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Influence of Long Term Fertilization on Yield and Active Pools of Soil Organic Carbon in an Typic Haplustepts under Groundnut-Wheat Cropping Sequence

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A B S T R A C T

The effect of integrated nutrient management (INM) on yields and active pools of soil organic carbon (SOC) under groundnut-wheat cropping sequence of a Haplustepts soil was studied in a long term field experiment initiated since 1999 at Junagadh, Gujarat. Effect on varying doses of N, NP, NPK, NPK with FYM, Zn, S and *Rhizobium* on yields and active pools of SOC viz., soil microbial biomass carbon (SMBC), soil microbial biomass nitrogen (SMBN), soil microbial biomass phosphorus (SMBP), water soluble carbon (WSC), water soluble carbohydrate (WS-CHO) and dehydrogenase activity (DHA) after 16 year of groundnut-wheat crop sequence was studied. The result revealed that application of 50 % NPK + FYM @ 10 t ha^{-1} to groundnut and 100 % NPK to wheat significantly increased the groundnut yield and wheat yield. The highest and significant increase active pools of soil organic carbon was also observed under combine application of 50% NPK + FYM @ 10 t ha^{-1} to groundnut and 100 % NPK to wheat. These results indicate that long-term integrated use of FYM with chemical fertilizers or use of FYM alone exerted significant effect on the active pools of soil organic carbon.

Introduction

Soil organic matter (SOM) plays a key role in the improvement of soil physical, chemical and biological properties. Conservation of the quantity and quality of soil organic matter (SOM) is considered a central component of sustainable soil management and maintenance of soil quality (Doran *et al.,* 1996). Organic manure and inorganic fertilizer are the most common materials applied in agricultural management to improve soil quality and crop productivity (Verma and Sharma, 2007). Many studies have shown that balanced application of inorganic fertilizers or organic manure plus inorganic fertilizers can increase SOC and maintain soil productivity. Soil organic carbon (SOC) is an important index of soil fertility because of its relationship to crop productivity (Vinther *et al.*, 2004; Pan *et al.*, 2009). For instance, declining SOC levels often leads to decreased crop productivity

(Lal, 2006). Thus, maintaining SOC level is essential for agricultural sustainability. The concept of sustainable agricultural production emphasizes the importance of SOC management for food security and environment protection (Pan *et al.*, 2009).

Plant residue is the primary source of SOM formation. The SOM is composed of series of fractions from very active and passive pools. These fractions act as highly sensitive indicators of soil fertility and productivity. In the sequence of humification process, first the decomposition products of the original plant residues are active fractions. The active fractions include soil microbial biomass; water soluble carbohydrates and it rarely comprise more than 10 to 20 % of total SOM (Smith and Paul, 1990). It provides most of the readily accessible food for the soil organisms. Microbial biomass and its activity are usually positively correlated with SOM due to a dependence on both the quantity and quality of degradable carbon sources. Microbial biomass represents a significant part of the active SOM pool (Schnurer *et al.*, 1985). The active fractions can be readily increased by the addition of fresh plant and animal residues, but they are also readily lost when such additions are reduced or tillage is intensified. Particularly, the presence of SOM is regarded as being critical for soil function and soil quality. Soil organic matter is one of our most important natural resources and from antiquity man has recognized that soil fertility may be maintained or improved by adding organic manures. Our objective was to study the changes of SOC fractions under a 16-year field experiment in Typic Haplustepts soil and to explain the relationship between different active pools of SOC fractions and crop yield. Improved understanding of active pools of soil organic carbon will provide valuable information for establishing sustainable fertilizer management systems to maintain and enhance soil quality.

Materials and Methods

Study site description

The AICRP LTFE was started in the year 1999 at Instructional Farm, College of Agriculture, Junagadh Agricultural University at Junagadh to study effect of continuous application of fertilizers (N, P, and K) and manure in a groundnut-wheat crop rotation.

In present work of LTFE soils, which was started 16 years back on *Typic Haplustepts* calcareous clay soil, there was addition of different amounts of major nutrients fertilizers, which changes in soil status in terms of major nutrients as well as soil organic carbon fraction content in soil.

The climate is tropical in Junagadh. The average annual temperature is 25.7 °C in Junagadh. Average annual rainfall is about 903 mm with 45 rainy days. About 91% of the annual rainfall is received during southwest monsoon season (June-September).

