

Original Research Article

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Effect of Long-Term Double Rice Cultivation with Different Management Practices on C Sequestration and Economics under Hot Semi-Arid Climate in India

A. Krishna Chaitanya^{1*}, Shyam Prasad Majumder¹, Dhaneshwar Padhan¹, Shrikant Badole¹, Ashim Datta², Biswapati Mandal¹ and G. Kiran Reddy³

¹Bidhan Chandra Krishi Viswavidyalaya, Kalyani-741235, West Bengal, India

²ICAR-Central Soil Salinity Research Institute, Karnal-132 001, Haryana, India

³Professor Jayashankar Telangana State Agricultural University, Jagtial- 505327, Telangana, India

*Corresponding author

ABSTRACT

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Studying the dynamics of soil organic carbon (SOC) is important for understanding the C stabilization into different pools. Carbon sequestration in soils has the potential to curb global warming besides maintaining sustainability of agricultural system under tropical and subtropical climate. Thus, a 14-year old experiment was used to assess the impact of double rice cropping system with manuring and grades of fertilization on SOC sequestration and crop yield sustainability in an Inceptisol in southern India. There was significant decrease ($p < 0.05$) in bulk density with increasing using organics over control. Sole FYM applied plots showed greater amount of C sequestration (3.9 Mg ha^{-1}) followed by RDF+FYM (2.4 Mg ha^{-1}) > RDF (1.1 Mg ha^{-1}) > 150% RDF (1.0 Mg ha^{-1}) > fallow (0.3 Mg ha^{-1}), but depleted in 50% RDF (-0.28 Mg ha^{-1}) and control (-1.1 Mg ha^{-1}). The increased dose of fertilization/ N increased amount of C sequestered, followed sigmoid curve pattern. RDF+FYM treatment showed greater crop yield sustainability with good benefit: cost ratio.

Introduction

Soil organic carbon (SOC) is one of the most important components in soil that contributes positively to soil fertility, soil tilth, crop production, and overall soil sustainability (Lal, 1997; Reeves, 1997). Since soil is the major reservoir of terrestrial C any attempt to enrich this reservoir through sequestration of atmospheric C will help to manage global warming and achieve global food security to a great extent.

Crop cultivation is known to adversely affect the distribution and stability of soil aggregates and reduces SOC stock in soils (Kong *et al.*, 2005). The impacts of cultivation on C stock have commonly been observed to be restricted mostly to surface soils and/or to root zone depth (Paustian *et al.*, 1997b). Altering soil physico-chemical properties by management practices may increase one or more of the protective attributes which

ultimately increases C in soils provided C inputs to soil do not decrease.

Intensive cultivation of crops with inputs like fertilizers, organics and chemicals, water, tillage which are used to increase economic yield of crops, also may normally be expected to result in buildup of C stock in soils (Wright and Hons, 2004). Aboveground and belowground C may be a major source for SOC accumulation in soils. However, there is a lack of information on quantification of the mass of belowground residue C produced by plant roots from various crops under fallow and cultivated land management systems in the subtropical India. Crop species play important roles in C sequestration because their residues vary in quantity and quality (e.g. lignin, phenolic content, C/N), which affect their decomposition and turnover rates in soil (Martens 2000). In contrast, numerous reports show that C stock in soils has declined with intensive cultivation using modern inputs (Swarup *et al.*, 2000; Lal, 2004a). In fact, the magnitude of decline or enhancement of SOC due to continuous cultivation depends on the balance between the loss of C by oxidative forces of tillage operation and the quantity and quality of crop residues that are returned and organics added to the soils. The loss of C is enormous in tropical and sub-tropical regions because of high atmospheric temperature (Lal, 2004a).

Therefore, the hypothesis set out for the study was to study the changes of physico-chemical properties, carbon sequestration potential and economic aspects of different nutrient management practices.

Materials and Methods

Site description

A long-term experiment was established in the year 2000 at the experimental farm of the

Regional Agricultural Research Station (18°45' N, 78°45' E), Jagtial, Telangana with double rice (*Oryza sativa* L.) cropping system. The area receives, on an average, annual rainfall of approximately 600-900 mm. The mean annual minimum and maximum temperatures were 10.0°C and 37.6°C respectively. The soil was classified as *Inceptisol*, Typic Ustochrept, black clay with clayey texture. The site had the soil moisture and temperature regimes of ustic and isohyperthermic, respectively.

