept in refrigerator at 4°C temperature for analysis of biological attributes while rest of the samples were air dried, cleaned, ground, sieved (2 mm) and stored for analysis of other parameters. A portion of the dried samples were further ground and passed through 0.5 mm sieve for determining soil organic carbon (SOC) content. Separately, another set of samples were collected using core sampler for determining the bulk density (BD)

of soil (Blake and Hartge 1986). Evaluating the chemical attributes of the soil encompassed determining soil pH (Page *et al.* 1982), available nitrogen (Av. N) (Subbiah and Asija 1956), available phosphorus (Av. P) (Bray and Kurtz 1945), available potassium (Av. K) (Hanway and Heidel 1952), easily oxidisable soil organic carbon (SOC) (Walkley and Black 1934) and total organic carbon (TOC) (Snyder and Trofymow 1984). Furthermore, four fractions of SOC such as very labile, labile, less labile and non-labile fraction were separated through a modified Walkley and Black method (Chan *et al.* 2001) using different acid-aqueous ratios (0.5:1, 1:1 and 2:1) and compared with TOC. The fractions of SOC were summarised into active [Σ (very labile + labile)] and passive pools [Σ (less labile + non-labile)] based on degrees of susceptibility to decomposition and expressed in terms of percent of TOC. In addition, lability index (LI) of different treatments was determined from the fractions of SOC (Singh *et al.* 2023):

$$\text{Lability index} = [(\text{Very labile carbon}/\text{TOC}) \times 3 + (\text{Labile carbon}/\text{TOC}) \times 2 + (\text{Less labile}/\text{TOC}) \times 1]$$

To evaluate the biological aspects of the soil, measurements were taken for dehydrogenase activity (DHA) (Dick *et al.* 1996) and soil microbial biomass carbon (MBC) (Vance *et al.* 1987). Sustainable yield index (SYI) was computed as per the empirical equation given by Kumari *et al.* (2013) and the influence of various soil attributes on SYI was expressed using regression equation:

$$\text{SYI} = [(\text{Mean Yield} - \text{Standard Deviation})/Y_{\text{max}}]$$

where Y_{max} , Highest yield achieved among all management practices tested in any treatment in any of the year. The significance of difference among the treatment means were assessed using Duncan's multiple range tests (Gomez and Gomez 1984).

RESULTS AND DISCUSSION

Soil reaction and bulk density: The study displayed that the soil pH varied from 4.1 in treatment N to 6.3 in lime amended plots (Table 2). A remarkable increase in pH (34%) in both the lime treated plots was noticed as compare to only NPK. Acidic nitrogenous fertilizer and rapid nitrification which releases proton contributed to reduction in pH in case of only inorganic nitrogen treated plot (Zhang *et al.* 2020) while maintaining soil pH near neutral in lime-treated plots can be attributed to the neutralizing effect of lime on acidic soil (Enesi *et al.* 2023). The lowest BD of soil under field condition was observed in FYM treated plot (1.31 Mg/m³) which was at par with $\frac{1}{2}(N+FYM)+P_{X/2}+K_{Y/2}$; in contrast, the control plot showed the highest BD of 1.61 Mg/m³. Addition of manures enhance soil organic matter content, improves soil aggregation and aeration, resulted a lower mass per unit volume of soil in the manures treated plots (Fang *et al.* 2021).

Available nutrients: Available nutrients especially the primary nutrient elements (N, P and K) play crucial role in promoting plant growth, maximize yield and lead towards

Table 1 Treatment details

Treatment	Sources of nutrient			Amendment
	N	P	K	
Control	-	-	-	-
N	Urea	-	-	-
FYM	FYM	-	-	-
$\frac{1}{2}(N + FYM) + P_{X/2} + K_{Y/2}$	FYM and Urea	SSP	MOP	-
NPK	Urea	SSP	MOP	-
NPK + L	Urea	SSP	MOP	Lime
$P_{(A-X)}K_{(B-Y)} + FYM + L$	FYM	SSP	MOP	Lime

A and B, Full dose of P and K; X and Y, Amount of P and K present in full dose of FYM.

