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Effect of enriched organic manures and traditional practices on soil carbon dynamics and yield of maize-rice cropping system in coastal lowlands

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Abstract
The present study investigated the effects of enriched manures, inorganic fertilizers and their integrated use on maize-rice cropping system and soil mineral N and organic C pools under rainfed condition. The study comprised seven treatments and three replications in a RBD experiment for two years. The results revealed that yield of maize and rice increased significantly ranging from 48 to 121% due to integrated use of enriched manures and chemical fertilizers over control and application of manures alone. However, plots amended with enriched manures maintained higher total organic carbon, labile carbon, microbial biomass carbon and mineralizable carbon over control and farmers practice. Mineral N and C/N ratio in soil improved significantly with application of 100% NPK followed by enriched compost+50% NPK. Although farmers practice of *in-situ* residue recycling helps in maintaining soil carbon and recorded 17% higher yield than control but insufficient to meet the nutrient requirement of cereal cropping systems. The effect of enriched organic manures as revealed by principal component analysis was comparable with inorganic fertilizer in terms of yield and soil fertility as indicated by different soil carbon pools. This highlighted the potentials of using enriched organic manures as alternatives to inorganic fertilizers under rainfed and low input systems. This study will be helpful in crafting sustainable nutrient management programs in future to enhance crop productivity and soil organic carbon with minimum nutrient loss.

Keywords: Organic manures, soil carbon pools, mineral nitrogen, PCA, tropical island

Introduction
Practicing intensive cropping without proper soil management practices lead to decline in soil fertility and system productivity. Among the different soil properties that define soil fertility, soil organic matter (SOM) is an important determinant of soil fertility, productivity and sustainability, and is a useful indicator of soil quality (Doran and Parkin 1994) [6]. At the same time the dynamics of SOM is influenced by soil management practices such as tillage, mulching, removal of crop residues and application of organic and mineral fertilizers. Therefore, unsustainable soil management practices particularly ineffective source of nutrients result in loss of soil organic carbon (SOC) and its associated decrease in nutrient supply to soil.

Deterioration of soil quality and associated yield decline or stagnation under intensive cropping systems is invariably linked to SOM management (Dawe *et al*. 2000) [5]. This is applicable even in low input rainfed system where crop residues are removed from the farm or burned down. Past studies concluded that total SOC consists of labile or actively cycling pool and non-labile or resistant/recalcitrant or passive pool with varying residence time. The labile or active SOC fractions, such as microbial biomass C (MBC), potential mineralizable C and $KMnO_4$-oxidizable organic C are considered to be the most sensitive indicators of management-induced changes for soil quality than total SOC (Blair *et al.* 1995) [4]. Labile carbon comprises of amino acids, simple carbohydrates, a fraction of microorganisms and other simple organic compounds. The living soil organic C pool or MBC and potentially mineralizable C (Cmin) is considered as an important component of the active SOC (Nannipieri *et al*. 1990) [13] and established parameter to monitor soil biological activity (Anderson 1982) [1].

The nutrient turnover in soil-plant system is considerably high in cereal based cropping system; thus, any management system that improves and maintains the SOC and nutrient status, particularly mineral N of the soil, is desirable. The method commonly followed for improving the quality and productivity of soils is addition of organic matter.

In Andaman Islands, farmers normally harvest only rice grains and leave the crop residues in the same field that are ploughed back before the land preparation for the next rice crop during the pre-monsoon season. However, intensification or diversification of rice monocrop in the coastal lowlands results in nutrient depletion and loss of soil biodiversity. In this context, it is necessary to give priority to recycle crop residues and addition of organic manures for sustainable crop production and maintenance of soil fertility. Further, use of enriched manures or recycled organic wastes for sustaining soil fertility and microbial diversity has gained importance in recent years due to high cost of chemical fertilizers. However, limited information is available on the effects of vermicompost, enriched compost and farmyard manure on soil properties and crop yield under rainfed farming system in an island ecosystem. Thus in the present study, we examined the effect of different enriched manures prepared from crop residues/animal wastes through different methods on maize-rice cropping system and their impact on soil organic carbon dynamics and mineral nitrogen.