Two rice (*Oryza sativa* L) crops (cv. JGL 3855) were grown annually in the experiment. The experiment was laid out in randomized block design with three replications (plot size: 12 m × 9 m) and consisted of the following treatments: (i) control (plots without RDF fertilizers and organics), (ii) 50% RDF (*i.e.*, 60-30-20), (iii) 100% RDF (*i.e.*, 120-60-40), (iv) 150% RDF (*i.e.*, 180-90-60), (v) 100% RDF + farmyard manure (10 t ha⁻¹, in each *kharif*), (vi) farmyard manure (10 t ha⁻¹, in each *kharif* and *rabi*) and (vii) Fallow.

Soil analysis

The pH of the soil was determined in 1:2.5 soil: water and soil: 0.02M CaCl₂ suspension by using digital pH meter (Jackson, 1973). Electrical conductivity (EC) of soil-water suspension (1: 2.5) was estimated with the help of a direct reading conductivity meter (Model: systronics, 363) outlined by (Jackson, 1973).

Bulk density was determined by core sampler (5.0 cm length and 5.0 cm diameter) method following the protocol of Blake and Hartge (1986). Soil organic carbon was determined by using rapid titration method (wet combustion method) as described by Walkley and Black (1934). C stock, amount of C sequestration, C buildup rate and % buildup over control treatments were calculated by

using the following equations (Mandal *et al.*, 2007)

$$C \text{ stock (Mg ha}^{-1}\text{)} = \text{O.C (\%)} \times \text{BD (Mg m}^{-3}\text{)} \\ \times \text{soil depth (m)} \times 100$$

$$C \text{ sequestration (Mg C ha}^{-1}\text{soil)} = \text{Current SOC} - \text{initial SOC}$$

$$C \text{ build up rate (Mg C ha}^{-1}\text{y}^{-1}\text{)} = \frac{C_{\text{fert+org or } C_{\text{fert or } C_{\text{org}}} - C_{\text{cont}}}{\text{Years of experimentation}}$$

$$\%C \text{ build up} = \frac{C_{\text{fert+org or } C_{\text{fert or } C_{\text{org}}} - C_{\text{cont}}}{C_{\text{cont}}} \times 10$$

The data were analysed using randomized block design (RBD). Statistical analysis was performed by DOS-based SPSS version 17.0. The SPSS procedure was used for analysis of variance (ANOVA) to determine the statistical significance of treatments. The 5.0% probability level is regarded as statistically significant.

Economics of carbon sequestration

The cost of cultivation of rice crop under different treatments was calculated separately by taking into account prices of various inputs included land preparation, seed, fertilizers, charges of human labor, fertilizer application, plant protection, harvesting, and threshing per ha. Returns were calculated taking into account price of the rice. The cost and returns were calculated using current market prices of inputs and rice (minimum support price offered by the Government of India- Rs. 1400/100 kg rice). Net income was calculated as the difference between gross income and total costs of inputs.

Results and Discussion

Soil physico-chemical properties

Changes in basic physico-chemical properties of the soils under different treatments are

presented in table 1. The soils were alkali in reaction with pH_w and pH_{Ca} ranging from 8.17 to 8.43 and 7.26 to 7.63, respectively. Results also showed that soil pH_w and pH_{Ca} decreased significantly under FYM treatment, in other treatments they were at par. The lowest pH_w and pH_{Ca} (8.17 and 7.26, respectively) were observed in FYM treatment. However, highest pH_w (8.43) under control, pH_{Ca} (7.63) under fallow treatment were observed. The pH of the soils was lower in all the treatments when measured in 0.01M CaCl_2 solution (pH_{Ca}). On an average, pH_{Ca} was about 0.81 units less than that of the pH_w irrespective of treatments.

The bulk density values of the soils under different treatments varied from 1.38 to 1.50 Mg m^{-3} (Table 1). The FYM treatment had the lowest bulk density value at *i.e.*, 1.38 Mg m^{-3} . Soil BD decreased with the application of FYM because of increase in SOC concentration and the root biomass (Halvorson *et al.*, 1999).

The attendant increase in aggregation and macroporosity improved soil tilth and aeration (Du *et al.*, 2009). Soil BD was negatively correlated with SOC concentration ($Y = -1.887x + 3.555$, $R^2 = 0.63$).