sustainability when maintained optimally in the soil. The soil analysis unveiled a significantly higher content of Av. N in NPK (259 kg/ha) and 1/2(N+FYM)+P_{X/2}+K_{Y/2} (247 kg/ha) as compare to other treatments (Table 2) which could be due to the direct supplying of N through inorganic fertilizers and mineralization from applied FYM (Dhaliwal *et al.* 2021, Tamuli *et al.* 2024). A drastic variation of Av. P was observed among the treatments ranging from 426 kg/ha in NPK to as low as 7.12 kg/ha in the control. Continuous addition of P through chemical fertilizers and FYM contributed to higher Av. P in NPK and 1/2(N+FYM)+P_{X/2}+K_{Y/2} treatments. Colloidal effect of FYM reduced P fixation by deactivating the influence of iron, manganese and hydroxyl-aluminium ion (Vishwanath *et al.* 2022). Moreover, lime induced pH adjustment increases P availability in the lime amended treatments (Mahapatra *et al.* 2018). The lowest amount of Av. K was recorded in N treated plot which was not significantly different from control. This could be due to not replenishing the K taken up by crop for a long period under intensive cropping. The highest amount was observed in NPK followed by P_(A-X)K_(B-Y)+FYM+L treatment might be due to the addition of K to the available pool continuously either through inorganic fertilizer or from mineralization of FYM. Moreover, K adsorption at non-specific site induced by FYM may also aids in maintaining higher levels of readily available potassium in the soil (Das *et al.* 2021).

Soil organic carbon and its fractions: Easily oxidisable SOC, the most vital component of soil organic matter was significantly higher in FYM treated plot (7.98 g/kg) followed by P_(A-X)K_(B-Y)+FYM+L (7.02 g/kg) over other treatments (Table 2). The elevated level of SOC in the plots treated with FYM might be due to incorporation of thoroughly decomposed organic manure over the years, coupled with higher crop growth, rhizodeposition and residue return to the field. Moreover, enhanced microbial activities in response to added manures triggered the decomposition of root biomass, resulted a greater accumulation of carbon in the soil (Ghosh *et al.* 2018). Conversely, unfertilized control plot

had the lowest carbon content (4.73 g/kg), likely attributed to its poor net primary productivity, resulting in minimal biomass production (Trivedi *et al.* 2020). Separation of various fractions of SOC by increasing oxidising condition resulted that, the proportion of active fractions were considerably higher under control and treatment N i.e. 62.7 and 62.4% of their respective TOC (Fig. 1). In contrast, the plots with added manures exhibited higher proportion of passive fraction among the treatments of which the highest proportion was observed in FYM treated plot (46.9%) followed by 1/2(N+FYM)+P_{X/2}+K_{Y/2} (45.6%). This could be due to the presence of polyphenol compounds and lignin in the FYM that form stable complexes with protein, resisting further microbial degradation (Anantha *et al.* 2020). The LI of carbon followed the trend of active fractions of SOC, producing a higher index of 1.86 in the control while, it has been narrowed down to 1.62 in the FYM treated plot (Fig. 1). Manure incorporation enriched both the labile

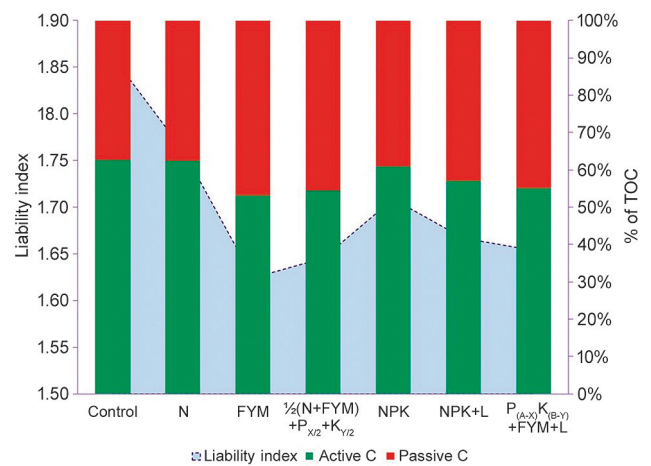


Fig. 1 Proportion of active and passive fraction of carbon and liability index under different treatments (0–45 cm).

TOC, Total organic carbon; A and B, Full dose of P and K; x and y, Amount of P and K present in full dose of FYM.

