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Effect of long-term use of inorganic fertilizers, organic manures and their combination on active carbon pools under rice-rice cropping system

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Abstract
A field experiment entitled "Carbon sequestration and soil health under long term soil fertility management in rice-rice cropping system" was carried out under field conditions during both *kharif* and *rabi* seasons of 2016-2017 and 2017- 2018 at Andhra Pradesh Rice Research Institute and Regional Agricultural Research Station, Maruteru, West Godavari district in the ongoing All India Coordinated Research Project on Long Term Fertilizer Experiment Project. The results reported that MBC, WSC and $KMnO_4$-C representing active carbon pools were observed highest with the application of 100% RDF in combination with $ZnSO_4$ and FYM @5t ha^{-1}. However, it was on par with that of application of 50% NPK + 50% N through FYM except for MBC. The higher MBC was observed with the application of 100% RDF in combination with $ZnSO_4$ and FYM @5t ha^{-1} and it was on par with the only organic treated plot i.e. FYM @ 10t ha^{-1} and with the application of 50% NPK + 50% N through FYM.

Keywords: organic manures, inorganics, MBC and $KMnO_4$-C

Introduction
Soil is the major reservoir of terrestrial organic carbon in the biosphere, which plays an important role in global carbon cycle. Large scale changes in land use like deforestation and agricultural activities like biomass burning, ploughing, drainage, low input farming have resulted in significant changes in SOC pools (Lal, 2013) [4]. To better understand the mechanism by which C is lost of stabilized in the soil, the SOC pools is separated in to a labile or actively cycling pool, a slow pool and a stable or passive, recalcitrant pool with varying residence times (Parton and Rasmussen, 1994) [6]. The total carbon pool constitutes a major global reservoir comprising of SOC pool and SIC pool.

Rice (*Oryza sativa* L.) is the principal food crop of the world, contributes to about 60% of the world's food. Rice is the major cereal crop feeding two- third of the global population. Rice occupies one-third of the world's crop land planted to cereals and provides 30-60% of the calories consumed by nearly three billion people (Gurra *et al*., 1998) [2]. Higher production requirements for the future to meet the demands of growing population need to be achieved, maintaining the soil quality and sustainability of the productivity at the same time.

Materials and Methods
A long-term field experiment was initiated in *kharif*, 1989 with rice-rice cropping system at APRRI & RARS, Maruteru, West Godavari. The experiment was carried out under field conditions during *kharif* and *rabi* seasons of 2016-2017 and 2017- 2018 at Andhra Pradesh Rice Research Institute and Regional Agricultural Research Station, Maruteru, West Godavari district in the ongoing All India Coordinated Research Project on Long Term Fertilizer Experiment Project. The treatments consisted of control, 100 per cent recommended dose of NPK, 100 per cent recommended dose of NK, 100 per cent recommended dose of PK, 100 per cent recommended dose of NP, 100 per cent recommended dose of NPK+$ZnSO_4$ @ 40 kg/ ha, 100 per cent recommended dose of NPK+$ZnSO_4$ @ 40 kg/ ha + FYM @ 5 t ha^{-1}, 50 per cent recommended dose of NPK, 50% NPK + 50% N through green manures, 50% NPK + 50% N through FYM, 50% NPK + 25% N through green manures + 25% N through FYM and FYM only @ 10 t/ha. There were twelve treatments laidout in RBD with three replications for both *kharif* and *rabi* seasons in two years of study.

Nitrogen was applied through urea in three equal splits (1/3rd basal+1/3rd at tillering+1/3rd at panicle initiation stage). Phosphorus was applied through DAP was used duly taking its N content into account and potassium as muriate of potash (60% K_2O) and zinc as zinc sulphate ($ZnSO_4.7H_2O$). The entire dose of phosphorus, potassium and zinc were applied as basal. Recommended dose of fertilizer for *kharif* season was 90: 60: 60 N: P_2O_5: K_2O kg ha^{-1} and for *rabi* season it was 180: 90: 60 N: P_2O_5: K_2O kg ha^{-1}. Well decomposed farmyard manure (FYM) manure and *Calotropis* (green leaf manure) were applied two weeks before transplanting. The experiment on rice – rice sequence as detailed above was repeated on a same site during *kharif* 2016-17 and *rabi* 2017-18, respectively. Popular cultivars of *kharif* rice and *rabi* rice, MTU-1061, MTU-1010 respectively, were used for the study. Data was collected on active carbon pools (MBC, WSC and $KMnO_4$-C) of both *kharif* and *rabi* rice. MBC was estimated by fumigation- extraction method. Water soluble organic carbon in soil was determined as per the procedure outlined by Mc Gill *et al*. (1986) [5]. Blair *et al.* (1995) [1] suggested the method for determination of soil labile carbon using potassium permanganate which has been modified by Weil *et al.* (2003) [10].