Materials and Method

Experimental Site and Soil

A field experiment was conducted for two years (2016-2018) at the Bloomsdale research farm of Central Island Agricultural Research Institute, Port Blair following maize-rice crop rotation. The study area falls under humid tropical climate with distinct wet and dry season. The islands receive copious amounts of annual rainfall averaging 2900 to 3100 mm with the mean maximum and mean minimum temperature of 32 °C and 22 °C, respectively. The relative humidity varies from 68 to 86%. The major land forms are longitudinal hills or parallel ridges, valley areas between the parallel ridges and coastal plains. The soil was sandy clay loam; slightly acidic (pH 6.4) and non-saline (EC 0.26 d Sm^{-1}). The arable crops such as rice, pulses, and vegetables are grown in valley and coastal plains while plantations of coconut and arecanut are found in the slopes of the longitudinal hills.

Experimental Design

A field experiment was laid out in a randomized block design with seven treatments and three replications having plot size of 4 m × 3 m each to evaluate the effect of different enriched organic manures and chemical fertilizers on maize-rice crop rotation. The seven treatments consisting of T1: Control; T2: 100% recommended dose of NPK fertilizers (120, 60, 60 NPK); T3: Vermicompost on recommended N equivalent basis (10 t ha^{-1}); T4: Enriched compost on recommended N equivalent basis (7 t ha^{-1}); T5: 50% NPK + vermicompost (5 t ha^{-1}); T6: 50% NPK + enriched compost (3.5 t h^{-1}); T7: Farmers practice (residue recycling + one ton FYM) were used for the field experiment. Vermicompost, enriched compost (Azospirillum, P solubilizer and growth promoter), and FYM were prepared in the institute form and used for the present field experiment. The recommended doses of nitrogen, phosphorus and potassium (120 kg N, 60 kg P_2O_5 and 60 kg K_2O ha^{-1}) as well as other treatments were computed as per the experimental design. Urea, diammonium phosphate and muriate of potash were used as the source of N, P and K. Entire quantities of variable amounts of enriched manures and chemical fertilizers were applied each year to both the crops (maize, var. mahyco-1 during summer and rice var. CIARI Dhan-5 during rainy season) before sowing and mixed thoroughly into the soil.

Plant and Soil Analyses

Crops were harvested, yield attributes for each year recorded and the grain and straw/ stover samples analyzed for N content by micro-Kjeldahl method (Jackson 1973) [10]. The soil was analyzed for pH, electrical conductivity (EC), cation exchange capacity (CEC); Walkley Black C; $KMnO_4$-oxidizable labile C (Blair *et al.* 1995) [4]; microbial biomass C and N (Jenkinson and Powlson 1976) [11]; mineral N (NH_4^+ and NO_3^-); available P and available K by following standard procedures (Jackson 1973) [10]. Mineralizable carbon was determined by measuring the amount of CO_2 evolved from soil as outlined by Anderson (1982) [1]. Total C content in manures was determined by the method as developed by Snyder and Trofymow (1984) [18], while total N was determined by micro-Kjeldahl method (Jackson 1973) [10]. The chemical characteristics of these manures are presented in table 1.

Table 1: Chemical characteristics of manures used in this study

Properties	Vermicompost	Enriched compost	FYM
Moisture (%)	8.4	7.3	6.4
pH	7.3	7.1	6.6
Total C (%)	36	33	32
N content (%)	1.2	1.6	0.8
C/N ratio	30	21	40
P content (%)	0.57	0.62	0.46
K content (%)	1.08	1.13	0.51
Ca (%)	0.84	0.87	0.57
Mg (%)	0.47	0.41	0.38

Statistical Analysis

The data obtained from the field experiments on yield, N uptake, soil mineral N, fractions of SOC and other parameters were subjected to analysis of variance (ANOVA) using randomized block design. Critical difference (CD) at $P = 0.05$ was used to test the differences between the means of individual treatments using SAS software.

