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Impact of Continuous Fertilization and Manuring on Soil Chemical Properties and Carbon Fractions in Alfisols

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Abstract

A long term fertilizer experiment has been under progress since 1986 at Zonal Agricultural Research Station, GKVK, University of Agricultural Sciences, Bangalore with finger millet-maize cropping sequence consisting of twelve treatments and replicated four times in a randomized block design. The present study was conducted to assess the influence of continuous fertilizer and manure application on soil chemical properties and soil organic carbon (SOC) fractions in long term fertilizer experiment during 2019-20. Long term application of organic and inorganic fertilizers together (100% NPK + FYM + lime, 100% NPK + FYM) or balanced fertilization (100% NPK, 150% NPK, 100% NPK + hand weeding, 100% NPK + lime) for about 33 cropping cycles led to marked increase in soil chemical parameters and different SOC fractions. However, continuous cultivation of crops without or imbalanced nutrient supply [50% NPK, 100% NP, 100% N, 100% NPK (S-free P fertilizer) and absolute control] led to decline in SOC content as well as soil nutrient content. Organic carbon fractions were recorded higher in uncultivated soil compared to cultivated soil. Balanced fertilization and organic matter addition has played an important role in improving all carbon pools in the soil after 33 years of cropping cycle. The concentration of different SOC fractions in soil were in the order following: Wakley and Black's oxidizable carbon > particulate organic carbon > carbohydrate carbon > microbial biomass carbon > water soluble carbon.

Keywords : Organic and Inorganic fertilizers, Long term fertilizer experiment, Soil organic carbon, Carbon fractions

Soil organic carbon (SOC) is one of the most widely used soil quality indicator together with pH, available P and K. It affects various soil chemical, physical and biological properties and plays a primary role in multiple soil functions in agricultural soils, such as nutrient cycling, soil aggregate formation, water retention and habitat provision for biodiversity. Soil organic carbon also plays an important role in climate regulation, with the potential of increasing carbon sequestration, offsetting fossil-fuel emissions and counteracting yield reduction created by extreme weather events. Despite the importance of SOC, its depletion is one of the main threats for agricultural soils. Agricultural measures that are aimed at increasing SOC stocks are therefore becoming a priority worldwide.

Soil organic carbon is not sensitive to short-term changes of soil quality with different soil or crop management practices due to high background levels and natural soil variability. SOC pool is comprised of labile or actively cycling pool and stable, passive/ recalcitrant pools with varying residence time (Zogg *et al*., 2000). Labile C pool, with rapid turnover rate, is an important energy source for the soil food web and thus influences nutrient cycling for maintaining soil quality and its productivity. Passive or recalcitrant pool is very slowly altered by microbial activities. Some C pools like microbial biomass C, water extractable organic C and oxidisable organic C are used as indicators of soil quality and are much more sensitive to change in soil management practices. Long-term experiments are useful to monitor changes in pools of SOC as influenced by different cropping systems, soil management practices, fertilizer usage and residue utilization. However, little information is known about the long-term application of inorganic fertilizers either alone or with organic manure on SOC. Hence, a study was under taken with the objective to evaluate the effect of long term application of fertilizers and manures on soil chemical properties and different carbon fractions in finger millet-maize cropping system of long term fertilizer experiment.

Material and Methods

A field experiment on long term fertilizer experiment (LTFE) is in progress since 1986 at UAS, GKVK, Bengaluru in *Alfisols* with finger millet-hybrid maize cropping sequence. The experimental site is located in the 'E-18' block, Zonal Agricultural Research Station, University of Agricultural Sciences, GKVK, Bengaluru. The LTFE research station is located at an altitude of 930 meters above MSL, latitude of $13^0$4' 37" north, longitude of $77^0$34' 33" east. The experiment consists of eleven treatments which are replicated four times in a Randomized Block Design. However, for the present study only three replications and one more additional treatment of fallow land was considered. The details of experimental treatments, recommended dose of fertilizers for the study crops, sources of fertilizers etc. are as follows.

Initial Soil Characteristics

The soil colour is red and belonged to sandy clay loam texture and was classified as lateritic soil. Details of initial soil properties of the experimental site are presented in Table 1.

