Original Research Article

Rice-based climate resilient farming practices influencing the soil physical parameters, carbon dynamics and system productivity in *Inceptisols* under coastal agro-ecosystem

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ABSTRACT

A field experiment was carried out to assess the influence of different rice establishment technique {System of Rice Intensification (SRI) and Conventional method of transplanting (CMT)}, rice-based cropping sequence {rice-groundnut-fallow (RGF) and rice-toria-greengram (RTG)}, mulching practices {No mulching (WoM) and Crop residue mulch (CRM)} and nutrient management practices{100% recommended dose of fertilizer (RDF) and 75% RDF + 25% N through FYM (INM)} on the different physical properties of the soil under changing climate at the Central Research Station, Odisha University of Agriculture and Technology, Bhubaneswar in the East and South Eastern Coastal Plain Zone of Odisha, India. The field experiment was conducted in split-plot design replicated thrice. Considerable build-up of SOC by 5.2%, 10.3% and 13.9% was observed under RTG, CRM and INM over RGF, WoM and RDF, respectively. Both CRM and INM registered higher proportion of water stable micro (14.8 %and 15.7 %) and macro-aggregates (5.2 % and 9.2 %), respectively over WoM and RDF. The CRM and INM remarkably elevated the macro-aggregate carbon by 13.9 % and 15.7 %, respectively over the initial contents (10.2 g kg-1). Additionally, the RGF and CRM recorded significantly higher REY of 9.2 t ha-1 and 9 t ha-1 over RTG and WoM treatments, respectively. Thus, SRI system along with mulching rice straw in toria and toria biomass to green gram and INM practices has been identified as the most suitable climate resilient farming practice in the coastal agro-ecosystem of Odisha, India because of its significant impact in soil physical properties including carbon storage, and thus synergizing effects for favourable soil ecosystem functioning.

Keywords: Bulk density, Crop residue, Integrated nutrient management, Rice-based cropping system, Soil organic carbon, System of rice intensification, **carbon dynamics, climate resilient, farming practices**

1. INTRODUCTION

Due to increased quantities of emission of a variety of greenhouse gases (GHGs) into the aerial atmosphere, of which carbon and nitrogen containing gases are the most significant, the global climate is changing and placing prodigious pressure on the productivity and sustainability of agricultural output globally. The IPCC [1] revealed that between 0.7 and 2.1 gigatons of carbon are lost annually due to land use transformation and associated land degradation processes (such as erosion, tillage work, combustion of biomass, excessive fertilizer usage, and residue clean-up). This represents more than half of the carbon absorbed by land. A changed climate will negatively affect the diverse soil properties and processes since soils are inextricably related to the atmospheric complexity through the microbial mediated nutrient and hydrological cycles [2]. The prospect of further fluctuations and the swelling scale of budding climate change impressions necessitate addressing agricultural mitigation and adaptation measures more coherently.To slow down the footprints of climate alteration, soil organic carbon (SOC) storage has received a lot of attention [3]. Most of the pedological parameters, like the soil textural class, depth, bulk or particle density, aeration, the fraction of coarse fragments etc. determine the likelihood of carbon storage. Apart from this, the level of SOC in a specific soil relies on many factors counting land use and its management, diverse cropping sequences, residue mediated cohesive nutrient application and microbial traits. SOC is the core of soil health and its decrement in soil has an adverse impact on overall soil healthiness. Reduction in SOC also reduces microbial biomass carbon (MBC) as SOC is the prime source of nutrition for the assorted microflora, and reduces soil aggregation, porosity, and soil moisture content [4], which necessitates the need for climate-resilient agricultural practices to improve soil quality, increase SOC, and feed India's estimated 1.48-billion population by 2030. The labile pools of SOC act as the nutrient reservoir in soil, which could easily deplete if need arises [5]. On the other context, these pools of soil organic matter (SOM) have a quick turnover spell [6], and are highly delicate to alteration in land management, crop establishment and cropping patterns [7-8].