Soil description

The experiment soils are calcareous in nature derived from trap basalt, lime stone and sand stone under semi-arid climate. Taxonomically, the soil is classified as *Haplustepts*. The soil is dominated by smectite group of clay minerals, which give rise to mild cracking in dry season, due to which it is further classified as Typic Haplustepts at sub group level.

The experimental soils was calcareous ($CaCO_3$- 42.2 %) in nature, alkaline in reaction (pH 8.2), free from salinity ($EC_{2.5}$- 0.19 dS m^{-1}), had CEC 27.3 cmol (p+) kg and clayey in texture. From fertility point of views, it was medium in available nitrogen (271.23 kg ha^{-1}), low in available phosphorus (P_2O_5-25.51 kg ha^{-1}) but high in available potassium (K_2O-363.57 kg ha^{-1}).

Treatments

The long-term experiment included twelve fertilization treatments and each treatment had four replicates were arranged in a randomized block design. All plots were continuously under groundnut - wheat rotation from the beginning of the experiment.

The twelve treatments were T_1- 50 % NPK of recommended doses in Groundnut-wheat sequence, T_2- 100 % N P K of recommended doses in Groundnut -wheat sequence, T_3 -150 %N P K of recommended doses in Groundnut -wheat sequence, T_4 - 100 % N P K of recommended doses in Groundnut –wheat sequence + $ZnSO_4$ @ 50 kg ha^{-1} once in three year to Groundnut only (*i.e.* 99, 02, 05 *etc*.), T_5 - N P K as per soil test, T_6 - 100 % N P of recommended doses in Groundnut –wheat sequence, T_7 - 100 % N of recommended doses in Groundnut -wheat sequence, T_8 - 50 % N P K of recommended doses+ FYM @ 10 t ha^{-1} to Groundnut and 100 % N P K to wheat, T_9 - Only FYM @ 25 t ha^{-1} to Groundnut only, T_{10} - 50 % N P K of recommended doses + *Rhizobium* + PSM to Groundnut and100 % N P K to wheat, T_{11} - 100 % N P K of recommended doses in Groundnut -wheat sequence (P as SSP) and T_{12} –Control.

Soil sampling and analysis

In the experiment, groundnut crop was grown during *kharif* 1999-2000 and wheat crop was grown during *rabi* 1999-2000. The soil samples were collected during three periods (1^{st} and 16^{th}years), initial year (1999- before Groundnut) and 16^{th}year (2015- after Wheat).

For the present study, soil samples were collected after harvest of wheat crop with the help of tube auger from the each plot of the above mentioned treatments representing the plough layer (20 cm). These soil samples were cleaned and air-dried. The soil samples, after air-drying, were ground with wooden mortar and pestle to pass through a 2 mm plastic sieve. The bulk soil samples were stored in polyethylene bags for chemical analysis.

The soil samples were analyzed for determining the active fraction of organic carbon on the basis of method mentioned below.

Organic carbon

Organic carbon was determined by wet oxidation method (Walkley and Black, 1935).

Soil microbial biomass carbon

Soil microbial biomass carbon was determined by chloroform-fumigation incubation method (Jenkinson and Powlson, 1976; Jenkinson and Ladd, 1981)

Soil microbial biomass nitrogen

Soil microbial biomass nitrogen was determined by chloroform-fumigation extraction method (Brookes *et al.*, 1985)

Soil microbial biomass phosphorous

Soil microbial biomass phosphorous was determined by chloroform- fumigation incubation method (Brookes *et al.*, 1982; Srivastava and Singh, 1988)

Water soluble carbon

Water soluble carbon was determined by acid extraction method (Meloon and Sommcr's, 1996)

Water soluble carbohydrates

Water soluble carbohydrates were determined by hydralytic extraction with H_2SO_4 (Chebire and Mundie, 1966)

Soil dehydrogenase activity

Soil dehydrogenase activity was determined by anthrone extraction method (Casida *et al.,* 1964)

Statistical analysis

All the analytical data recorded during the course of investigation were subjected to statistical analysis by using Randomized Block Design. Statistical analysis was completed using the SPSS 16.0 software package for Windows. Statistically significant differences were identified using analysis of variance ANOVA. As per the method outlined by Panse and Sukhatme (1985), the value of test at 5 and 1 per cent level of significant was determine and the values of SEm, CV per cent also calculate. The pooled analysis of two cycles of data was carried out as per procedure suggested by Cochran and Cox (1967).