Table 1

Initial soil properties of the experimental site, GKVK, Bengaluru

Subgroup	:	*KandicPaleustalfs*
Series	:	Vijayapura
Taxonomy	:	Fine, mixed *Isohyperthermic Kandicpaleustalfs*
Chemical properties		
pH (1:2.5, soil : water suspension)	:	6.17
Electrical conductivity (EC, dSm^{-1})	:	0.059
CEC [c mol (p+) kg^{-1}]	:	12.20
Organic carbon (%)	:	0.46
Available nitrogen (kg ha^{-1})	:	256.7
Availablephosphorus (kg ha^{-1})	:	34.3
Availablepotassium (kg ha^{-1})	:	123.1
Exchangeable calcium [c mol (p^+) kg^{-1}]	:	3.25
Exchangeable magnesium [c mol (p^+) kg^{-1}]	:	1.55
Available sulphur (mg kg^{-1})	:	20.34
DTPA extractable micronutrients (mg kg^{-1})		
Zinc	:	2.34
Copper	:	2.30
Manganese	:	108.40
Iron	:	5.22

Treatments Details

Treatment	NPK dosage (kg ha^{-1})		Fertilizer Source
	Finger millet	Hybrid maize	
T_1: 50% NPK	50 – 11 – 21	50 – 16 – 41	Urea, SSP, MOP
T_2: 100% NPK	100 – 22 – 42	100 – 32 – 82	Urea, SSP, MOP
T_3: 150% NPK	150 – 33 – 63	150 – 48 – 123	Urea, SSP, MOP
T_4: 100% NPK + HW	100 – 22 – 42	100 – 32 – 82	Urea, SSP, MOP
T_5: 100% NPK + lime	100 – 22 – 42	100 – 32 – 82	Urea, SSP, MOP, lime
T_6: 100% NP	100 – 22 – 00	100 – 32 – 00	Urea, SSP
T_7: 100% N	100 – 00 – 00	100 – 00 – 00	Urea
T_8: 100% NPK + FYM	100 – 22 – 42	100 – 32 – 82	Urea, SSP, MOP
T_9: 100% NPK (S-free)	100 – 22 – 42	100 – 32 – 82	Urea, DAP, MOP
T_{10}: 100% NPK + FYM + lime	100 – 22 – 42	100 – 32 – 82	Urea, SSP, MOP, lime
T_{11}: Control	00 – 00 – 00	00 – 00 – 00	-
T_{12}: Fallow land	00 – 00 – 00	00 – 00 – 00	-

Note : Farm yard manure (FYM) @ 15 t ha^{-1}applied to finger millet alone; Lime applied based on lime requirement; T_4: Hand weeding done twice in each crop and chemical weeding is practiced in all other treatments

Collection and Analysis of Soil Samples

Composite soil samples were collected using soil tube auger from each plot by collecting soil samples at a depth of 0-15 cm after 33rd crop cycle *i.e.*, after the harvest of maize crop (2020). In fallow land (T_{12}), the soil sample was collected at three locations adjacent to experimental plots where no cultivation has been done since inception of the experiment. Further soil samples were air dried, ground, passed through 0.2 mm sieve and subjected for analysis of various properties following standard procedures presented in Table 2.

Estimation of Soil Organic Carbon Fractions

Water soluble carbon : Water-extractable organic carbon was determined by shaking 10 g of soil with 20 mL of deionized water for 1 h (McGill *et al.*, 1986).

Particulate organic carbon : Particulate organic carbon was determined with modification to the method described by Cambardella and Elliot (1992).

Microbial biomass carbon : Soil microbial biomass carbon was estimated by fumigation extraction method as detailed by Carter (1991).

Carbohydrate carbon : Carbohydrates were extracted from fine earth samples, after suspension in H_2SO_4, by incubating the suspension for 2.5 h at 85^0C on water bath. After incubation, the suspension was centrifuged and the supernatant was analyzed for total soluble soil carbohydrates using phenol – sulphuric acid method (Dubois *et al*., 1956).

Results and Discussion

The data pertaining to chemical properties of soils as influenced by long term fertilizer treatments are presented in Table 3 and Table 4.