Based on Agricultural Statistics at a Glance's report [9], rice provides food for over 50 per cent of the world's 8 billion burgeoning population, is the main source of nutrition for over 60% of millions of India’s populaces and provides breathing for 120-140 million people living in the countryside. As reported [10-12], rice-based cropping methods are widely used throughout the nation and, more specifically, in eastern India. Methane emissions from rice production are significant [13-14]. When paddies are submerged under water, the soil's conditions are almost ideal for producing methane. A variety of rice planting techniques, such as aerophilic rice production and SRI, have been shown to lessen GHG emanations from different scenarios of rice fields [15]. This is because SRI encompasses cultivating rice in nearly saturated soil environments with reduced water, which is conducive to curtailing methane emissions and uses 20–30% less water than conventional planting.Additionally, this practice enhances soil's physicochemical and biotic characteristics, scaling up the throughput of ensuing crops in succession. Cropping order involving legumes helps in biological nitrogen fixation, thus modifying crop fertilization schedule [16]. Legumes can only realistically be included in wide arena of eastern India as a post-paddy crop cultivated on remaining soil moisture. The build-up, complex dynamism, and transfer of inorganic soil N to a succeeding rice crop [17] can be significantly impacted by post-rice legumes [18]. A large portion of the Indian population relies on legumes as the primary component of their usual diet since, when combined with cereals, they offer a great blend of vegetarian protein with a substantial amount of biological value [19]. Legumes also can help the soil recover. Similar to how adding oilseed crops impacts the nutritional security of a cropping system, their greater market price also alters the cropping system's profitability [20].

Crop residue mulching increases nutrients accessible [21], maintains soil temperature [22], promotes beneficial soil microbial happenings, increases SOM and facilitates storage of carbon leading to carbon sequestration [22], inhibits proliferation of weeds, elevates produce quality, and ultimately increases crop health and production. So, mulching may be an effective adaptive measure to changing climate. But there is a huge competition for residue for the production of biofuel as well [23]. So, a strategy dubbed integrated nutrient management (INM) aims to boost agricultural output while preserving the ecosystem for future generations. It is an approach that combines both inorganic and organic plant nutrients to increase crop yield, stop soil erosion, and contribute to meeting future humanity's dietary needs. Ineffective dealing with inorganic fertilizers results in greater costs, environmental damage, and an upsurge in the release of GHGs, including CH4 and N2O, which contribute significantly to global temperature alterations [24]. A good quality organic input like farmyard manure (FYM) with the lower dose of chemical fertilizers augments enzyme activities within the rhizosphere and improves the MBC, MBN and SOC, thereby reducing the emission of GHGs [25].

Thus, the present study on climate resilient farming practices was carried out to assess sustainable rice-based farming practices (crop establishment technique, cropping system, mulching, and nutrient management) in coastal agro-ecosystem and their carbon storage potential and the impact of rice-based farming practices on soil attributes including soil physicochemical attributes. The study's conclusions will augment the knowledge of climate resilient farming practices in coastal agro-ecosystems.

2. MATERIAL AND METHODS

The experiment was conducted in the B-block farm of the “Central Research Farm of Odisha University of Agriculture and Technology, Bhubaneswar, Odisha” with geo-codes of 20015´ N Latitude and 85052´E Longitude and 25.9 m above MSL. The farm hails from the “East and South Eastern Coastal Plain” amongst “Odisha’s ten agro-climatic Zone”. The soil of the experimental site was developed from alluvium and is nearly level (slope of 0 -1 %), sandy loam in textural class, slightly acidic (pH 6.2), and belongs to the soil order Typic Epiaquepts. The experiment conducted was 5th cropping year of the ongoing “Long-Term Experiment of the All India Coordinated Research Project (AICRP) on Integrated farming system (IFS)” that was established during 2011-12. A subtropical climate with a boiling and humid summer (March–June), a warm and rainy monsoon (mid-June to mid-October), and a pleasant and dry winter (November–February) best describes the climate of the trial site. The annual mean rainfall is only 1527.4 mm, roughly 75% of that total fall between June and September. The mean seasonal max temperature was 33.1°C, and the min temperature was 22.1°C alongside a variation of RH in 39-82% from Feb to July (Fig. 1). The precipitation volume received throughout the growing period of 2015-16 (1631.5 mm) indicates an above normal rainfall year.