Results and Discussion

Microbial Biomass Carbon (MBC)

Data pertaining to microbial biomass carbon as influenced by different treatments are presented in the table (1, 2, 3 and 4) and indicated that microbial biomass carbon increased at harvest when compared to initial stage in all the four seasons of study during 2016-17 and 2017-18.

At initial stage among the twelve treatments, significantly highest microbial biomass carbon 410.6, 417.9 and 423.1, 427.6 mg kg^{-1} in *kharif*, *rabi* 2016-17 and *kharif*, *rabi* 2017-18, respectively was recorded in treatment T_7 (FYM along with 100 per cent RDF + $ZnSO_4$) over all other treatments and the lowest microbial biomass carbon (187.6, 190.6 and 193.5, 195.3 mg kg^{-1}) was observed in the control plot (T_1). During both the years of *rabi* season, among the inorganic treatments the treatment T_6 (100% RDF + $ZnSO_4$) recorded highest MBC and significantly superior over treatment T_4 (100% PK) and T_8 (50% NPK) however it was on par with treatment T_3 (100% NK) and T_2 (100% NPK).

At initial stage among the inorganic treatments the treatment T_6 (100% RDF + $ZnSO_4$) recorded highest MBC and significantly superior over treatments T_4 (100% PK), T_5 (100% NP) and T_8 (50% NPK) but it was on par with treatment T_2 (100% NPK) and T_3 (100% NK). Similar results were observed in both years of study in *kharif* and *rabi* seasons.

At harvest, among the different the treatments the T_7 (100% RDF + $ZnSO_4$ + FYM) treatment recorded significantly higher microbial biomass carbon (418.8, 423.8 and 428.7, 430.2 mg kg^{-1} in *kharif, rabi* 2016-17 and *kharif*, *rabi* 2017-18, respectively) over all other treatments and the lowest SMBC content (191.5, 194.8 and 196.9, 199.3 mg kg^{-1}) was recorded in T_1 (control). All the conjuctive treatments showed significant effect on SMBC content.

Among the inorganic treatments, the treatment T_6 (100% RDF + $ZnSO_4$) recorded the highest MBC and it was significantly superior over treatment T_4 (100% PK) and T_8 (50% NPK) however it was on par with treatment T_3 (100% NK), T_5 (100% NP) and T_2 (100% RDF). Similar results were observed in both the years of study in *kharif* and *rabi* seasons.

Among the organic sources, FYM maintained higher MBC content than green manure incorporation. This might be due to wider C: N ratio of organic sources like FYM which had triggered the microbial population and thus MBC. FYM might have provided congenial conditions for microbial growth and multiplication. Microbial biomass carbon was related to microbial population and the imbalanced use of fertilizers or nutrients decreased MBC due to limitation imposed by other major nutrients which were essential for microbial synthesis (Rudrappa *et al.*, 2006) [7].

The experimental results revealed that the application of FYM alone or in combination with chemical fertilizers significantly increased the soil microbial biomass carbon (SMBC). Similar results were also reported by Verma and Mathur (2009) [9]. The supply of additional mineralizable and readily hydrolysable C due to organic manure application resulted in higher soil microbial biomass carbon. It indicated that manure addition resulted in higher SMBC than inorganic fertilization or no fertilization (control).

Table 1: Effect of long-term use of inorganic fertilizers, organic manures and their combination on soil MBC, WSC and $KMnO_4$-C (mg kg^{-1}) under rice (*Kharif*, 2016)