Results and Discussion

Groundnut pod yield

The pod yield of groundnut were significantly influenced by various treatments in 16th years result and maximum values of pod yield (1146.75 kg ha^{-1}) were recorded under application of 50 % NPK of RDF + FYM @ 10 t ha^{-1} to groundnut-wheat sequence & 100% NPK to wheat (T_8) followed by (1046.75 kg ha^{-1}) FYM @ 25 t.ha^{-1} to groundnut only (T_9). The pod yield of groundnut were not influenced significantly by various treatments of experiment, in 1st year but numerically higher pod yield was recorded under T_6 treatment (100 % NP of recommended dose of Groundnut-Wheat sequence) in 1st year (Table 1). This finding result was support from the work of Redda and Kebede (2017) who observed that increased crop yield with combine application of FYM @ 9 t ha^{-1} and 75 kg ha^{-1} inorganic fertilizer. Vala *et al.,* (2017) also reported that the yield of groundnut was significantly increased with combine application of organic and inorganic fertilizers. Similarly Bhattacharyya *et al.,* (2015) found that the crop yield was increased significantly by 74 % over the control under the combined application of FYM + NPK.

Groundnut haulm yield

The haulm yields of groundnut were significantly influenced by various treatments in 16th years result and maximum haulm yield (2614.66 and 2037.25 kg ha^{-1}) were recorded under 50 % NPK of RDF + FYM @ 10 t ha^{-1} to groundnut-wheat sequence and 100 % NPK to wheat (T_8) and this treatment also statistically at par with T_2, T_3, T_4 and T_9 treatment respectively. The haulm yield of groundnut did not influenced significantly by various treatments of experiment, in 1st year, but numerically higher haulm yield was recorded under T_2 treatment. Balaguravaih *et al.,* (2005) reported that influence of long-term use of inorganic and organic manures increased sustainable production of groundnut yield. Similar Das *et al.,* (2011) reported that FYM application @ 15 t ha^{-1} along with 100 % NPK fertilizers and optimal dose of NPK (100 %) along with Zn produced maximum yields in comparison to alone application of NPK fertilizers.

Wheat grain yield

The grain yields of wheat were significantly affected by various fertilization treatments of LTFE experiment in 1st year as well as in 16 years. Significantly maximum values of grain yield (3407 kg ha^{-1}) were obtained under treatment of 50 % NPK of RDF + FYM @ 10 t ha^{-1} to groundnut-wheat sequence & 100% NPK to wheat (T_8) and this treatment was at par (3309.50 kg ha^{-1}) with FYM @ 25 t ha^{-1} to groundnut only (T_9) during 16th year, whereas significantly the higher grain yield of 1908.50 kg ha^{-1} was recorded under T_2 treatment (100 % NPK of RDF) and it was at par with T_3, T_4, T_5, T_6, T_8 and T_{11} treatment in first year results (Table 1). Verma *et al.,* (2012) also reported similar results that the use of FYM along with 100 % NPK increased crop productivity. The overall wheat grain yield increased after 16 year of experimentation compare to initial year. Rawal *et al.,* (2015) observed that wheat grain yields were consistently higher in the NPK and FYM treatments than in treatments, where one or more nutrients were lacking. This result was also supported by Singh *et al.,* (2017) who reported that highest productivity of wheat was recorded in the treatment comprising 100 % NPK + FYM in long term fertilizers experiment.

Wheat straw yield

The significantly higher straw yields (3911 and 4406 kg ha^{-1}) were registered with T_8 treatment (50 % NPK of RDF + FYM @ 10 t ha^{-1} to groundnut-wheat sequence & 100% NPK to wheat) during 16th year, respectively and this treatment was statistically at par with T_9 treatment (FYM @ 25 t.ha^{-1} to groundnut only) during 16th year. Whereas significantly higher straw yield (3090 kg ha^{-1}) was recorded with T_2 treatment which was at par with T_3, T_4, T_5, T_6, T_8 and T_{11} during 1st year (Table 1). The results corroborate the finding of Ravankar *et al.,* (2004) who reported that the highest yield of wheat were recorded by 100 % NPK with 10 tonnes FYM ha^{-1} and the lowest under control. Sarawad and Sing (2004) was also reported that significant higher yield was observed under plots treated with 100 % NPK + FYM than others. Similarly result was also found by Brar *et al.,* (2015) who reported that continuous cropping and integrated use of organic and inorganic fertilizers increased soil C sequestration and crop yields.