Soil pH

The plots treated continuously with fertilizers alone recorded lower pH values than those treated in combination with lime. Significantly higher soil pH of 6.28 was recorded in the uncultivated soil (T_{12}) and is on par with plots applied with 100 per cent NPK + FYM + lime (T_{10}), control (T_{11}) and T_5 which received 100 per cent NPK + lime (5.97, 5.83 and 5.67, respectively). In the inorganic treatments, T_7 (100% N), T_3 (150% NPK), T_6 (100% NP) and T_9 (100% NPK- S free) significantly lower acidic pH values of 4.60, 4.82, 4.85 and 5.15 were recorded, respectively. With the increase in dosage of N fertilizer in treatments consisting 50 per cent NPK (T_1) and 150 per cent NPK (T_3), the pH declined to 5.36 and 4.82 from initial soil pH (6.17).

TABLE 2

Methods followed for the analysis of soil samples

Parameters	Methods	References
pH (1:2.5)	Potentiometric method	Jackson (1973)
EC (1:2.5)	Conductometric method	Jackson (1973)
Organic carbon (g kg^{-1})	Wet oxidation method	Wakley and Black (1934)
Available nitrogen (kg N ha^{-1})	Alkaline potassium permanganate method	Subbiah and Asija (1956)
Available phosphorous (kg P_2O_5 ha^{-1})	Bray's extractant using spectrophotometer	Jackson (1973)
Available potassium (kg K_2O ha^{-1})	Ammonium acetate extractant using flame photometery	Jackson (1973)
Available sulphur (mg kg^{-1})	Turbidometric method	Jackson (1973)
Exchangable calcium [c mol (p+) kg^{-1}]	Complexometric titration	Jackson (1973)
Exchangable magnesium [c mol (p+) kg^{-1}]	Complexometric titration	Jackson (1973)
DTPA extractable Fe, Mn, Zn and Cu (mg kg^{-1})	Atomic absorption spectrophotometry	Lindsay and Norvel, (1978)

TABLE 3

Effect of long term manuring and fertilization on chemical properties of soil after 33 years of finger millet - maize cropping sequence

Treatments	pH	EC (dS m^{-1})	Avail. N (kg ha^{-1})	Avail. P_2O_5 (kg ha^{-1})	Avail. K_2O (kg ha^{-1})
T_1 : 50 % NPK	5.36	0.10	163.07	68.76	139.07
T_2 : 100 % NPK	5.26	0.12	183.98	96.24	165.20
T_3 : 150 % NPK	4.82	0.14	204.89	217.44	232.15
T_4 : 100 % NPK+ HW	5.23	0.11	176.25	102.31	158.73
T_5 : 100 % NPK+ lime	5.67	0.12	167.36	85.24	176.24
T_6 : 100 % NP	4.85	0.13	171.79	176.26	83.87
T_7 : 100 % N	4.60	0.09	199.00	53.03	91.42
T_8 : 100 % NPK+ FYM	5.64	0.14	210.64	165.24	213.61
T_9 : 100 % NPK(S-free)	5.15	0.11	186.92	145.24	161.50
T_{10} : 100 % NPK+ FYM+ lime	5.97	0.15	238.34	198.14	216.43
T_{11} : Control	5.83	0.13	158.89	39.16	119.08
T_{12} : Uncultivated land	6.28	0.13	255.06	44.90	142.11
Initial value	6.17	0.059	257	34	123
SEm ±	0.30	0.01	6.17	4.51	5.64
CD at 5 %	0.87	0.03	18.11	13.22	16.54

TABLE 4

Effect of long term manuring and fertilization on secondary and micronutrients content in soil after 33 years of finger millet – maize cropping sequence