Results and Discussion

Yield of Crops

The results indicated that application of 100% NPK as well as integrated use of manures like vermicompost, enriched compost, along with 50% NPK produced significantly higher yield in both maize and rice than control (Fig. 1). This might be due to higher supply of plant nutrients by application of organic and/or chemical fertilizers to both the crops where initial soil was low in available N and organic C content. The grain yield of maize increased by 56% with 100% NPK fertilizer over control. Integrated use of 50% NPK and enriched manures *viz*., T5 and T6 resulted in 48% and 51% increase in grain yield of maize, respectively over control. Whereas farmers practice (residue recycling + one ton FYM) resulted in 17% yield advantage over control. Similarly integrated use of 50% NPK and enriched manures *viz.*, T5 and T6 resulted in 68% and 121% increase in grain yield of rice, respectively over control. Farmers practice gave 14.5% yield advantage in rice over control. In general, soil amended with combined application of enriched manures and 50% NPK gave yields of both maize and rice comparable to those obtained with 100% NPK fertilizer. The results with the significant effects of organic and inorganic fertilizers on yield and soil properties are in corroboration with other studies (Satyanarayana et al., 2002 [15]; Saha *et al.* 2008[14]; Ayoola and Makinde, 2009) [2].

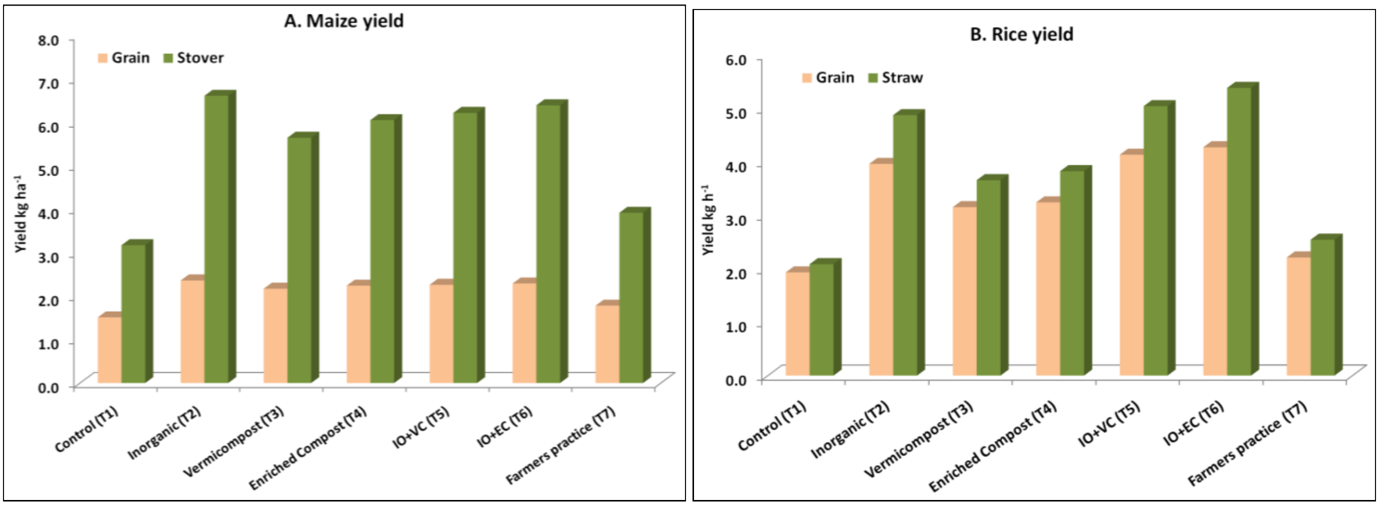

Fig 1: Effect of enriched manures and inorganic fertilizers on maize and rice yield

Changes in Soil Carbon Pools

Soil organic carbon levels at a point of time reflect the long-term balance between additions of organic carbon from different sources and its losses through different pathways. The passive C pool change very slowly and hence hardly serves as a good indicator to change due to management practices. On the other hand labile C pool comprising microbial biomass carbon (MBC), potential mineralizable C and $KMnO_4$-oxidizable organic C is the fraction of SOC with rapid turnover rates which serves as the energy source for the microbes and thus influences nutrient cycling for maintaining soil quality and its productivity (Blair *et al.* 1995) [4]. Thus in this study different carbon pools under maize-rice system were quantified.