The oxidizable organic C content of the soils varied from 7.5 to 10.3 g kg^{-1} among the treatments; on an average, its magnitude had the following orders: FYM (10.3 g kg^{-1}) > RDF+FYM (9.4 g kg^{-1}) > 150% RDF (8.8 g kg^{-1}) > RDF (8.7 g kg^{-1}) > 50% RDF (8.0 g kg^{-1}) > fallow (7.9 g kg^{-1}) > Control (7.5 g kg^{-1}) treatments (Table 3).

Yield and plant derived C inputs into soil

On an average, grain yield was higher for both seasons (*kharif* and *rabi*) with RDF along with FYM than only RDF or other treatments (Fig. 1 and Table 2). Crop residues left over in the fields were computed from the

existing database in literature taking into consideration the data of biomass yield obtained during the whole period of experimentation (Table 4). The cumulative C input values for the studied cropping systems were computed using harvested yield data for the last 14 years (2000–2014). Empirical equations were used to estimate crop residue-derived C inputs. Stubble biomass and rhizodeposition C of rice, was assumed to be 2.5 and 15% of total above ground biomass at maturity and root biomass assumed as 19 and 14 % of total above ground biomass for control and other fertilized treatments, respectively (Bronson *et al.*, 1998). The extra C input through photosynthetic aquatic organism of rice was also accounted for following Saito and Watanabe (1978). The estimated C concentrations of rice stubbles and root residues were 31.8 and 41.2%, while mean C concentrations of FYM were 26.35%, respectively. Following the procedure as stated above, an estimate of plant derived C inputs into the soils was made (Table 4).

Results from the yield data showed that the yields were significantly ($p < 0.05$) increased with the application of different inorganic, organic inputs as compared to control. The rice crop productivity was also calculated through sustainable yield index (SYI) using yield data of 14 years, to offset annual variation in the yield and to highlight

treatment impact over the years (Table 2). The annual C inputs value was significantly ($p < 0.05$) higher in FYM treatment (4.05 Mg ha⁻¹) as compared to the others, as more amount of C (1.96 Mg ha⁻¹) was added through FYM (Srilatha *et al.*, 2013). Cultivation with or without inorganics and organics (RDF+FYM and control) produced 1.05 and 2.13 fold lower annual C inputs than FYM treatment (Table 4). Balanced fertilization with organics has improved crop yields, subsequently contributed the high amount of C inputs into the soils. Similar observations have also been reported by others (Mandal *et al.*, 2007; Majumder *et al.*, 2008; Gupta Choudhury, 2011).

C sequestration

Cultivation over the years with control and 50% RDF caused a net decrease in both SOC (8.6 and 3.6% of the fallow, respectively). Double rice cultivation needs intensive tillage, puddling thereby destroying soil structure, and subsequently affecting distribution and stability of the aggregates (Six *et al.*, 2002) which resulted in declining carbon content of soils. Our results are in line with Mandal *et al.*, (2007) and Majumder *et al.*, (2007, 2008) who reported similar magnitude of SOC depletion (2-15% of fallow).

Table.1 Some basic physico-chemical properties of experimental soils

Treatment	pHw	pHca	EC (mS/m)	BD (Mg m ⁻³)	OC (%)
Control	8.43 ^a	7.61 ^a	4.34 ^a	1.45 ^b	0.75 ^d
50% RDF	8.33 ^{ab}	7.52 ^{ab}	4.57 ^a	1.43 ^{bc}	0.80 ^{cd}
RDF	8.31 ^a	7.56 ^{ab}	3.69 ^{bc}	1.42 ^{bcd}	0.87 ^{bc}
150% RDF	8.35 ^a	7.51 ^{ab}	3.47 ^c	1.39 ^{cd}	0.88 ^b
RDF+FYM	8.20 ^{bc}	7.39 ^{bc}	3.64 ^{bc}	1.40 ^{bcd}	0.94 ^b
FYM	8.17 ^c	7.26 ^c	3.40 ^c	1.38 ^d	1.03 ^a
Fallow	8.41 ^a	7.63 ^a	4.14 ^{ab}	1.50 ^a	0.79 ^{cd}

Table.2 Mean seasonal grain yield (Mg ha⁻¹) and sustainable yield index (SYI) Under different treatments

Treatment	Kharif	Rabi	Annual productivity	SYI
Control	3.22 ^b	2.59 ^b	5.81 ^b	0.57
50% RDF	4.74 ^a	3.90 ^a	8.64 ^a	0.61
RDF	5.60 ^a	4.87 ^a	10.47 ^a	0.68
150% RDF	4.53 ^a	3.41 ^{ab}	7.95 ^a	0.68
RDF+FYM	5.86 ^a	5.16 ^a	11.02 ^a	0.70
FYM	4.33 ^{ab}	3.52 ^{ab}	7.85 ^a	0.63