Organic Carbon (O. C.)

The organic carbon was significantly affected by difference INM treatment in 16th year and it was recorded higher under application of FYM @ 25 t/ha to groundnut only (T_9) followed by 50 % NPK of RDF + FYM @ 10 t ha^{-1} to groundnut-wheat sequence and 100% NPK to wheat (T_8). In long term, there seems to be an increase in soil organic carbon after 16th year experimentation (Table 2). This result is corroborated with the finding of Reddy *et al.,* (2017) who reported that among the various treatment continuous use of farm yard manure with 100 % NPK treatment resulted in highest organic carbon content in soil compared to other treatments. There was overall increased in organic carbon status of LTFE soils after 16th year as compared to initial status (1st year). In 1st year the non-significantly higher value of organic carbon was observed under 50 % NPK of RDF in Groundnut-Wheat sequence (T_1) treatment followed by T_6 (150 % NPK of RDF in Groundnut-Wheat sequence).

Pant *et al.,* (2017) reported that long-term combine application of 100 % NPK and FYM increased the organic carbon content in soil after crop harvest. The FYM application improved soil physical condition, ultimately root growth increases and more biomass added to the soil, seems to increases organic carbon status of the particular soil.

Soil microbial biomass carbon

With respect to status of SMBC, during 2000 and 2016, with treatment T_8 (50 % NPK of recommended doses in Groundnut -Wheat sequence + FYM @ 10 t ha^{-1} to Groundnut and 100 % NPK to Wheat) showed the significantly higher value of SMBC (Table 3). In 1st year result it is at par with T_5 (NPK as per soil test) and T_9 (FYM @ 25 t ha^{-1} to Groundnut only).

Table.1 Influence of different treatment on groundnut and wheat yield in 1st year and 16th year of LTFE soils

Treatment	Groundnut Yield (kg ha^{-1})				Wheat Yield (kg ha^{-1})			
	Pod Yield		Haulm Yield		Grain Yield		Straw Yield	
	1st year	16th year	1st year	16th year	1st year	16th Year	1st year	16th year
T_1	962.00	816.25	1790.50	1640.75	1589.00	2093.00	2696.75	2802.50
T_2	984.75	941.50	2018.25	1781.00	1908.50	2758.50	3090.25	3526.75
T_3	916.25	1012.75	1758.00	1960.50	1878.50	2893.00	2847.25	3728.75
T_4	1048.00	951.50	1985.75	1969.75	1806.50	2694.50	2650.25	3419.25
T_5	929.25	928.50	1676.50	1757.50	1856.50	2720.25	2819.50	3434.75
T_6	1101.75	735.50	1969.50	1610.75	1718.75	2426.00	2696.75	2992.50
T_7	927.50	622.00	1693.00	1370.00	1111.00	1562.50	1921.25	2056.75
T_8	916.25	1146.75	1888.00	2037.25	1898.25	3407.00	2766.00	4406.25
T_9	875.75	1046.75	1693.00	1873.50	1289.25	3309.50	2141.25	3966.75
T_{10}	963.50	856.00	2002.00	1709.00	1419.00	2566.50	2581.00	3307.50
T_{11}	1017.25	918.50	1871.50	1735.00	1608.75	2752.50	2963.00	3494.25
T_{12}	968.25	709.75	1725.50	1400.25	1309.25	1678.75	2072.00	2231.25
MEAN	967.54	890.48	1839.29	1737.10	1616.10	2571.83	2603.77	3280.60
S.Em.±	74.12	46.13	131.39	90.22	107.36	132.29	155.89	176.34
C.D. at 5 %	NS	132.73	NS	259.58	309.12	380.62	448.86	507.37
C.V. %	15.32	10.36	14.29	10.39	13.29	10.29	11.97	10.75

Table.2 Influence of different treatment on status of organic carbon in 1st and 16th year of LTFE soils

Treatment	Organic Carbon (%)	
	1st year	16th year
T_1	0.615	0.621
T_2	0.548	0.677
T_3	0.510	0.668
T_4	0.555	0.684
T_5	0.525	0.670
T_6	0.600	0.621
T_7	0.510	0.631
T_8	0.563	0.758
T_9	0.525	0.790
T_{10}	0.563	0.649
T_{11}	0.563	0.667
T_{12}	0.540	0.631
MEAN	0.551	0.672
S.Em.±	0.048	0.015
C.D. at 5 %	NS	0.044
C.V. %	17.240	4.550