Total carbon (Walkley Black carbon / wet method)

Much of the current database on terrestrial C content was commonly determined by wet digestion method (Bhattacharyya et al., 2000) [3]. In recent times many researchers are interested not only in the total soil C content but also in specific components of soil C and the dynamics of its turnover. There could be methodological differences with the change of the analytical procedures and the instruments. Thus, clay content specific correction factor was proposed by Velmurugan et al., (2009) [19] to covert the wet digestion based estimate to dry combustion (1.42) which indicated 30-40% higher TOC value than estimate by wet digestion. Nevertheless in the present study wet digestion method was used for ease of comparison with other studies.

It was observed that combined application of enriched manures along with chemical fertilizers maintained significantly higher total organic carbon (TOC) content in soil than control as well as plots receiving manures and chemical fertilizers applied alone (Table 2). Data revealed that TOC (Walkley Black Carbon) content significantly improved in the treatments receiving sole application of manures over control after rice crop accounting for 12% and 10% increase in enriched compost and vermicompost, respectively. Further TOC content increased ranging from 7-10% due to combined or sole application of enriched manures over inorganic treatment (100% NPK). Interestingly farmers practice also increased TOC by 10% over control indicating the importance of residue recycling after rice. Similar results of higher SOC content have also been recorded in soil amended with FYM and green manure in a rice–wheat cropping system by Sharma *et al.* (2001) [17]. Our data indicated that there was no significant decline in SOC content from the initial value due to maize-rice cropping system under rainfed condition which is in agreement with the findings of Gong *et al.* (2009) [7].

Labile organic carbon (LBC)

In general $KMnO_4$-oxidixable labile organic carbon (LBC) content significantly increased due to enriched manure and inorganic fertilizer application. The effect was highly pronounced after rice than maize indicating more LBC addition (Table 2). The LBC in soil after maize varied from 521 mg kg^{-1} in control (T1) to 586 mg kg^{-1} in T6. Treatment receiving 50% NPK + enriched compost resulted in 59% higher LBC in soil over control. Application of value added manures alone or in combination with 50% NPK significantly improved the LBC content ranging from 9-13% compared to 100% NPK. Interestingly farmers practice recorded 3.6% and 14.5% higher LBC over control after maize and rice, respectively. In comparison to TOC, there was more variation in LBC content in soils under various nutrient management treatments. This result indicates that application of enriched organic manures and chemical fertilizers can build-up this pool of organic C in a short time span. At the same time rice straw recycling by farmers also found to improve the LBC. Our result corroborates the earlier report that showed significant increase in LBC content in soil in response to crop residue incorporation and annual addition of N, P and K fertilizers (Graham *et al.* 2002) [9].

Microbial biomass carbon (MBC)

Soil amended with enriched manures and chemical fertilizers significantly improved the microbial biomass carbon (MBC) fraction over control and farmer practice. At the same time enriched manure addition either alone or combined with 50% NPK resulted in 18-25% increase in MBC over inorganic treatment. In contrast to the other C pool, the effect of manure addition on MBC was much pronounced after maize harvest. High MBC after maize than rice might be due to changes in community structure and size of microbial population coupled with influences of plant growth. In addition, improvement in the soil physical properties due to organic manures can make the soil environment more favourable for microbial life. Among the treatments enriched compost along with 50% NPK recorded the highest increase in MBC over all the other treatments. Combined application of manures and chemical fertilizers provides a balanced supply of nutrients and carbon, which in turn might maintain the higher population of microbes, increases the root biomass with the resultant SOC. Increase in MBC with increasing rate of application of FYM along with mineral N was also reported by Kukreja *et al.* (1991) [12]. However it should be noted that microbial biomass is a small but very dynamic component of soil organic matter that fluctuates with weather, crop, input, season and agricultural systems.