Table.3 Influence of treatments on SOC sequestration

Treatment	OC (g kg ⁻¹)	C stock (Mg ha ⁻¹)	C Sequestered (Mg ha ⁻¹)	Rate of C sequestration (Mg ha ⁻¹ y ⁻¹)
Initial	7.9 ^{cd}	17.4 ^{cd}	-	-
Control	7.5 ^d	16.4 ^d	-1.06 ^d	-
50% RDF	8.0 ^{cd}	17.1 ^{cd}	-0.28 ^{cd}	-
RDF	8.7 ^{bc}	18.5 ^{bc}	1.05 ^{bc}	0.08
150% RDF	8.8 ^b	18.4 ^{bc}	0.99 ^{bc}	0.07
RDF+FYM	9.4 ^b	19.9 ^{ab}	2.43 ^{ab}	0.17
FYM	10.3 ^a	21.3 ^a	3.85 ^a	0.27
Fallow	7.9 ^{cd}	17.8 ^{cd}	0.34 ^{cd}	0.02

Table.4 Annual C inputs (Mg ha⁻¹) returned to soil from rice-rice cropping system

Treatments	BC Stub	BC Root	C Rhiz	BC Aqua	Organic ammended C	Annual C input
Control	0.09	0.93	0.73	0.14		1.90
50% RDF	0.13	0.97	1.04	0.14		2.28
RDF	0.16	1.17	1.25	0.14		2.72
150% RDF	0.13	0.93	1.00	0.14		2.20
RDF+FYM	0.17	1.24	1.32	0.14	0.98	3.85
FYM	0.12	0.88	0.95	0.14	1.96	4.05

Table.5 Cumulative grain yield and benefit: cost ratio under different Management practices in double rice cropping system

Treatment	Grain yield t ha ⁻¹	Cost 000' □ ha ⁻¹	Returns 000' □ ha ⁻¹	Net returns 000' □ ha ⁻¹	B:C
Control	81	398	1140	7412	1.9
50% RDF	121	471	1691	1220	2.6
RDF	146	543	2050	1506	2.8
150% RDF	161	616	2250	1634	2.7
RDF+FYM	155	823	2163	1340	1.6
FYM	109	958	1532	574	0.6

Fig.1 Annual grain yield (Mg ha⁻¹) of rice under different treatments (2000-2014)

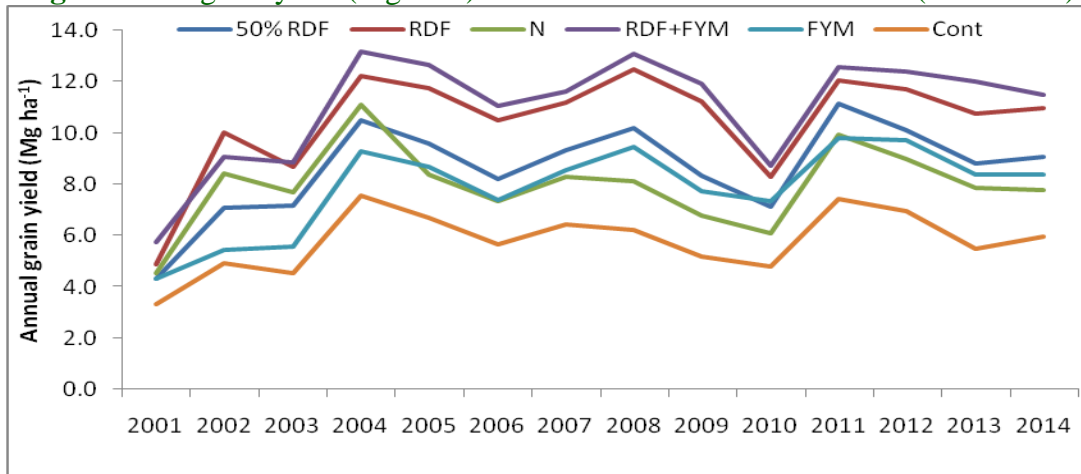
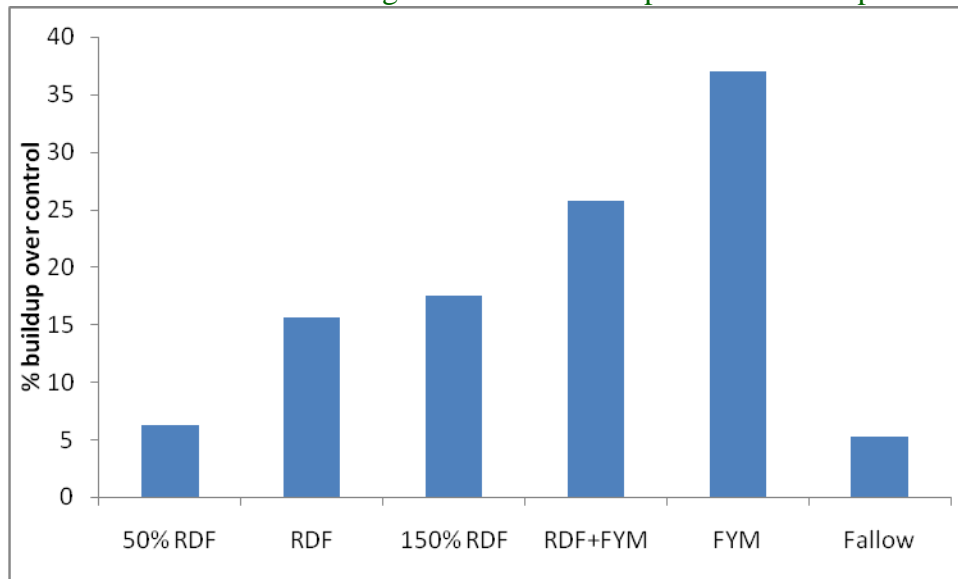