Treatments	Exch. Ca	Exch. Mg	Avail. S	Zinc	Copper	Iron	Manganese
	[c mol (P^+) kg^{-1}]		(mg kg^{-1})				
T_1 : 50% NPK	5.00	2.50	9.98	3.03	1.51	10.57	18.64
T_2 : 100% NPK	4.67	2.17	12.80	3.11	1.66	14.77	21.25
T_3 : 150% NPK	4.83	1.83	16.28	2.69	1.53	16.47	24.90
T_4 : 100% NPK+ HW	4.33	2.00	12.80	2.48	1.61	14.29	19.48
T_5 : 100% NPK+ lime	5.33	2.33	14.76	4.04	1.49	9.90	19.85
T_6 : 100% NP	4.17	1.50	15.41	3.28	1.44	11.46	25.50
T_7 : 100% N	3.67	1.33	9.77	2.92	1.41	12.72	17.27
T_8 : 100% NPK+ FYM	5.17	2.67	13.67	5.29	1.88	17.96	23.38
T_9 : 100% NPK(S-free)	3.83	1.67	8.46	2.45	1.72	12.11	20.85
T_{10} : 100% NPK+ FYM+ lime	5.83	2.83	15.62	5.44	1.75	16.25	21.84
T_{11} : Control	4.00	2.17	11.94	2.42	1.39	7.45	14.88
T_{12} : Uncultivated land	4.33	2.33	14.11	3.62	1.63	9.93	22.77
Initial value	3.25	1.55	20	2.34	2.30	5.22	108.40
SEm±	0.36	0.21	0.97	0.22	0.12	0.89	1.62
CD at 5%	1.05	0.61	2.85	0.66	0.36	2.62	4.75

Application of lime and FYM significantly increased the soil pH compared to fertilizer alone treatments. Lime may have aided in the release of hydroxyl ions, which then react with hydrogen ions in the soil to reduce soil acidity. Higher pH under FYM treatment was due to the deactivation of Fe^{3+} and Al^{3+} with the release of basic cations such as Ca^{2+}, Mg^{2+} and K^{+} during its decomposition. Chemical fertilizer treatments have resulted in a drop in soil pH, notably in plots that have received fertilizers alone that are high in nitrogen. The results were in agreement with the findings of Sudhir *et al*. (2010). The acid-producing nature of urea as a nitrogenous fertilizer which when nitrified produces H^{+} ions. This might be one of the reasons for higher pH value noticed in uncultivated soil over cultivated soil. The use of lime together with FYM resulted in a rise in soil pH, according to Pradhan and Mishra (1982).

Electrical Conductivity (dS m^{-1})

Significantly highest EC value of 0.15 dS m^{-1} was recorded inT_{10} (100% NPK + NPK + lime) and is on par with 0.14 dS m^{-1} in T_3 (150% NPK) and 0.14 dS m^{-1} in T_8 (100% NPK + FYM). Among the treatments, lowest EC of 0.09 dS m^{-1} was observed in the treatment T_7 (100% N). The limed plots recorded relatively higher amounts of soluble salts than non-limed plots. Increase in doses of fertilizers increased the soil EC, from 0.10 dS m^{-1} (50% NPK) to 0.14 dS m^{-1} (150% NPK).

In comparison to control plot, electrical conductivity of the soil was significantly higher in plots treated with fertilizers and lime. The reason for relatively higher soluble salt content in lime amended plots could be attributed to the release of calcium from lime. Similar results were reported by Vig and Bhumbla (1970) and Subramanian & Kumaraswamy (1989).

Available Nitrogen (kg ha^{-1})

When compared to initial soil values, irrespective of treatments there was decrease in available nitrogen content after 33 years. Significantly higher available nitrogen content (255.06 kg ha^{-1}) was recorded in uncultivated plot which is on par with treatment T_{10}: 100 per cent NPK + FYM + lime (238.34 kg ha^{-1}). The available nitrogen content was significantly low in control treatment T_{11} (158.89 kg ha^{-1}) which is on par with T_1 of 50 per cent NPK (163.07 kg ha^{-1}). Application of higher doses of fertilizer increased significantly the available nitrogen from 163.07 kg ha^{-1} (50% NPK) to 204.89 kg ha^{-1} (150% NPK).

The treatment that received FYM along with inorganic fertilizers had a higher available nitrogen content. This could be due to beneficial effects of organic manures and their mineralization into available nitrogen forms. Similar results were reported by Katkar *et al*., 2002. Higher application of fertilizers increases the available N due to increased root biomass that lead to higher organic matter accumulation (Surekha and Rao, 2009). Available N is higher in uncultivated land compare to cultivated land due to higher organic matter accumulation in no tillage had effect on N mineralization (Balota *et al*., 2004).

Available Phosphorous (kg ha^{-1})

In soil, the significantly higher available phosphorus content of 217.44 kg ha^{-1}, 198.14 kg ha^{-1} and 176.26 kg ha^{-1} were observed in treatments T_3 (150% NPK), T_{10} (100% NPK + FYM + lime) and T_6 (100% NP), respectively. There was significant build-up of phosphorus in all the treatments over the initial status except control: T_{11} (39.16 kg ha^{-1}), uncultivated land (44.90 kg ha^{-1}) and T_7 (53.03 kg ha^{-1}) which received only 100 per cent N.