Treatments	Microbial biomass carbon		Water soluble carbon (mg kg^{-1})		$KMnO_4$- extractable carbon (mg kg^{-1})	
	Initial	Harvest	Initial	Harvest	Initial	Harvest
T_1 Control	187.6	191.5	14.2	15.8	250.6	252.9
T_2 100% RDF	301.4	307.8	17.1	19.9	341.8	345.7
T_3 100% NK	269.8	274.5	16.5	18.2	336.2	339.5
T_4 100% PK	227.5	232.9	15.4	17.5	328.4	331.8
T_5 100% NP	249.2	256.7	15.9	18.0	330.9	333.6
T_6 100% RDF + $ZnSO_4$ @ 40 kg/ha	309.5	315.4	17.5	20.1	345.7	349.8
T_7 100% RDF + $ZnSO_4$ @ 40 kg/ha + FYM @ 5t/ha	410.6	418.8	20.6	24.7	462.4	467.3
T_8 50% NPK	263.4	269.6	16.0	18.1	306.2	309.4
T_9 50% NPK + 50% N through Green Manures	330.2	339.9	18.1	22.3	406.7	411.6
T_{10} 50% NPK + 50% N through FYM	347.5	358.7	19.8	23.0	432.8	437.9
T_{11} 50% NPK + 25% N through GM + 25% N through FYM	328.5	339.6	18.5	22.9	416.9	421.5
T_{12} FYM only @ 10 t/ha	367.8	378.4	19.2	21.7	386.3	390.7
SEm ±	12.30	13.57	0.409	0.546	12.922	13.67
CD @ 0.05	36.1	39.8	1.2	1.6	37.9	40.1
CV (%)	7.12	7.85	6.9	6.5	6.8	7.1

Table 2: Effect of long-term use of inorganic fertilizers, organic manures and their combination on soil MBC, WSC and $KMnO_4$-C (mg kg^{-1}) under rice (*Rabi*, 2017)

Treatments	Microbial biomass carbon		Water soluble carbon (mg kg^{-1})		$KMnO_4$- extractable carbon (mg kg^{-1})	
	Initial	Harvest	Initial	Harvest	Initial	Harvest
T_1 Control	190.6	194.8	14.6	17.9	251.8	253.9
T_2 100% RDF	306.4	312.4	18.6	21.4	344.9	348.1
T_3 100% NK	273.8	278.9	17.9	20.5	338.3	341.9
T_4 100% PK	231.6	235.4	16.3	19.8	330.7	333.7
T_5 100% NP	255.9	258.3	17.8	19.6	332.9	335.2
T_6 100% RDF + $ZnSO_4$ @ 40 kg/ha	314.3	317.5	19.8	22.9	348.4	352.3
T_7 100% RDF + $ZnSO_4$ @ 40 kg/ha + FYM @ 5t/ha	417.9	423.8	24.1	28.5	466.2	470.2
T_8 50% NPK	268.5	272.7	17.1	19.1	308.3	311.8
T_9 50% NPK + 50% N through Green Manures	338.6	344.9	22.5	26.1	410.5	414.7
T_{10} 50% NPK + 50% N through FYM	357.8	366.5	22.8	25.9	436.2	440.6
T_{11} 50% NPK + 25% N through GM + 25% N through FYM	338.1	347.8	21.6	23.6	420.3	424.9
T_{12} FYM only @ 10 t/ha	377.5	385.4	20.8	24.5	389.2	393.5
SEm ±	12.82	14.96	0.477	0.75	12.20	11.55
CD @ 0.05	37.6	43.9	1.4	2.2	35.8	33.9
CV (%)	7.42	8.66	7.1	7.4	6.9	7.5

Table 3: Effect of long-term use of inorganic fertilizers, organic manures and their combination on soil MBC, WSC and $KMnO_4$-C (mg kg^{-1}) under rice (*Kharif*, 2017)

Treatments	Microbial biomass carbon		Water soluble carbon (mg kg^{-1})		$KMnO_4$- extractable carbon (mg kg^{-1})	
	Initial	Harvest	Initial	Harvest	Initial	Harvest
T_1 Control	193.5	196.9	14.3	18.9	252.7	254.8
T_2 100% RDF	311.6	316.7	20.8	23.4	347.2	350.2
T_3 100% NK	277.3	282.4	19.4	22.6	340.8	343.7
T_4 100% PK	234.5	238.5	18.6	21.7	332.6	335.9
T_5 100% NP	257.8	260.9	18.1	22.1	334.3	337.6
T_6 100% RDF + $ZnSO_4$ @ 40 kg/ha	316.5	319.9	22.2	25.9	351.7	354.9
T_7 100% RDF + $ZnSO_4$ @ 40 kg/ha + FYM @ 5t/ha	423.1	428.7	28.1	32.6	469.3	472.4
T_8 50% NPK	271.9	274.7	18.3	20.5	310.9	313.8
T_9 50% NPK + 50% N through Green Manures	343.6	350.6	25.8	29.5	413.8	417.4
T_{10} 50% NPK + 50% N through FYM	365.3	371.9	24.8	28.4	439.1	443.1
T_{11} 50% NPK + 25% N through GM + 25% N through FYM	346.9	349.6	22.7	26.4	423.8	426.7
T_{12} FYM only @ 10 t/ha	384.7	390.8	23.9	27.5	392.7	395.5
SEm ±	15.65	13.02	0.818	1.023	14.08	12.17
CD @ 0.05	45.9	38.2	2.4	3.0	41.3	35.7
CV (%)	9.05	7.53	7.9	6.8	6.74	7.9

