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Long-term Fertility Management Effect on Soil Carbon Fractions under Godavari Zone

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Long-term fertilizer experiments provide the best possible means of studying changes in soil properties and processes for identifying the emerging needs in nutrient imbalances and deficiencies to formulate future strategies for maintaining soil health. A long-term experiment was conducted in Godavari Alluvials at Andhra Pradesh Rice Research Institute, Maruteru in Andhra Pradesh located at 81º44′ E longitude, 16º37′ N latitude and 5 m above mean sea level. In *kharif* the highest organic carbon (OC) content (1.70%) was noticed in the treatment T_6 receiving 50% recommended dose of nitrogen (RDN) + 50% N through FYM followed by T_3 (FYM @ 10 t ha^{-1}) and T_5 (50% RDN + 50% N through green leaf manure (*Calotropis* spp.) with 1.69 and 1.65% of OC, respectively. All the treatments showed higher organic carbon content (recorded in 2016) than the initial value (0.55%) which was recorded at the initiation of the experiment in 1989. Similar trends were observed in *rabi* with soil organic carbon content varying from 0.53 to 1.88%. The highest soil microbial biomass carbon (523.7 mg kg^{-1}) was observed in T_4 (100% RDF + FYM @ 5 t ha^{-1}) followed by T_6, T_7, T_5 and T_8 treatments with SMBC of 482.6, 476.2, 434.8 and 413.4 mg kg^{-1}, respectively. The highest mineralizable carbon (1218 & 1235 mg CO_2-C kg^{-1} in *kharif* and *rabi*, respectively) was recorded in T_4 (100% RDF + FYM @ 5 t ha^{-1}). These results suggest that long-term application of organic manures alone or in combination with RDF has resulted in the buildup of soil organic carbon content even under tropical climates. The soils were rich in clay content (Godavari Zone) and there was relatively higher soil organic carbon content. Further, the addition of organic manures improved the macro aggregates and carbon storage inside the aggregates which was protected from decomposition.

(***Key words:*** *Carbon stocks, Godavari Zone, Mineralizable carbon, Rice-rice cropping system, Soil organic and inorganic carbon, Soil microbial biomass carbon*)

Acidification, alkalinity, salinity, imbalanced fertilizer use, and declining organic matter content contributes to reduction in soil fertility causing soil degradation. External factors like atmospheric pollution and climate change have an impact on these processes. With the treatment of primary, secondary, and micronutrient deficiencies, boosting the efficacy of applied nutrients, and creating a favourable soil physical environment, integrated use of fertilizers along with organic manures aid in maintaining yield stability. It's been shown that integrated nutrient management (INM) in cropping systems has been demonstrated to be more effective than individual crops due to residual effects, notably nitrogen impacts. The best way to examine changes in soil properties, accumulation or depletion of soil organic carbon under integrated nutrient management (INM) practices, and understand their dynamics under different cropping systems is through long-term fertilizer experiments. These practices not only stop soil deterioration but also enable sustainable management of soil organic carbon.

By capturing atmospheric carbon through various management techniques, such as the use of crop rotation (Wright and Hons, 2005), a combination of inorganic

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fertilizers and organic amendments (Majumdar *et al.,* 2008), and appropriate tillage techniques, soil organic carbon stores need to be enhanced (Lal, 2009). It is well recognized that organic carbon pools have an impact on the physical, chemical, and biological characteristics of soil. By modifications to soil structure, porosity, compaction, aggregation, and ease of root formation, organic carbon has an impact on the physical qualities of soil. It is essential for the recycling of the nutrients N, P, S and Zn. The population and species variety of macro flora and microflora, soil microbial biomass carbon (SMBC), and microbial activities resulting in the transformation of soil biomass and chemical detoxification are all influenced by soil organic carbon. Keeping the above points in view, a field experiment was conducted to know the magnitude of soil organic carbon fractions and carbon sequestration rate under the influence of a long-term fertilizer experiment.