Table.3 Influence of different treatment on status of soil microbial biomass carbon, soil microbial biomass nitrogen and soil microbial biomass phosphorus in 1st and 16th year of LTFE soils

Treatment	SMBC (mg kg^{-1})		SMBN (mg kg^{-1})		SMBP (mg kg^{-1})	
	1st year	16th year	1st year	16th year	1st year	16th year
T_1	87.72	122.52	6.70	10.27	12.53	10.54
T_2	104.84	144.65	6.96	11.86	11.30	10.63
T_3	101.02	227.91	7.04	12.51	14.42	11.03
T_4	100.80	181.98	7.88	12.83	12.90	10.38
T_5	232.51	218.29	8.00	11.84	10.10	9.68
T_6	184.33	209.48	6.95	10.23	11.72	9.33
T_7	180.50	193.93	8.18	11.30	14.31	8.98
T_8	243.01	268.68	10.18	17.17	16.82	12.07
T_9	222.32	244.71	8.85	15.42	15.00	11.74
T_{10}	196.30	222.33	7.08	12.13	14.02	11.21
T_{11}	124.32	188.39	7.88	11.07	14.22	10.73
T_{12}	86.50	112.26	6.40	9.63	8.51	7.51
MEAN	155.35	194.59	7.67	12.19	12.99	10.32
S.Em.±	9.45	7.68	0.40	0.59	0.47	0.46
C.D. at 5 %	27.20	22.08	1.14	1.70	1.35	1.32
C.V. %	12.17	7.89	10.36	9.69	7.23	8.89

Table.4 Influence of different treatment on status of water soluble carbon, water soluble carbohydrate and dehydrogenase activity in 1st and 16th year of LTFE soils

Treatment	WSC (mg kg^{-1})		WS-CHO (mg kg^{-1})		DHA (µg TPF^{-1} 24 hr^{-1} g^{-1} soil)	
	1st year	16th year	1st year	16th year	1st year	16th year
T_1	24.00	33.75	36.50	43.25	36.50	32.25
T_2	30.00	38.25	37.50	45.00	42.50	41.25
T_3	38.00	41.00	38.50	44.50	30.00	33.75
T_4	34.75	42.00	31.50	41.00	46.50	35.50
T_5	29.50	40.75	41.50	45.50	33.50	38.00
T_6	34.50	38.25	40.50	47.50	38.25	33.75
T_7	36.50	39.25	33.50	40.25	46.50	35.50
T_8	44.50	52.50	46.50	54.25	52.50	44.25
T_9	40.50	47.50	42.50	50.50	49.50	42.75
T_{10}	21.50	33.75	27.50	37.00	31.50	32.75
T_{11}	28.50	35.75	41.00	44.25	40.50	33.75
T_{12}	20.50	28.50	26.50	34.00	29.50	27.25
MEAN	31.90	39.27	36.96	43.92	39.77	35.90
S.Em.±	0.90	1.11	1.38	1.26	2.30	2.26
C.D. at 5 %	2.58	3.19	3.98	3.62	6.61	6.51
C.V. %	5.62	5.65	7.48	5.74	11.56	12.6

Soil and crop management practices can greatly influences soil biological activity through their effect on quantity and quality of organic carbon added to soil. Use of FYM alone or in combination with chemical fertilizers significantly increased soil microbial biomass carbon (SMBC). There was overall increase in SMBC status of soil after 16 years as compared to initial status. Khan and Wani (2017) reported that significant build-up of soil microbial biomass carbon (SMBC) were maintained under FYM and integrated nutrient management involving FYM and NPK than unfertilized control plot in 0-15 and 15-30 cm soil depths. Similar results were also found by Verma and Mathur (2007). The supply of additional mineralizable and readily hydrolysable C due to organic manure application resulted in higher microbial activity and higher SMBC. It indicated that manure addition resulted in higher SMBC than inorganic fertilization or no fertilization (Control). The availability of soil microbial biomass carbon were significantly increased with the integrated application of organic manure (FYM @ 10 t ha^{-1}) and mineral fertilizers (100 % NPK) over control and other fertilizer treatment Katkar *et al.,* (2011).