Anions formed during the breakdown of organic matter may be responsible for P availability in FYM applied treatments. Liming neutralises Fe and Al hydroxides and releasing P from such oxides. Continuous inorganic P fertiliser application at higher content contributed significantly to soil P. The availability of phosphorous and its accumulation in soil are mostly depends on phosphorus fixation in the soil according to Wang *et al*. (2010). Continuous cropping without P fertilization decreased the available P in soil. These results corroborates with the findings of Vinutha *et al*. (2010).

Available Potassium (kg ha^{-1})

The available potassium content of soil was recorded significantly higher in the treatments T_3 (232.15 kg ha^{-1}) followed by T_{10} (216.43 kg ha^{-1}) and T_8 (213.61 kg ha^{-1}) which received 150% NPK, 100% NPK + FYM + lime and 100% NPK + FYM, respectively. When compare to initial value, the potassium content gets depleted in the treatments T_6 (100% NP), T_7 (100% N) and T_{11} (control) where K was not applied and available K_2O content in these treatments were 83.87 kg ha^{-1}, 91.42 kg ha^{-1} and 119.08 kg ha^{-1}, respectively.

The available potassium was higher in plots that received a higher dose of inorganic fertilizers, as well as plots that received FYM and inorganic fertilisers on a continuous basis when compared to other treatments. These results are corroborated with findings of Prasad *et al*. (1996). Bansal (1992) observed that FYM has a positive effect on the solubility of insoluble potassium compounds during the decomposition process.

Exchangeable Calcium [c mol (p$^+$) kg^{-1}]

The plots treated with lime were found to contain significantly higher amount of exchangeable Ca in the soil. The highest exchangeable Ca [5.83 c mol (p$^+$) kg^{-1}] was recorded in treatment T_{10} (100% NPK + FYM + lime) which is on par with T_5: 100% NPK + lime [5.33 c (p$^+$) mol kg^{-1}] and T_8 : 100% NPK + FYM [5.17 c (p$^+$) mol kg^{-1}]. The reduction in exchangeable calcium was highest in case of T_7 [3.67 c mol (p$^+$) kg^{-1}] over all other treatments but is on par with T_9 [3.83 c mol (p$^+$) kg^{-1} and control [4.00 c mol (p$^+$) kg^{-1}].

Lower exchangeable Ca was recorded in treatments where only N fertilizer was applied. The increase in Ca content was in plots where single super phosphate was used as a source of P. Furthermore, addition of FYM also increased exchangeable Ca. Similar results are reported by Sharma *et al*. (2014) and Shantakumari (2007). The direct addition of calcium in the form of calcium carbonate over the years increased the exchangeable calcium content of soil in lime treated plots.

Exchangeable Magnesium [c mol (p$^+$) kg^{-1}]

The exchangeable magnesium content was recorded significantly higher in treatment T_{10}: 100 per cent NPK + FYM + lime [2.83 c (p$^+$) mol kg^{-1}] which is on par with T_8: 100 per cent NPK + FYM [2.67 c (p$^+$) mol kg^{-1}]. Exchangeable magnesium was significantly low in case of T_7: 100% N [1.33 c mol (p$^+$) kg^{-1}] followed by T_6: 100% NP [1.50 c mol (p$^+$) kg^{-1}].

Continuous cropping without nutrient application from an external source might have diminished the exchangeable magnesium reserve. In the current study, exchangeable magnesium was shown to be lower in plots treated with only NPK fertilisers compared to plots treated with fertilisers, FYM and lime. Lime can also contribute Mg to some extent as it contains some amount of Mg as impurity. Similar results were reported by Prasad *et al*. (1996) and Babu *et al*. (2007).

Available Sulphur (mg kg^{-1})

Significantly higher available sulphur content of 16.28 mg kg^{-1}, 15.62 mg kg^{-1} and 15.41 mg kg^{-1} was noticed in T_3 (150% NPK), T_{10} (100% NPK + FYM + lime) and T_6 (100% NP), respectively. Whereas, lowest value of 8.46 mg kg^{-1} was in T_9 where no sulphur was added and found on par with T_7: 100 per cent N (9.77 mg kg^{-1}) and T_1: 50% NPK (9.98 mg kg^{-1}). Available sulphur content increased significantly with higher dose of fertilizer application *i.e.*, 150 per cent NPK (16.28 mg kg^{-1}).