MATERIALS AND METHODS

The rice-rice cropping system was initiated during the 1989 *kharif* season at Andhra Pradesh Rice Research Institute in Maruteru, Andhra Pradesh, India located at 81º44′ E longitude, 16º37′ N latitude and 5 m above mean sea level. A total of 17.50 lakh ha of cultivated area is located in the Godavari zone, which includes the East and West Godavari regions. At the time of crop growth period during July to March, (both *kharif* and *rabi* seasons of 2016) the mean maximum and minimum temperatures were 30.5°C and 23.1°C, respectively. An overall of rainfall 1319 mm was received during the crop growth period. Soils of deltaic alluvium, red soils with clay, red loams, coastal sands and saline soils are found in this zone. The experimental field had sand, silt, and clay contents of 43, 26 and 31%, correspondingly with a clay loam texture.

Composite soil samples were drawn from 0-15 cm depth at harvest of both kharif and sabi seasons in the year 2016. After air drying in the shade, the soil was pounded, sieved through a 2 mm sieve and stored in neatly labelled polythene bags for soil analysis for different parameters by adopting standard methods. The soil inorganic carbon (SIC) was determined by rapid titration method as described by Richards (1954), soil organic carbon (SOC) by wet oxidation method (Walkley and Black, 1934); Soil microbial biomass carbon (SMBC) by fumigation extraction method (Witt *et al.,* 2000), labile carbon by potassium permanganate oxidation method (Blair *et al.,* 1995; Weil *et al.,* 2003). Mineralizable carbon was measured by incubating a sample of field moist soil in a sealed chamber containing an alkali trap. The CO_2-C accumulated in the trap was measured by acid titration (Franzluebbers, 1999). Calculation of SOC stock was done by multiplying OC content (g g^{-1}), bulk density (Mg m^{-3}) and thickness (m) of surface soil. The bulk density of the soil was 1.35 Mg m^{-3}

SOC stock in soils (Mg ha^{-1}) = OC content × BD × Soil depth

Similarly, for the SIC the calculation was made using 12% C values of $CaCO_3$ percentage. The sum of SOC + SIC gives the total carbon (TC) content for a particular soil depth which can be expressed in Mg ha^{-1}. This experiment was carried out in a randomized block design with eight treatments and three replications. The treatment details in both kharif and rabi were as follows:

T_1 – Control (No fertilizer)

T_2 - 100% Recommended fertilizer dose (RDF) (NPK @ 120-60-40 kg ha^{-1}) + $ZnSO_4$ @ 40 kg ha^{-1}

T_3 - FYM @ 10 t ha^{-1}

T_4 - 100% RDF + FYM @ 5 t ha^{-1}

T_5 - 50% Recommended dose of nitrogen (RDN) + 50% N through green leaf manure (*Calotropis* spp @ 2.8 t ha^{-1})

T_6 - 50% RDN + 50 % N through FYM @ 6.4 t ha^{-1}

T_7 - 50% RDN + 25 % N through green leaf manure (*Calotropis* spp @ 1.9 t ha^{-1}) + 25% N as FYM @ 3.2 t ha^{-1}

T_8 - 50 % RDN + *Azospirillum* @ 2.5 kg ha^{-1}

The experimental field was tilled with a tractor-drawn disc plough. Around 15 days prior to transplanting, irrigation water was applied to the field, and power tiller puddles were then created. A wooden plank was used to level the ground after the last puddling. The plots were set up according to the experimental design and the field was surrounded by irrigation and drainage canals. All the plots were ploughed separately according to the treatments. The rice seedling of variety

MTU-1061 was raised; 25 days old seedlings were transplanted manually at 20 × 10 cm spacing. The suggested amount of fertilizer was applied as urea (46% nitrogen), diammonium phosphate (18% nitrogen and 46% phosphorus), muriate of potash (60% potassium oxide), and zinc sulphate ($ZnSO_4.7H_2O$) @ 40 kg ha^{-1}. Recommended doses of P and K were also applied to the treatments from T_5 to T_8. Organic manures were applied two weeks before transplanting. Addition of FYM and *Azospirillum* was done as per the treatments. An application of the *Azospirillum* mixture was made one week after transplanting. Until the crop reached maturity, the water level was maintained at a depth of 2 cm during the vegetative stage and 5 cm during the reproductive stage. At the point of physiological maturity, when about 95% of the grains had turned golden colour, harvesting was carried out.