Soil microbial biomass nitrogen

The soil microbial biomass nitrogen content of soils showed significant difference in the years 2000 and 2016 (Table 3) with application of different INM treatment. The treatment T_8 (50 % NPK of recommended doses in Groundnut -Wheat sequence + FYM @ 10 t ha^{-1} to Groundnut and 100 % NPK to Wheat.) showed significantly higher value of SMBN in the year 2000 and 2016. High soil carbon content, more root proliferation and additional supply of N by FYM to microorganism might be responsible for increasing the level of SMBN. Kumari *et al.,* (2011) also reported that continuous application of organic manure alone or in combination with inorganic fertilizer significantly influenced the soil microbial biomass nitrogen. FYM is not only rich in C but also in N and other macro and micronutrients. But the availability of nutrients to the crop from FYM is generally lower than N from inorganic fertilizer because of the slow release of organically bound N and volatilization of NH_3 from the manure especially in calcareous soil (Beauchamp, 1983). Therefore, a combined application of FYM and fertilizer in the present study apparently provided supply of nutrients in balanced proportion which was reflected in terms of increased amounts of microbial biomass N. Other alternate amendments, *viz.,* $ZnSO_4$ fertilizer application produced similar effect on microbial biomass N as that of NPK. In control, there was reduction in biomass N from that observed with optimal NPK for both crops (groundnut and wheat). With increase in fertilizer level from 100 to 150 % there was a significant increase in biomass N over control. There was overall increase in SMBN status of soil after 16 years as compared to initial status. Because the SMBN was influence by added N through organic and in organic fertilizers as its produce large quantity of crop residues which provided available substrate for maintains of larger SMBN during the growing season (Salinas *et al.,* 1997). Kaur *et al.,* (2008) also observed that soil microbial biomass nitrogen was increased with an application of NPK and NPK + FYM than others treatment.

Soil microbial biomass phosphorus

The soil microbial biomass phosphorus content in soils of different treatments showed significant difference under the LTFE in the years 2000 and 2016 (Table 3). The results revealed that the treatment T_8 (50 % N P K of recommended doses in Groundnut -Wheat sequence + FYM @ 10 t ha^{-1} Groundnut and

100 % N P K to Wheat.) registered significantly higher value of SMBP (16.8 mg kg^{-1}) in year 2000. Similarly the same treatment T_8 showed significantly higher values (12.07 mg kg^{-1}) of SMBP in year 2016 and it was at par with T_9, T_{10} and T_3 treatment. There was overall decrease in SMBP status of soil after 16 years as compared to initial status. The continuous application of chemical fertilizers either alone or in combination with FYM increased the soil microbial biomass phosphorus (SMBP) content as compared to zero fertilized plots. Integrated use of organic and inorganic significantly increased the crop productivity and thereby provided substrates essential for microbial growth and activity which are probably responsible for this increase in SMBP. The low content in control plot could be due to no addition of any external input into the soil over the years and thereby poor crop productivity. Low content of SMBP in 100 % N alone was observed. Reason attributed is the reduction of microbial cells due to absence of any phosphate substrate. The addition of higher levels of phosphorus through external source might have influenced the metabolism of microorganisms, which is probably responsible for higher levels of SMBP. Similar elevation in SMBP with the application of super-optimal dose of NPK and the rise in content of SMBP were also reported by Santhy *et al.,* (2004). The result finding was also corroborated with Kumari *et al.,* (2011) who observed that continuous application of organic manure alone or in combination with inorganic fertilizer significantly influenced the soil microbial biomass phosphorus.

Water Soluble Carbon (WSC)

Water soluble carbon (WSC) increased year wise irrespective of the treatments (Table 4). The results showed that the treatment T_8 (50 % NPK of recommended doses in Groundnut -Wheat sequence + FYM @ 10 t ha^{-1} Groundnut and 100 % NPK to Wheat) registered significantly higher (44.50 and 52.50 mg kg^{-1}) WSC during 2000 and 2016 respectively followed by treatment T_9 (FYM @ 25 t ha^{-1} to Groundnut only). There was overall increase in WSC status of soil after 16 years as compared to initial status. Of course, this built-up was after many years as a result of large amount of clay particles enriched with water soluble carbon through addition of FYM and chemical fertilizers (Liang *et al.,* 1995).