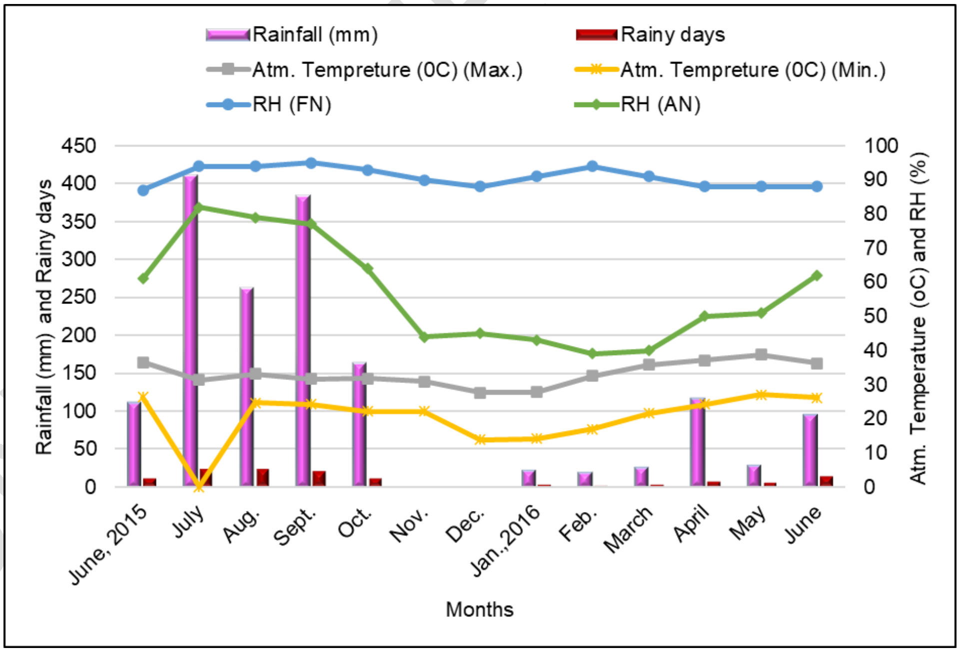

Fig. 1. Monthly meteorological data during the cropping season of 2015-16 (RH: Relative humidity; FN: Forenoon; AN: Afternoon)

2.1Crop management and data collection

In a moist nursery bed, rice seedlings were raised. Before sowing, the seeds were immersed in regular water for 12 hours and incubated in a gunny bag for about 24 hours. On the muddy ground near the main field, raised beds were created that were 8–10 cm high and 1.0 m wide. The raised beds were sprayed with a concoction of well-mixed soil and FYM in a ratio of 1:1 until they were about 5 cm deep. Separate lines of 50 g m-2 sprouted seeds were sown. The sprouting seeds were covered with a concoction of soil and FYM that had been thoroughly mixed, and the beds were kept moist using effective water management techniques. Seedlings of 12- and 25 days-old were planted under SRI and CMT, respectively. The main field was ploughed by a tractor mounted cage wheel. Two raised beds of 1.5 m width interspersed with a channel width of 30 cm were made in each plot for SRI. The beds were levelled carefully so that water would not stagnate at any place on the bed. Fertilizers and well decomposed FYM as per the treatments were broadcasted and incorporated thoroughly in the bed. One 12-day-old young plant was placed with its soil and linked seed (embryo) on the grids that the marker had marked. 25-day-old seedlings were transplanted using the traditional method on levelled fields, 2-3 per hill, at 200 sq. cm spacings. Without altering the permanent layout, field operations were carried out in the summer and rabi seasons after harvesting the earlier crops. The crop varieties used are Naveen, Smruti, Parvati and IPM-02-14 for rice, groundnut, toria, and greengram, respectively. The seed rate and spacing used, manure and fertilizer applied for different crops are given in Table 2. The manures and fertilizers as per the treatments were applied through FYM (0.5-0.2-0.5 % N2-P2O5-K2O), urea (46 % N2), SSP (16% P2O5) and MOP (60% K2O). A full dosage of FYM, phosphorous (P) and potassium (K) and one-fourth of nitrogen(K) were applied immediately after layout of the experiment. The top dressing of nitrogen was undertaken twice, half at 10-15 days afterward transplanting (just before 1st weeding) and the remaining one-fourth at panicle initiation. The composition of FYM, rice straw and toria biomass is represented in Table 3. Following up the first intercultural operations between 21 and 30 DAS, the corresponding crops of rabi and summer were mulched with the preceding crops residues 5.5 t ha-1 and 3.5 t ha-1, respectively.