The available sulphur content of soil was higher in plots treated with sulphur containing fertilizers (SSP). Jagadeesh (2000) reported similar results on considerable increase in sulphur content due to addition of FYM and sulphur containing fertilizers (SSP). They found lower in the treatments receiving sulphur free fertilizers (DAP as a P source) and imbalanced supply of nutrients. Application of lime increases the available sulphur as liming results in net mineralization of soil organic S and its accumulation in the soil (Haynes and Naidu, 1998).

DTPA Extractable Micronutrients

DTPA-zinc (mg kg^{-1})

Significant difference among the treatments was noticed with respect to zinc content in soil. Significantly higher zinc content was recorded in treatment T_{10} receiving 100 per cent NPK + FYM + lime (5.44 mg kg^{-1}) followed on par with treatment T_8 receiving 100 per cent NPK + FYM (5.29 mg kg^{-1}) whereas, significantly lower zinc content of 2.42 mg kg^{-1} and 2.45 mg kg^{-1} was recorded in treatment T_{11} (Control) and T_9 [100 per cent NPK (S-free)], respectively.

DTPA - Copper (mg kg^{-1})

Copper content was recorded higher in T_8 receiving 100 per cent NPK + FYM (1.88 mg kg^{-1}) which is on par with T_{10} receiving 100 per cent NPK + FYM + lime (1.75 mg kg^{-1}). However, significantly lower copper content of 1.39 mg kg^{-1} and 1.41 mg kg^{-1} was observed in treatment T_{11} (control) and T_7 which received 100 per cent N, respectively.

DTPA - Iron (mg kg^{-1})

There was significant difference in DTPA extractable iron content among different treatments. Iron content was recorded higher in T_8 (17.96 mg kg^{-1}) which is on par with T_3 (16.47 mg kg^{-1}) which has received 100 per cent NPK + FYM and 150 per cent NPK, respectively. However, significantly lower iron content of 7.45 mg kg^{-1} was observed in treatment T_{11} (control) followed by T_5 which received 100 per cent NPK + lime (9.90 mg kg^{-1}).

DTPA - Manganese (mg kg^{-1})

Significantly higher amount of manganese content was recorded in treatment that receives T_6: 100 per cent NP (25.50 mg kg^{-1}) followed by T_3: 150 per cent NPK (24.90 mg kg^{-1}). However, significantly lower value of manganese content was recorded in treatment that was not received with any inorganic or organic manures (T_{11}: 14.88 mg kg^{-1}).

Integrated application of inorganic fertilizers and FYM amended plots showed appreciable quantities of micronutrients in the soil. This might be due to the FYM containing appreciable quantities of micronutrients and contributing significantly to soil upon decomposition. Addition of high root biomass by continuous cropping of Finger millet - Maize also added sustainable micronutrients. Similar observations in long term fertilizer experiment were also recorded by Verma *et al*. (2012). The addition of organic materials to the soil may have increased microbial activity and hence the production of complex organic chemicals such as humic and fulvic acids, which function as chelating agents during the decomposition of organic manure and crop residue. This could have increased the solubility, mobility and availability of micronutrients by preventing precipitation, fixing, oxidation and leaching. Similar findings were reported by Ismail *et al*. (2002) and Kumar *et al*. (2008).

Different Fractions of Soil Organic Carbon

The data pertaining to the effect of long term manuring and fertilization on soil organic carbon fractions are presented in Table 5.

Wakley and Black Oxidizable Carbon (g kg^{-1})

Significantly higher OC values were recorded in T_{12} which is an uncultivated land (7.10 g kg^{-1}) followed by T_{10} receiving 100 per cent NPK + FYM + lime (6.60 g kg^{-1}) and T_8 with 100 per cent NPK + FYM (6.01 g kg^{-1}) over control (4.02 g kg^{-1}). Significantly lower values (4.02, 4.25 and 4.40 g kg^{-1}) were recorded in control (T_{11}) and the plots treated with imbalanced fertilizers *i.e.,*100 per cent N alone (T_7) and 100 per cent NP (T_6), respectively. Organic carbon content increased significantly with increased dose of fertilizer application from 4.75 g kg^{-1} (50% NPK) to 5.68 g kg^{-1} (150% NPK) which might be due to larger addition of root biomass in plots treated with inorganic fertilizer had a greater impact on the accumulation of soil organic carbon.