Mineralizable carbon

Carbon mineralization is a reflection on the availability of carbon for microbial activity. Data revealed significant impact of nutrient management practices on the mineralizable carbon as a measure of rate of soil respiration. Addition of manures alone resulted in significant increase in soil respiration than control as well as treatment receiving 100% NPK after rice. Integrated use of nutrients maintained higher mineralizable carbon than sole application of enriched manures or 100% NPK fertilizers, which was probably because of greater root biomass due to better crop growth with the former. Significant impact on mineralizable carbon after rice harvest was due to application of manures either alone or in combination with the resultant enhanced microbial growth and higher labile C. In the present study, mineralizable C increased with combined application of enriched manures and chemical fertilizers which might be due to increased plant growth and biomass production including greater root biomass. This increases the percentage of easily decomposable organic matter and thus higher evolution of CO_2 (Govaerts *et al.* 2006) [8]. The differences in the rate of C mineralization may be attributed to the presence of variable amounts of labile organic C accumulated in response to crop rotation. Therefore, balanced application of manures and fertilizers particularly enriched manures may contribute more labile C substrate to sustain the mineralization process.

Table 2: Changes in carbon pools in soil after maize and rice as affected by manures and chemical fertilizers in a maize-rice cropping system

Treatments	Total organic carbon (%)		Labile carbon (mg kg^{-1})		MBC (mg kg^{-1})		Mineralizable carbon (µg CO_2 g^{-1} h^{-1})	
	After Maize	After Rice	After Maize	After Rice	After Maize	After Rice	After Maize	After Rice
Control (T1)	0.52	0.58	521	545	232	209	7.9	8.72
Inorganic (T2)	0.55	0.61	538	766	253	228	9.4	10.35
Vermicompost (T3)	0.61	0.67	561	840	304	278	10.8	11.64
Enriched Compost (T4)	0.62	0.67	558	831	309	283	11.2	12.05
IO+VC (T5)	0.57	0.64	579	862	299	273	11.2	12.09
IO+EC (T6)	0.59	0.65	586	869	316	290	11.4	12.20
Farmers practice (T7)	0.58	0.64	540	624	271	248	8.6	9.45
CD (P=0.05)	0.11	0.12	37	59	14.8	9.5	0.92	0.84

Total carbon – Walkley Black C; Labile carbon – $KMnO_4$ oxidizable; MBC – Microbial biomass C; Mineralizable C – CO_2 evolution (rate of respiration)

Changes in mineral nitrogen and C/N ratio

Mineral nitrogen (NH_4^+ and NO_3^-) status in soil improved significantly due to application of enriched organic manures and chemical fertilizers over control both in maize and rice crops (Table 3).

Highest mineral N (86.4 mg kg^{-1}) in soil after maize was found in treatment receiving 100% RDF (T2) which was 46% higher than control. Further, integrated use of enriched manures along with 50% NPK resulted in higher mineral N in soil after maize than sole application of manures. Among the treatments which received either only manure or in combination with 50% RDF, T6 (compost with effective microbes) recorded the highest mineral N indicating its effectiveness for supplying mineral N to plants. Interestingly farmers practice recorded 12% increase in mineral N content than control treatment.

In addition to readily available mineral N in soil, C/N ratio indicates the combined N which can be mineralizable but at lower C/N values. Thus the lower C/N ratio indicates the more readily available mineral N while higher value indicates N in locked form with C. Among the treatments 100% NPK and combined application of manures and 50% NPK recorded lowest C/N ratio. Further under organic production system high maize-rice system yields can be achieved by enriching the manure. For this reason, nutrients contained in organic manures are released more slowly and are stored for a longer time in the soil, thereby ensuring a long residual effect, supporting better root development, leading to higher crop yields (Sharma and Mittra, 1991) [16]. These results suggest that integrated nutrient management is more effective in supplying mineral N in soil than only chemical fertilizers in maize-rice rotation.

Principal component analysis

The data matrix of different variables was subjected to principal component analysis (PCA) in order to decrease the number of descriptors associated with the data set while still explaining the maximum amount of variability present in the data. It is observed from the PCA score plot that T3 and T4 are placed close to the centre line in the top right hand side quadrant.