Table 1. Treatment Details

Treatments			
Main plots	**Sub plots**		
SRI	RGF	WoM+ RDF	(Where, SRI: "System of Rice Intensification"; CMT: "Conventional method of transplanting"; RGF: "rice-groundnut-fallow"; RTG: "rice-toria-greengram"; WoM: "No mulching"; CRM: "Crop residue mulch to *rabi* and summercrops only"; RDF: "100% recommended dose of fertilizer"; INM: "75% RDF + 25% N through FYM to all the crops")
	RGF	WoM + INM	
	RGF	CRM + RDF	
	RGF	CRM + INM	
	RTG	WoM+ RDF	
	RTG	WoM + INM	
	RTG	CRM + RDF	
	RTG	CRM + INM	
CMT	RGF	WoM+ RDF	
	RGF	WoM + INM	
	RGF	CRM + RDF	
	RGF	CRM + INM	

	RTG	WoM+ RDF	
	RTG	WoM + INM	
	RTG	CRM + RDF	
	RTG	CRM + INM	

Table 2. Seed rate, spacing, manure and fertilizer for different crops

Crop	Seed rate (kg ha^{-1})	Spacing (cm)		Manure (t ha $^{-1}$)	Fertilizer applied (kg ha-1)					
					N					
		Row to row	Plant to plant		Basal	1st topdressing	2nd topdressing	Total	P_2O_5	K_2O
Rice (SRI)	5	25	25	4	20	40	20	80	40	40
Rice (CMT)	50	20	10	4	20	40	20	80	40	40
Ground-nut	175	30	10	1	20	-	-	20	40	40
Toria	10	30	10	3	30	30	-	60	30	30
Green-gram	25	25	10	1	20	-	-	20	40	20

Table 3. Composition of FYM, rice straw and toria biomass

	C (%)	N (%)	P (%)	K (%)	C:N
FYM	20.0	0.50	0.26	0.49	33.3:1
Rice straw	40.0	0.80	0.26	1.60	50:1
Toria biomass	38.0	0.50	0.15	1.60	76:1

Employing a cono-weeder, weeding for the SRI approach was done thrice at 10-day periods beginning 10 days after transplanting (DAT). The cono-weeder was used carefully so that there would not be any disturbance to the plants in the rows but there was proper churning of the weeds along with mud. Two hand weeding were completed at 20 and 35 DAT of CMT rice. At 20 and 35 DAS, two hoeing and weeding operations were carried out on the rabi crops. To maintain the ideal plant population, thinning in toria was done 15 to 20 DAS. Two manual weeding were performed in the summer crop at 15 and 35 DAS.

Yellow and well ripened panicles from each subplot was harvested. Before being threshed using an axial flow thresher that was powered, the harvest was 4-5 days sun dried. Ground nuts and toria were harvested for grain during the rabi season. Following thorough sun drying, the yield data had a reduced moisture content of 6-8% for oilseeds and 10% for pulses. Following sun drying all the crops to a moisture content of 14 and 15%, the by-product yields of each crop were measured. Greengram was harvested in the summer when 80 to 90 per cent of the pods had dried. Grain yields were reported after full sun drying to lower the moisture content in greengram to 10%. After seven days of solar drying, by-product yields were collected with a roughly 14–15% moisture level.

2.2 Collection and preparation of soil sample

Composite soil samples were obtained from each treatment plot using standard procedures of soil collection and sample preparation from 0-15 cm depth initially (2011-12) and at the end of the 5th cropping cycle (2015-16) and kept safely in the laboratory for further analysis of various soil physicochemical properties.

100 g of dehydrated soil was used to determine the water stable aggregates (WSA) and carbon associated (WSAC). Field damp samples were softly decanted through a 10 mm filter and desiccated at 40 ˚C for 48 hours. A different percentage of the sieved soils was air dried for 2–3 days before being used to calculate the SOC, total carbon content, and water-holding capacity (WHC). To calculate the soil BD, undisturbed core samples were obtained from all treatments at a depth of 0 to 15 cm with the help of a core sampler. Samples were obtained at 15 cm intervals from 0 to 105 cm to measure SOC. Soil cores from the same depth ranges were collected to determine BD, carbon stock and carbon sequestration rate. The BD of the experimental plots was analyzed by the standard procedure of the core sampler method [26], as illustrated in equation (1). First, a cylindrical metal of known volume was driven into a desired depth. Then, the complete core was removed, dried in an automated oven, and weighed.