Table 2 Effect of manuring, fertilization and amendments on soil properties and grain yield

Treatment	pH	BD (Mg/m ³)	Av. N P K			SOC (g/kg)	MBC (µg/g)	DHA (µgTPF/ g/24 h)	Grain yield (t/ha)			
			(kg/ha)						Maize		Wheat	
			2021– 22	2022– 23	2021– 22				2022– 23			
Control	5.6c	1.61a	141e	7.12f	170d	4.73e	181c	4.44d	0.52d	0.52d	1.10d	0.60d
N	4.1e	1.59a	216c	23.2e	168d	5.32d	195c	4.16d	0.96d	0.48d	1.07d	0.55d
FYM	6.1b	1.31c	187d	136d	213abc	7.98a	295a	14.7ab	2.60b	2.84c	2.48c	2.15c
1/2(N+FYM)+P _{X/2} +K _{Y/2}	5.7c	1.43	247a	349b	200c	5.91c	310a	13.7b	4.90a	4.20a	4.28a	3.16b
NPK	4.7d	1.50ab	259a	426a	223a	5.40d	252b	9.68c	1.94c	3.79b	3.25b	2.37c
NPK+L	6.3a	1.49ab	241ab	225c	205bc	5.44d	261b	15.9a	4.63a	4.51a	4.27a	4.20a
P _(A-X) K _(B-Y) +FYM+L	6.3a	1.43bc	223bc	224c	222ab	7.02b	297a	14.2ab	2.92b	2.76c	2.08c	2.11c
Mean	5.5	1.47	216	198	200	5.97	256	10.1	2.64	2.73	2.65	2.16
CD (P<0.05)	0.14	0.13	19.2	15.6	17.3	0.32	21.1	1.83	0.71	0.60	0.58	0.53
CV (%)	1.37	5.02	4.93	4.36	4.79	2.96	4.59	9.37	15.5	13.5	13.0	14.3

Means with similar lowercase letters within a column are not significant at P<0.05.

A and B, Full dose of P and K; x and y, Amount of P and K present in full dose of FYM.

and non-labile pools of SOC but, contributed largely in the non-labile pools (Alam *et al.* 2019), lowering the LI in FYM treatment.

Soil microbial biomass carbon (MBC) and dehydrogenase activity: Microbial biomass carbon, one of the most sensitive pools of SOC was varied between 2.9–3.9% of TOC among the treatments. The greatest amount of MBC was found in the plot treated with $\frac{1}{2}(N+FYM)+P_{X/2}+K_{Y/2}$ (310 $\mu\text{g/g}$) while being at par with FYM and $P_{(A-X)}K_{(B-Y)}+FYM+L$ treatment (Table 2). Adequate nutrient supply through manures, fertilizers and amendments augments microbial activities in soil that resulted a higher MBC in those plots (Howe *et al.* 2024). The oxidative capacity of soil measured through activity of dehydrogenase enzyme was ranged from 4.16 $\mu\text{g TPF/g/24 h}$ in the treatment N to as high as 15.9 $\mu\text{g TPF/g/24 h}$ in NPK+L treated plot. Presence of easily decomposable carbon sources supplied through crop residues or manures could be the reason of enhanced DHA in the plots treated with lime and/or, manures in combination with fertilizers (Vishwanath *et al.* 2022).

Crop yield and sustainable yield index as influenced by soil properties: Sixty-seven years of manuring, fertilization and liming in the acidic soils of Ranchi revealed that, the grain yield of maize and wheat was significantly higher in the plots received lime or, FYM along with balanced nutrients as compare to control or imbalanced nutrient management (Table 2). The highest yield was obtained from $\frac{1}{2}(N+FYM)+P_{X/2}+K_{Y/2}$ treatment in the year 2021–22 for both the crops maize (4.90 t/ha) and wheat (4.28 t/ha), whereas NPK+L produced the maximum yield for both the crops in the following year (2022–23). However, the mean

yield did not differ significantly between the two treatments. The result is consistent with the findings of Kumari *et al.* (2013) in the same experimental site. Incorporation of lime and/or, organic manures in addition to chemical fertilizers improves soil physico-chemical and biological properties, increased nutrient retention and nutrient availability from their non-available or less available form that collectively contributed to higher crop yield (Dhaliwal *et al.* 2021). SYI