Fig.2 Influence of treatments on organic carbon build up in soil with respect to control



The 14 years of long term double rice cultivation in *Inceptisol* under different treatments resulted in a net gain or sequestration of SOC with the magnitude of: FYM (3.85 Mg ha⁻¹) > RDF+FYM (2.43 Mg ha⁻¹) > RDF (1.05 Mg ha⁻¹) > 150% RDF (0.99Mg ha⁻¹) > fallow (0.34 Mg ha⁻¹) but a loss or depletion in 50% RDF (0.28 Mg ha⁻¹) and control (1.066 Mg ha⁻¹). However, the rate of depletion in 50% RDF and control was very low. On the other hand, FYM exhibited a high rate of SOC sequestration (0.27 Mg ha⁻¹ y⁻¹) than RDF+FYM (0.17 Mg ha⁻¹ y⁻¹). This may be due to a lower amount of C input

accumulation in RDF+FYM than FYM treatment. The rate of sequestration also varied maintaining the same trend (Table 3). The treatment where only organics (FYM) was applied showed 37 % C build up with a rate of 0.27 Mg C ha⁻¹ y⁻¹ as compared to the control treatment (Fig. 2).

Economics of yields

Benefit, cost ratio calculated for different treatments showed that RDF treatment help to get more profits over other treatments. B: C ratio increased with increasing dose of

fertilization upto 100% RDF then decreased under 150% RDF (Table 5). In 150% RDF treatments yields were increased but the cost of inputs were greater than the increased yield price, hence B: C ratio declined. Organic applied treatment, RDF+FYM and FYM showed lower B: C ratio (1.6 and 0.6, respectively), as the cost of organic inputs (FYM) were greater.

Results indicating that RDF treatment can bring more profits to the farmers but failed to maintain soil sustainability, on the other hand FYM treatment can fix more C and have greater potential to maintain soil sustainability and quality but failed to bring good profits. But integrated treatment RDF+FYM capable of generating more profits besides maintaining soil sustainability. This was also supported by greater SYI if RDF+FYM treatments.

In conclusion, Organics (FYM) applied plots showed significantly ($p < 0.05$) lower bulk density and greater annual carbon inputs. Sole FYM applied plots showed greater amount of C sequestration (3.9 Mg ha^{-1}) followed by RDF+FYM (2.4 Mg ha^{-1}) > RDF (1.1 Mg ha^{-1}) > 150% RDF (1.0 Mg ha^{-1}) > fallow (0.3 Mg ha^{-1}), but depleted in 50% RDF (-0.28 Mg ha^{-1}) and control (-1.1 Mg ha^{-1}). RDF+FYM treatment showed greater crop yield sustainability (SYI) and sequestered more C, however RDF showed greater benefit: cost ratio but lower SYI and C sequestered. Hence we could conclude that RDF+FYM treatment could maintain soil sustainability and health for long time with good benefit: cost ratio.

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