Organic carbon content was found lower in cultivated land compared to uncultivated land due to cultivation reduces the input of plant residues and cause higher soil disturbance (Bueno *et al*., 2009). In general, use

TABLE 5

Effect of long term manuring and fertilization on soil organic carbon fractions

Treatments	OC ($g\ kg^{-1}$)	MBC ($mg\ kg^{-1}$)	WSC ($mg\ kg^{-1}$)	POC ($g\ kg^{-1}$)	CHO C ($g\ kg^{-1}$)
T_1 : 50% NPK	4.75	236.90	48.00	2.00	0.78
T_2 : 100%NPK	5.31	257.95	50.80	2.50	0.89
T_3 : 150%NPK	5.68	258.51	53.20	3.80	0.94
T_4 : 100%NPK+ HW	5.10	251.22	48.40	2.10	0.73
T_5 : 100%NPK + lime	4.82	248.13	51.60	3.70	0.77
T_6 : 100%NP	4.40	216.97	47.20	1.80	0.57
T_7 : 100%N	4.25	205.18	45.20	1.30	0.58
T_8 : 100%NPK + FYM	6.01	262.16	63.20	4.10	0.78
T_9 : 100%NPK(S-free)	4.50	243.92	41.20	1.90	0.68
T_{10} : 100%NPK + FYM + lime	6.60	286.58	61.60	4.20	0.70
T_{11} : Control	4.02	195.92	44.80	1.60	0.59
T_{12} : Uncultivated soil	7.10	324.76	68.40	6.10	1.04
SEm±	0.03	8.81	1.48	0.32	0.06
CD @ 5 %	0.09	25.85	4.33	0.93	0.18

Note : OC: Organic carbon; MBC: Microbial biomass carbon; WSC: water soluble carbon; POC: particulate organic carbon; CHO C: carbohydrate carbon

of FYM alone or in combination with fertilizers, which resulted in higher biomass production and lowest carbon content in the control due to low organic matter as a result of no fertilizer and manure application (Babhulkar *et al*., 2000). Similar results were also reported by Varalakshmi *et al*. (2005) and Bhattacharyya *et al*. (2011).

Microbial Biomass Carbon ($mg\ kg^{-1}$)

Microbial biomass carbon (MBC) in soil under finger millet-maize cropping system was significantly higher in treatment T_{12}: Uncultivated land (324.76 $mg\ kg^{-1}$) followed by T_{10} receiving 100 per cent NPK + FYM + lime (286.53 $mg\ kg^{-1}$) and T_8 receiving 100 per cent NPK + FYM (262.16 $mg\ kg^{-1}$). The significantly lower content of microbial biomass carbon was recorded in T_{11}: control (195.92 $mg\ kg^{-1}$) and found on par with T_7: 100 per cent N (205.18 $mg\ kg^{-1}$) in soil over continuous cropping.

The higher MBC value due to the combined application of FYM and NPK fertilizer is attributable to a higher turnover of root biomass produced under the FYM + NPK treatment (Moharana *et al*., 2012). The significant decline in MBC in cultivated soils than uncultivated soil is due to agricultural use. The disturbance caused by cultivation changes the size, composition and activity of the microbial community (Angers *et al*., 1993). Low MBC in the control treatment is because of unfavourable environment arising out of depletion of nutrients due to continuous cropping without any fertilization (Majumder *et al*., 2007).

Water Soluble Carbon ($mg\ kg^{-1}$)

The water soluble carbon which is most labile form of carbon was found significantly higher in the uncultivated soil (T_{12}: 68.40 $mg\ kg^{-1}$) followed by treatment T_8 (63.20 $mg\ kg^{-1}$) which is on par with T_{10} (61.60 $mg\ kg^{-1}$) which has received FYM and FYM + lime, respectively, along with 100 per cent NPK. Significantly lowest water soluble carbon content was found in the treatment T_9 (41.20 $mg\ kg^{-1}$) which has received 100 per cent NPK (S-free Phosphatic fertilizer) which is on par with the treatments T_{11} (absolute control) followed by the treatment T_7 (received only nitrogenous fertilizer) with the values of 44.80 mg kg^{-1} and 45.20 mg kg^{-1}, respectively.