Table 4: Effect of long-term use of inorganic fertilizers, organic manures and their combination on soil MBC, WSC and $KMnO_4$-C (mg kg^{-1}) under rice (*Rabi*, 2018)

Treatments	Microbial biomass carbon		Water soluble carbon (mg kg^{-1})		$KMnO_4$- extractable carbon (mg kg^{-1})	
	Initial	Harvest	Initial	Harvest	Initial	Harvest
T_1 Control	195.3	199.3	15.3	19.9	253.8	256.9
T_2 100% RDF	315.4	320.6	22.5	25.6	349.1	353.6
T_3 100% NK	281.8	283.5	21.9	23.7	342.8	345.8
T_4 100% PK	237.6	241.9	20.6	22.4	334.7	337.9
T_5 100% NP	259.3	262.5	21.7	23.9	336.2	339.7
T_6 100% RDF + $ZnSO_4$ @ 40 kg/ha	318.5	322.1	24.3	28.9	353.1	357.2
T_7 100% RDF + $ZnSO_4$ @ 40 kg/ha + FYM @ 5t/ha	427.6	430.2	32.1	37.4	471.1	476.9
T_8 50% NPK	273.3	277.1	19.4	21.9	312.2	315.8
T_9 50% NPK + 50% N through Green Manures	349.7	355.3	28.3	32.5	416.2	420.4
T_{10} 50% NPK + 50% N through FYM	370.8	374.9	27.5	31.3	442.9	446.3
T_{11} 50% NPK + 25% N through GM + 25% N through FYM	348.9	356.8	25.4	30.6	425.7	429.1
T_{12} FYM only @ 10 t/ha	389.5	394.4	26.3	29.1	394.2	398.2
SEm ±	13.74	14.28	1.330	1.398	13.57	14.04
CD @ 0.05	40.3	41.9	3.9	4.1	39.8	41.2
CV (%)	7.95	8.26	7.9	8.1	7.2	7.8

Water soluble carbon (WSC)

During the *kharif* season, at initial stage, the water soluble carbon in soil ranged from 14.2 to 20.6 and 14.3 to 28.1 mg kg^{-1} in 2016 and 2017, respectively. The highest water soluble carbon 20.6, 28.1 mg kg^{-1} in 2016 and in 2017, respectively was recorded by the treatment T_7 (100% RDF+ $ZnSO_4$ @ 40 kg ha^{-1}+ FYM @5 t/ha), it was significantly superior over other treatments but however it was on par with treatments

T_{10} (50% NPK+ 50% N through FYM) and lowest water soluble carbon of 14.2 and 14.3 mg kg^{-1} were produced with treatment T_1 (Control) during two years of study.

During *rabi* season, at initial stage, among all the treatments, the highest water soluble carbon was observed in treatment T_7 (100% NPK+ $ZnSO_4$ @ 40 kg ha^{-1}+ FYM @5 t ha^{-1}) which was significantly superior over all other treatments except T_{10} (50% NPK+ 50% N through FYM) during both the years of study and lowest was observed in control.

Among the inorganic treatments, at both initial and harvesting stages, the treatment T_6 (100% RDF + $ZnSO_4$) recorded the highest WSC and it was significantly superior over treatment T_4 (100% PK), T_5 (100% NP) and T_8 (50% NPK) but however it was on par with treatment T_2 (100% RDF) and T_3 (100% NK). Similar set of results were observed in both years of study during the *kharif* and *rabi* season.

At harvesting stage among all the treatments the treatment T_7 (100% NPK+ $ZnSO_4$ @ 40 kg ha^{-1} + FYM @5 t ha^{-1}) produced the significantly highest water soluble carbon content of 24.7, 28.5, 32.6 and 37.4 mg kg^{-1} in *kharif* and *rabi* 2016-17 and 2017-18, respectively and it was significantly superior over all other treatments and the lowest water soluble carbon content (15.8, 17.9, 18.9, 19.9 mg kg^{-1}) were produced with treatment T_1 (Control).

Water soluble C could be used as stability indicator of soil organic matter, higher value of water soluble C indicated lower stability and lower value higher stability of soil organic matter. The results suggested that application of FYM and green manure resulted in build–up of less stable soil organic matter, which will be easily decomposed with time. Positive effect of FYM and mineral fertilizers on water soluble C was reported by Simon, (2008) [8].