RESULTS AND DISCUSSION

The results pertaining to carbon fractions and carbon stocks in the soils of Godavari zone as influenced by different long term fertilizer experimental treatments are presented in Tables 1 and 2.

Soil organic carbon

The SOC content ranged from 0.58 to 1.70 % at the harvest of *kharif* rice crop (Table 1). All the treatments showed higher organic carbon content than the initial value (0.55%). The maximum SOC of 1.70% was noticed in the treatment getting 50% RDN + 50% N through FYM (T_6). Similar trends were noticed in *rabi* rice with the highest organic carbon content of 1.88% in the treatment receiving 50% RDN + 50% N through FYM followed by T_3 (FYM @ 10 t ha^{-1}). The lowest (0.53%) SOC was observed in T_1 (control). Using organic amendments like rice straw, FYM and green manure crops are known to enhance soil productivity in rice-wheat cropping (Nazir *et al.,* 2021; Ranjan *et al.,* 2023) and also add to organic carbon content in soil. The increase in root biomass is the cause of the observed changes, as evidenced by the significant increase in soil organic carbon following the incorporation of FYM (Martani *et al.,* 2023).

Soil microbial biomass carbon

The T_4 (100% RDF + FYM @ 5 t ha^{-1}) crop had the greatest SMBC, measuring 523.7 and 531.7 mg kg^{-1} in both *kharif* and *rabi*, respectively. In contrast to all INM treatments, T_4 had a substantial impact on the SMBC content (Table 1). Control had the minimum SMBC concentration (180.9 mg kg^{-1}). The application of mineral fertilizer in combination with organic manures serves as a nutrition source and energy (Mi *et al.,* 2022). Mineral fertilizers were added along with FYM, which increased microbial growth. This may be explained by the soil's microbial population having sufficient access to both C and N. The integrated use of organic manure and mineral fertilizers leads to higher microbial biomass carbon in soil over the sole application as observed by Srinivas *et al.* (2015).

Potassium permanganate carbon (Labile carbon)

At the time of kharif rice crop harvest, the $KMnO_4$ carbon content varied from 210.4 to 497.4 mg kg^{-1}. The highest labile carbon content (497.4 mg kg^{-1}) was noticed in T_4 *i.e.*, 100% RDF + FYM @ 5 t ha^{-1} followed by T_6 (50% RDN + 50% N through FYM) and T_7 (50% RDN + 25% N through green leaf manure + 25% N through FYM) treatments with active carbon content of 478.6 and 463.6 mg kg^{-1}, respectively. However, T_4 was on par with T_6 and T_7 but significantly better than T_2, T_3, T_5 and T_6 (Table 1).

Similar to this, the labile carbon content in soil after the *rabi* crop at harvest varied from 225.4 to 482.4 mg kg^{-1}. The treatments T_4 (100% RDF + FYM @ 5 t ha^{-1}), T_6 (50% RDN + 50% N through FYM), had the highest labile carbon content (482.4 mg kg^{-1}) and the highest active carbon contents (477.3 and 474.1 mg kg^{-1}) respectively. The lowest labile carbon content (225.4 mg kg^{-1}) was registered under the control treatment where no fertilizers had been added. The higher soil labile carbon values in the aforementioned treatments were a definite sign of the beneficial synergistic effects of organic manures on soil microflora, which increased the stock of SOC and the plant nutrient availability over the period of time. These results were in agreement with the findings of Pulleman *et al.* (2021) and Wade *et al.* (2020).