Water soluble organic C is composed of an array of molecules generally reflecting the composition of total SOC due to the soluble phase tending to be in equilibrium with the solid phase of SOC (Chantigny, 2003) and is regarded as an indicator of soil quality and functioning. Integrated application of inorganic fertilizer dose (100% NPK) either alone or in combination with FYM resulted in significant increase in WSC content compared to the control. Though, WSC represents less than 1 per cent of the total C in soil (Singh *et al*., 2003).

Particulate Organic Carbon (g kg^{-1})

Among the different treatments, significantly higher particulate organic carbon (POC) content *i.e.*, 6.10 g kg^{-1} was recorded in the uncultivated soil (T_{12}) followed by the treatment T_{10} (4.20 g kg^{-1}) which received FYM and lime along with 100 per cent NPK and it is on par with the treatment (T_8: 4.10 g kg^{-1}) received FYM + 100 per cent NPK. Particulate organic carbon content was significantly lower in T_7 (received only nitrogenous fertilizer) which is on par with the absolute control treatment (T_{11}) and the treatment T_6, received only nitrogenous and phosphatic fertilizer (1.30 g kg^{-1}, 1.60 g kg^{-1}, 1.80 g kg^{-1}, respectively).

Balanced fertilization and FYM application was most effective in increasing POC when compared with the use of chemical fertilizers alone. Particulate organic C is composed of crop residue as well as microbial and microfaunal debris and is often of recent origin. FYM can increase the root biomass and microbial biomass debris which is the main source of POC. The results were also in agreement with the findings of Rudrappa *et al*., 2006 and Nayak *et al*., 2012. Manure, NPK and Manure + NPK fertilizations increased the POC content and its contribution to TOC compared with control treatment. The control and inorganic alone resulted in the lowest levels of POC, because they produce the lowest biomass production as compared to the other treatments.

Carbohydrate Carbon(g kg^{-1})

Carbohydrate carbon was found to be significantly highest in T_{12} (1.04 g kg^{-1}: uncultivated soil) which is on par with the treatment (T_3: 0.94g kg^{-1}) receiving 150 per cent NPK and treatment T_2 (0.89 g kg^{-1}) receiving 100 per cent NPK when compared to treatments which received FYM along with inorganic fertilizers. Lower carbohydrate carbon content was found in the treatment T_6 (0.57 g kg^{-1}), T_7 (0.58 g kg^{-1}) and T_{11} (0.59 g kg^{-1}) which have received only NP, only P and no organic or inorganic fertilizers (absolute control), respectively.

Long term application of inorganic fertilizers along with organic manure had significantly higher carbohydrate carbon compared to rest of the treatments. This may be due to continuous application of nutrient source which influences crop yield which in turn adds to incorporation of root biomass. This is in accordance with findings of Manna *et al*. (2013). The application of 100 per cent NPK + lime also recorded lower carbohydrate carbon content over the treatment receiving 100 per cent NPK alone which might be due to enhanced oxidation of organic carbon due to lime, resulting in lower accumulation.

The concentration of different SOC fractions in soil were in the order of Wakley and Black's oxidizable carbon > particulate organic carbon > carbohydrate carbon > microbial biomass carbon > water soluble carbon.

Organic carbon fractions and various soil nutrient contents were found lower in cultivated soil compared to uncultivated soil because continuous cultivation reduces the input of plant residues and cause higher soil disturbance. Moreover, the small amount of plant residues present in cultivated soil undergoes an increased rate of decomposition and redistribution within soil as enhanced by frequent tillage. Among cultivated soil, different carbon fractions and nutrient levels recorded were highest in the treatments supplied with FYM along with 100 per cent NPK and lowest values were recorded in absolute control and in the treatments with imbalanced nutrient supply. Inorganic fertilizer plus organic manure with or without lime were the most efficient management system for sequestering SOC. Thus the present study indicates that integrated supply and balanced application of plant nutrients has a greater impact on improving soil fertility and different soil organic carbon fractions content.

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