This indicates the minimal effect on quality attributes having only vermicompost and enriched compost; however enriched compost had higher impact on variables than vermicompost (Fig. 2). On the other hand, T6 and T2 are placed in bottom right-hand side of loading plot indicating higher values of organic carbon, mineral nitrogen and yield. However, T6 had significantly more impact on the studied variables than T2. At the same time, T1 and T7 are placed in the negative side of the left quadrant but farmers practice (T7) had more impact on variables (OC, pH) than control (T1).

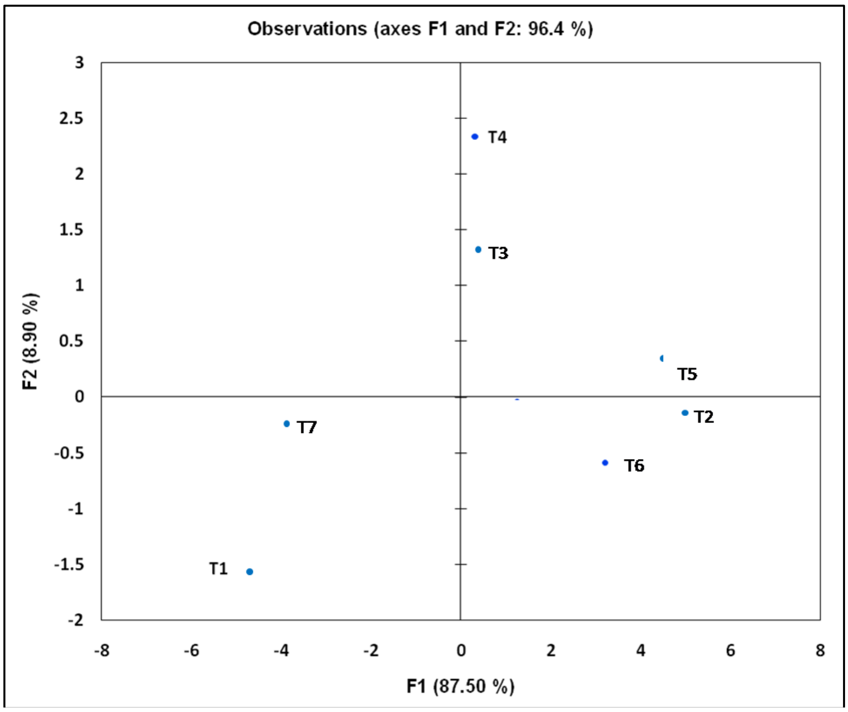

Fig 2: PCA score plot for different treatments

Table 3: Effect of manures and chemical fertilizers on mineral N and C/N ratio in a maize-rice cropping system

Treatments	Soil mineral N (mg kg^{-1})		C/N ratio	
	After Maize	After Rice	After Maize	After Rice
Control (T1)	58.7	49.7	8.8	11.8
Inorganic (T2)	86.4	75.9	6.4	8.0
Vermicompost (T3)	65.8	56.6	9.2	11.9
Enriched Compost (T4)	69.2	59.8	9.0	11.3
IO+VC (T5)	78.4	68.6	7.3	9.4
IO+EC (T6)	81.9	73.1	7.2	8.9
Farmers practice (T7)	65.8	56.4	8.8	11.4
CD (P=0.05)	5.8	5.4		

Conclusions

Analysis of earlier works clearly showed that chemical fertilizers are important input to get higher crop productivity, but over reliance on chemical fertilizers is associated with decline in soil carbon and other soil quality parameters. Therefore, an integrated use of inorganic fertilizers with organic manures is highly desirable approach for enhancing nutrient use while reducing the soil C loss. From this study it is concluded that soil amended with enriched manures along with half of the recommended chemical fertilizers significantly improved crop production, soil mineral N and organic carbon pools than sole application of manures in maize-rice crop rotation under rainfed conditions. While farmers practice help in maintaining soil carbon to some extend but insufficient to meet the nutrient requirement of cereal cropping systems. The results also demonstrated that integrated use manures along with effective microbes could be considered as a feasible and environment friendly option for recycling various farm wastes and increasing the carbon in different components in soil.

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