Mineralizable carbon

The mineralizable carbon content ranged from 798 to 1218 mg CO_2-C kg^{-1} at the harvest of *kharif*

Table 1. *Long-term effects of INM on different carbon fractions of the soils under rice-rice cropping system at Maruteru*

Treatments	OC (%)		Mineralizable-C (mg CO_2-C kg^{-1})		$KMnO_4$-C (mg kg^{-1})		SMBC (mg kg^{-1})	
	Kharif	*Rabi*	*Kharif*	*Rabi*	*Kharif*	*Rabi*	*Kharif*	*Rabi*
T_1 - Control	0.58	0.53	798	801	210.4	225.4	155.9	180.9
T_2 - 100% RDF + $ZnSO_4$ @ 40 kg ha^{-1}	1.15	1.25	835	843	327.4	335.6	323.7	368.7
T_3 - FYM @ 10 t ha^{-1}	1.69	1.85	982	995	394.3	400.9	398.5	402.5
T_4 - 100% RDF + FYM @ 5 t ha^{-1}	1.39	1.58	1218	1235	497.4	482.2	523.7	531.7
T_5 - 50% RDN + 50% N through green leaf manure (*Calotropis* spp)	1.65	1.80	1083	1097	456.3	468.5	434.8	455.8
T_6 - 50% RDN + 50% N through FYM	1.70	1.88	1195	1206	478.6	477.3	482.6	498.6
T_7 - 50% RDN + 25% N through green leaf manure (*Calotropis* spp) + 25% N through FYM	1.62	1.75	1121	1143	463.6	474.1	476.2	484.2
T_8 - 50% RDN + *Azospirillum* @ 2.5 kg ha^{-1}	1.40	1.60	994	1020	410.6	420.9	413.4	422.4
Initial	0.55							
CD (P=0.05)	0.16	0.17	228.7	231.9	34.89	35.70	35.33	36.57
SEm ±	0.05	0.06	74.7	75.7	11.39	11.66	11.54	11.94

Table 2. *Long-term effects of INM of treatments on carbon stocks and carbon sequestration rate under rice-rice cropping system at Maruteru*

Treatments	SOC (Mg ha^{-1})		SIC (Mg ha^{-1})		TC (Mg ha^{-1})	
	Kharif	*Rabi*	*Kharif*	*Rabi*	*Kharif*	*Rabi*
T_1 - Control	11.75	10.73	4.25	4.01	16.00	14.74
T_2 - 100% RDF + $ZnSO_4$ @ 40 kg ha^{-1}	23.29	25.31	4.62	4.76	27.90	30.08
T_3 - FYM @ 10 t ha^{-1}	34.22	37.46	5.20	5.86	39.42	43.32
T_4 - 100% RDF + FYM @ 5 t ha^{-1}	28.15	32.00	6.80	7.17	34.95	39.16
T_5 - 50% RDN + 50% N through green leaf manure (*Calotropis* spp)	33.41	36.45	5.35	6.76	38.76	43.21
T_6 - 50% RDN + 50% N through FYM	34.43	38.07	6.68	7.05	41.11	45.12
T_7 - 50% RDN + 25% N through green leaf manure (*Calotropis* spp) + 25% N through FYM	32.81	35.44	5.71	6.20	38.52	41.63
T_8 - 50% RDN + Azospirillum @ 2.5 kg ha^{-1}	28.35	32.40	6.12	6.39	34.47	38.79
Initial	11.14				11.14	