Highest water soluble carbon was observed in treatment receiving FYM alone followed by treatment with continuous addition of FYM in association with 100 % NPK fertilizers, whereas the lowest content was found in controlled treatment in both the crop. The newly humified organic carbon through FYM addition might have sustained higher amount of WSC in sole FYM treatment, whereas higher amount of water soluble carbon in the T_8 treatment (50 % NPK + FYM @ 10 t ha^{-1} to groundnut and 100 % NPK to wheat) might be due to its origin and root exudates and lysates and its presence in soil solution.

The results are in agreement with Yagi *et al.,* (2005) who attributed the same to the priming effect of the application of inorganic N or fresh organic material to the soil which stimulates the microbial activity and mineralization of N forms present in SOC helping thereby in decomposition of SOC with rapid release of WSC fraction.

This finding was also supported by Singh *et al.,* (2003) who reported that the application of 100 % NPK + FYM for about twenty eight years increased water soluble carbon by about 32 to 41 % compared to the plot receiving only 100 % NPK. Thus balance fertilization favored enrichment of water soluble carbon.

Water soluble carbohydrates

The significant higher value of WSC as 46.50 and 54.25 mg kg^{-1} were registered with T_8 treatment (50 % NPK of recommended doses in groundnut -wheat sequence + FYM @ 10 t ha^{-1} Groundnut and 100 % NPK to Wheat) during 2000 and 2016 respectively (Table 4). Water soluble carbohydrates serves as source and sink for mineral nutrients and organic substrates in a short – term and as a catalyst for conversion of plant nutrients from over a longer period and therefore influence crop productivity and nutrient cycling (Kumari *et al.,* 2011). There was overall increase in water soluble carbohydrate status of soil after 16 year as compared to initial status. The higher water soluble carbohydrate was observed in treatment which received FYM with mineral fertilizers in all span of LTFE experiment. This finding also corroborated with Mishra *et al.,* (2008) who reported that continuous organic manure application or in combination with inorganic fertilizer, significantly influenced water soluble carbohydrates over 100 % NPK and control.

Dehydrogenase activity

During 2000, treatment T_8 (50 % NPK of recommended doses in Groundnut -Wheat sequence + FYM @ 10 t ha^{-1} Groundnut and 100 % NPK to Wheat) registered significantly higher value of dehydrogenase activity and it was at par with T_4, T_7 and T_9 treatment. In case of the year during 2016, treatment T_8 showed higher value of dehydrogenase activity and it was at par with T_9, T_2 and T_5 treatment (Table 4). The addition of farmyard manure couple with mineral fertilization exerted a stimulating influence on preponderance of bacteria (Selvi *et al.*, 2004). Similar result was found by Kaur *et al.,* (2008) who observed that continuous application of fertilizers increased dehydrogenase activity significantly with an application of NPK and NPK + FYM than others treatment. The application of N fertilizers half as well as full doze although affect the dehydrogenase activity because of activity is strongly influenced by the presence of nitrate, which serves as an alternative electron acceptor resulting in low activity (Sneh *et al.,* 1998). The dehydrogenase activity is increase with increasing level of mineral fertilizer doses from 50 to 150 NPK. The increase in DHA was 18.6 % due to INM over 100% NPK through mineral fertilizers. The results are in line with the findings reported by Bhattacharyya *et al.,* (2008), whereas the dehydrogenase activity increases 4-5 folds due to FYM application along with NPK. This result also supported by Katkar *et al.,* (2011) who reported that the availability of dehydrogenase activity were significantly increased with the integrated application of organic manure (FYM @ 10 tones ha^{-1}) and mineral fertilizers (100 % NPK) over control and other fertilizer treatment.

The result of present investigation showed that combine application of mineral fertilizers with FYM maintain soil organic carbon level in soil, crop yield and showed significant higher values as compare to control. However significant higher values of organic carbon status and crop yields were observed with application of 50 % NPK + FYM @ 10 t ha^{-1} than other treatment. Integrated use of mineral fertilizers along with FYM significantly increased active pools of soil organic carbon and yield of groundnut and wheat as compare to unfertilized control and the initial values. The addition of NPK with FYM increased active fraction of organic carbon *viz*. SMBC, SMBN, SMBP, WSC, WS-CHO, DHA and yields of both groundnut and wheat under long term fertilization. Thus, NPK + FYM were the best option for increasing organic carbon status in soil and enhance crop yields. These results conclude that for sustainable crop production and maintaining soil quality, input of organic manure like FYM is of major importance and should be advocated in the nutrient management of intensive cropping system for improving soil fertility and biological properties of soils.

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