$KMnO_4$ - carbon

The glance at the data (Table 4.5,4.6, 4.7 and 4.8) revealed that soil $KMnO_4$-C content increased from initial to harvesting stage of the crop in all the experimental treatment in all the four seasons. At initial stage, the $KMnO_4$-C in soil ranged from 250.6 to 462.4 mg kg^{-1} in *kharif*, 2016; 251.8 to 466.2 in *rabi*, 2017; 252.7 to 469.3 in *kharif*, 2017 and 471.1 to 253.8 mg kg^{-1} in *rabi*, 2018. The significantly highest (462.4, 466.2 mg kg^{-1}) $KMnO_4$- carbon during *kharif* and *rabi*, respectively in 2016-17 and (469.3, 471.1 mg kg^{-1}) in 2017-18 was recorded in the treatment T_7 (100% NPK+ $ZnSO_4$ @ 40 kg ha^{-1} + FYM @5 t ha^{-1}) which was significantly superior over other treatments and lowest $KMnO_4$-C was recorded by the treatment T_1 (control) at initial stage.

Among the inorganic treatments, during the *kharif* season at initial stage, the treatment T_6 (100% RDF%+ $ZnSO_4$) recorded the highest $KMnO_4$ – carbon (345.7 in *kharif*, 16 and 351.7 mg kg^{-1} in *kharif*, 17 and it was significantly superior over T_8 and however it was on par with treatment T_2 (100% RDF), T_3 (100% NK), T_4 (100% PK) and T_5 (100% NP).

During the *rabi* season, among the inorganic treatments the treatment T_6 (100% RDF%+ $ZnSO_4$) recorded the significantly highest $KMnO_4$ – carbon over other inorganic treatments (T_2, T_3, T_4, T_5 and T_8). The averaged percentage increase of T_2 (100% RDF), T_3 (100% NK), T_4 (100% PK), T_5 (100% NP) and T_8 (50% NPK) treatments over control (T_1) were 38.36, 36.97, 34.35, 31.33, 32.20, 22.43 and 39.12, 37.54, 35.06, 31.87, 32.46 and 23.01respectively over T_1 (control) in 2017 and 2018 during the *rabi* season.

At harvesting stage among all the treatments the treatment T_7 (100% RDF + $ZnSO_4$ @ 40 kg ha^{-1} + FYM @5 t ha^{-1}) produced the significantly highest $KMnO_4$-C (467.3, 470.2472.4 and 476.9 mg kg^{-1} in *kharif*, *rabi* 2016-17 and *kharif*, *rabi* 2017-18, respectively which was significantly superior over all other treatments and the lowest $KMnO_4$-C (252.9, 253.9, 254.8 and 256.9) was recorded by the treatment T_1 (control).

Among the inorganic treatments, (T_2, T_3, T_4, $T_{5,}$ T_6 and T_8), the treatment T_6 (100% RDF +$ZnSO_4$) had recorded higher $KMnO_4$-C over T_2, T_3, T_4, T_5 and $T_{8.}$ However, the treatment T_2 (100% RDF) was on par with treatment T_3 (100% NK), T_4 (100% PK), T_5 (100% NP) but significantly superior over treatment T_8 (50% NPK). Similar trend of results were observed in both the years of study in *kharif* and *rabi* at harvesting stage.

Applications of organic manure, added substantial amount of organic carbon to soil. Thus, $KMnO_4$ extractable carbon content was more in organic treated plots than control, as $KMnO_4$ extractable carbon represented relatively younger organic compounds including labile humic material and polysaccharide (Haynes, 2005) [3].

Thus, the continuous cropping over the years without fertilizer application (*i.e.* control) resulted in a slight increase in labile carbon content of soil. However, the buildup was considerable in fertilizer treatments and maximum in FYM amended plots. Similar results were reported by Rudrappa *et al*. (2006) [7].

Conclusions

The labile carbon ($KMnO_4$- extractable carbon, MBC, WSC), less labile carbon (POC) and non-labile carbon (HAC+FAC) had contributed to soil organic carbon under different treatments in 0-15 cm soil (surface). Proportion of labile carbon was higher in case of only organics and also conjoint use of NPK and organic sources compared to control and inorganics only. Whenever, crops are grown continuously for several years in the same piece of land with application of inorganic fertilizers alone, the physical, chemical and biological activity of soils will be affected. Hence integrated use of organic and inorganic fertilizers is the best practice not only for improving the soil fertility and yields of crops but also to build up the carbon status.

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