Table 3. *Carbon sequestration (CS) rate (Mg ha^{-1} yr^{-1})*

	T_1		T_2		T_3		T_4		T_5		T_6		T_7		T_8	
	Kharif	*Rabi*	*Kharif*	*Rabi*	*Kharif*	*Rabi*	*Kharif*	*Rabi*	*Kharif*	*Rabi*	*Kharif*	*Rabi*	*Kharif*	*Rabi*	*Kharif*	*Rabi*
Final	11.75	10.73	23.29	25.31	34.22	37.46	28.15	30.22	33.41	36.45	34.43	38.07	32.81	35.44	28.35	32.40
Initial	11.14	11.14	11.14	11.14	11.14	11.14	11.14	11.14	11.14	11.14	11.14	11.14	11.14	11.14	11.14	11.14
Buildup	0.61	-0.41	12.15	14.17	23.08	26.32	17.01	20.86	22.27	25.31	23.29	26.93	21.67	24.30	17.21	21.26
CS rate	0.02	-0.02	0.47	0.55	0.89	1.01	0.65	0.80	0.86	0.97	0.90	1.04	0.83	0.93	0.66	0.82

crop. Highest (1218 CO_2-C kg^{-1}) was recorded in T_4 (100% RDF + FYM @ 5 t ha^{-1}). A significant effect of treatments was observed on soil mineralizable carbon content. Similarly in *rabi*, the maximum mineralizable carbon content was observed in T_4 (100% RDF + FYM @ 5 t ha^{-1}) followed by T_6 (50% RDN + 50% N through FYM) with 1206 mg CO_2-C kg^{-1} of mineralizable carbon. The lowest mineralizable carbon content in both *kharif* and *rabi* seasons were recorded in T_1 treatment (Table 1). Similar findings were reported by Toh *et al.* (2020).

Carbon stocks

The data regarding to soil carbon stocks of the study area are presented in Table 2 and Fig. 1.

Soil organic carbon stock

Higher content of soil organic carbon stock in *kharif* (34.43 Mg ha^{-1}) was recorded in T_6 (50% RDN + 50% N through FYM) followed by treatments receiving FYM @ 10 t ha^{-1} and 50% RDN + 50% N through green leaf manure (*Calotropis* sp) with SOC of 34.22 and 33.41 Mg ha^{-1}, respectively. In *rabi*, the highest content of SOC stock (38.07 Mg ha^{-1}) was recorded in T_6 (50% RDN + 50% N through FYM). The SOC stock lowest was recorded in control with 11.75 Mg ha^{-1} and 10.73 Mg ha^{-1} in *kharif* and *rabi*, respectively.

Soil inorganic carbon stock

The higher content of inorganic carbon stock in *kharif* (6.80 Mg ha^{-1}) and *rabi* (7.17 Mg ha^{-1}) were recorded in T_4 (100% RDF + FYM @ 5 t ha^{-1}) followed by T_6 (50% RDN + 50% N through FYM) with SIC stock of 6.68 and 7.05 Mg ha^{-1}, respectively. Whereas the lowest SIC stock was observed in T_1 in both *kharif* and *rabi* (4.25 and 4.01 Mg ha^{-1}, respectively).

Total carbon stock

The maximum content of total carbon stock was recorded in T_6 (50% RDN + 50% N through FYM) treatment under both *kharif* and *rabi*, with 41.11 and 45.12 Mg ha^{-1}, respectively (Table 2). This may be attributed to the build up of soil organic carbon in the treatment.

Build up or depletion of soil carbon

Among the treatments, T_6 (50% RDN + 50% N through FYM) showed the highest carbon buildup under both *kharif* (23.29 Mg ha^{-1}) and *rabi* (26.93 Mg ha^{-1}) (Table 2 and Fig. 2), whereas, depletion of soil organic carbon was noticed in the control treatment.