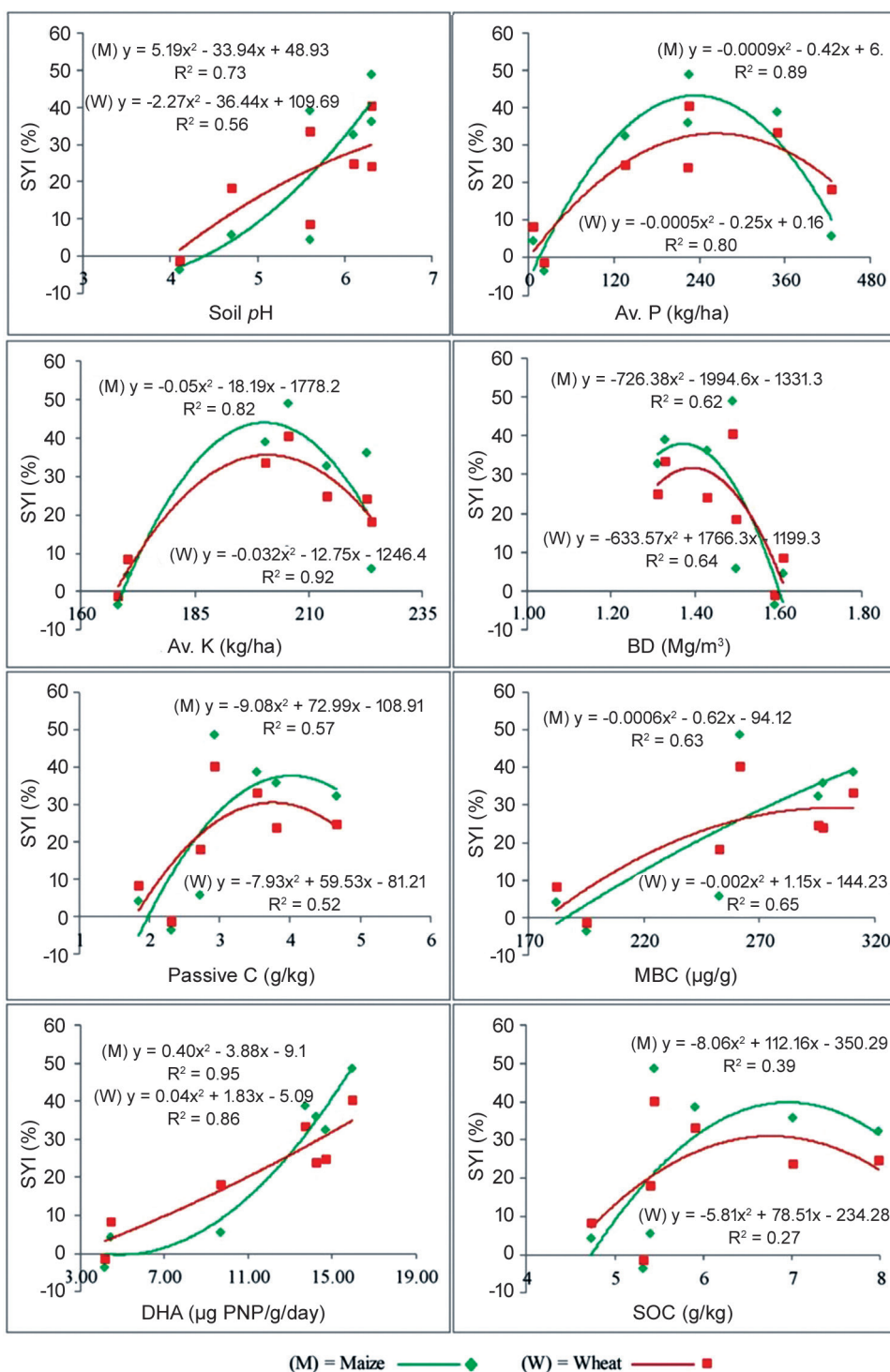


Fig. 2 Relationship between different soil parameters and sustainable yield index (SYI) (1956–2023). BD, Bulk density; MBC, Microbial biomass carbon; DHA, Dehydrogenase activity; SOC, Soil organic carbon.

was formulated from the grain yield of maize and wheat for entire period of experimentation and the relationship of different soil parameters and SYI was graphically represented through simple regression analysis (Fig. 2). The regression coefficient (R^2) was substantially higher with DHA (0.95) in maize and with Av. K (0.92) in case of wheat. Likewise, Av. P, soil pH, MBC, passive C fraction, BD and SOC exhibited considerably higher R^2 values for both maize and wheat, indicating their positive impact on yield sustainability in the acidic Alfisol. These parameters must be monitored carefully and managed optimally in order to sustain the cropping system in the region.

Continuous use of chemical fertilizers under intensive cropping deteriorates soil structure, disturbs its health and affects the natural productivity of soil in the long run. It is of utmost important to restore the soil health and replenish its nutrient pools which had been exploited. The study unveiled the beneficial effect of integrated use of organic manures, chemical fertilizers and lime on soil health and crop productivity in an acidic Alfisol. Nevertheless, inorganic fertilizer alone raised the level of soil available nutrients but, the treatments that received inorganic fertilizer in combination with manures and/or lime for a long period aided build-up of soil organic carbon in different pools, better nutrient availability, augmented microbial activities, and finally sustained the crop yield.

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