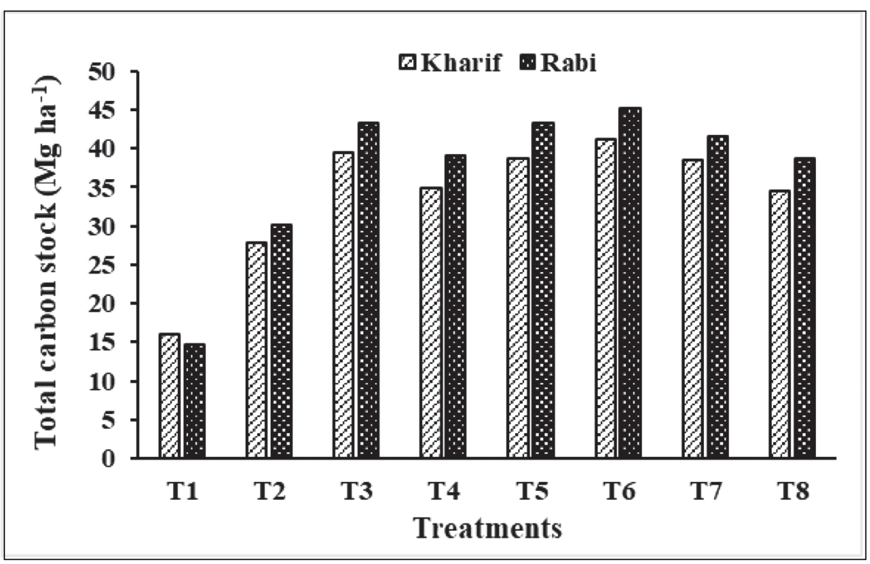

Fig. 1. *Long-term effects of INM on total carbon stock (Mg ha^{-1}) after harvest of rice-rice cropping system at Maruteru*

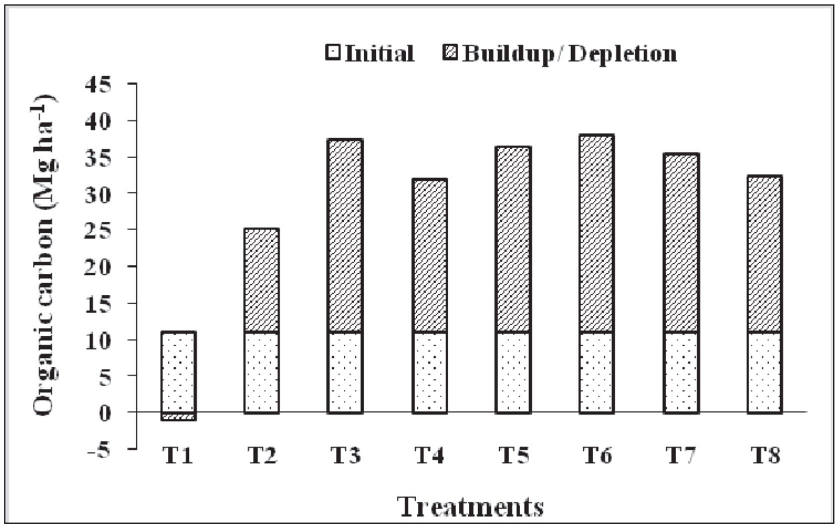

Fig. 2. *Long-term effects of INM on carbon buildup (Mg ha*$^{-1}$*) after harvest in rice-rice cropping system at Maruteru*

Carbon sequestration rate

From the results, it was observed that the highest carbon sequestration rate was recorded in T_6 (50% RDN + 50% N through FYM) under both *kharif* and *rabi* with 0.90 and 1.04 Mg ha^{-1} yr^{-1}, respectively (Table 3). Similar findings were also observed by Ghosh *et al.* (2021) in rice under integrated nutrient management.

Under long term the combined application of organic and inorganic fertilizers increased the carbon status of soils. In comparison to applications of 100% inorganic and 100% organic manures alone, the carbon fractions, total carbon stock, and rate of carbon sequestration were found to be high in treatment having 50% RDN + 50% organic manures. In addition to nutrient management techniques, carbon sequestration rate and maintenance of carbon stocks depends on the type of soil, its texture, the cropping system used, and the climatic conditions in which the crops are produced. Therefore, integrated use of organic along with inorganic fertilizers would be the most effective strategy for improving soil fertility and carbon stock.

CONFLICTS OF INTEREST

The authors do not have any competing interests.

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