BD (Mg m^{-3}) = Dry wt. of bulk sample /Volume of soil core ………… (1)

The measurements of the maximum WHC of the soil were calculated by standard Keen Raczkowski box technique as elucidated by Piper [27] given in equation (2). A filter paper was positioned at the bottom of the box. The soil was packed by taping the box several times on a wooden bench. A small portion of the soil was further added to the box and tapped as before. Finally, the box top was levelled by striking off the spare soil. The box was sited in a petri-dish comprising water and was left for 10-12 hrs. The box holding the saturated soil was removed from the petri-dish, weight was noted down and finally dried up in an automated oven and the corresponding weight was recorded.

Maximum Water Holding Capacity (%) = $[\{(c-a) – B\} / B] \times 100$ …………(2)

Where, [B = {(100 - m) (b - a)} / 100, a = box + filter paper weight, b = box+ air-dry soil weight, c = box + wet saturated soil weight, m = Water content of the air-dry soil, V= Internal volume of the box]

Wet sieving method was employed to assess the WSA in the soils using a 250 m and 53 m mesh sieve [28]. 100 gm 8 mm sieved soil was wetted in deionized water for 5 minutes. Sieves were manually shaken while the sample was submerged to separate the aggregates. The same process was carried out with sodium hexametaphosphate at 50% strength. The two aggregate fractions were obtained using a succession of two sieves of each 0.25 and 0.053 mm: (1) 0.25-2 mm for macro-aggregates, and (2) 0.053-0.25 mm for micro-aggregate. Different sieves used to separate soil aggregates fraction were dried up in an oven and was stated in percentages as given in equation (3) and (4).

Water stable macro aggregate = $((a-b)/c) \times 100$ ………….. (3)

Water stable micro aggregate = $((d-e)/c) \times 100$ ……………(4)

Where, “a” is Oven dried weight of 0.25 mm sieve after sieving in deionized water; “b” is oven dried weight of 0.25 mm sieve after sieving in Na-hexametaphosphate; “c” is weight of original soil used; “d” is oven dried weight of 0.053 mm sieve after sieving in deionized water and “e” is oven dried weight of 0.053 mm sieve after sieving in Na-hexametaphosphate.

The SOC was assessed by “modified Walkley and Black’s rapid titration technique” [29-30] using ferroin indicator. The soil total carbon (STC) was analysed by “dry combustion method” as per the standard protocol outlined [31]. The carbon content of both macro and micro aggregates was determined by taking a known weight of aggregate fraction for wet oxidation as per the standard procedure [32]. The SOC stock for a layer in the soil profile was estimated by equation (5).

SOC stock (Mg ha−1) = $A \times B \times C \times D$ ………………..(5)

Where [A = Area of 1 ha land (10000 CRM), B = BD of soil (Mg m-3), C = SOC (%), D = Soil depth (m)]

The carbon sequestration rate (CSR) can be estimated using equation (6).

CSR (Mg C ha-1 yr-1) = (C stock in soil after 5th years of experiment – C stock in soil before experiment initiation)/no. of years i.e., 5 …………………..(6)

The rice equivalent yield can be estimated as given in the equation (10).

REY (kg ha-1) = {(Yield of rice × MSP of rice) + (Yield of groundnut × MSP of groundnut) + (Yield of toria × MSP of toria) + (Yield of greengram × MSP of greengram)}/MSP of rice.(10)

Where, MSP is the Minimum support price issued each year before cropping year begins

Based on the current market worth for the price of the inputs and the value of the harvest, the monetary implications of production for various systems were computed. The cost ratio was computed for gross and net returns and benefits.

2.3 Statistical analysis

"Analysis of variance (ANOVA) techniques" that are appropriate to the split-plot design were used to assess the data provided in the current study statistically. The "F-test" was used to establish the statistical significance of the treatment effect, and the "least significant differences (LSD) at the 5% probability level" were used to corroborate the treatment means.

3. RESULTS AND DISCUSSION

3.1 Soil bulk density (BD) and water holding capacity (WHC)

Method of rice establishment did not significantly influence soil BD and WHC. The soil BD was influenced by various cropping systems, mulching and integrated nutrient management techniques at the end of the 5th cropping cycle are presented in Table 4. Inclusion of legume in RTG, CRM with crop residues and INM lowered the soil BD to 1.3 %, 1.3 % and 1.9 % over RGF, WoM and RDF, respectively. Practice of RTG, CRM with previous crop residues and INM in dry season crops lowered the BD by 1.9 %, 1.9 % and 2.6 %, respectively above initial. The lowermost BD was documented in the soils of RTG-CRM-INM under SRI system. In the current investigation, a negative correlation was observed between BD and SOC (R^2= -0.745**, Fig. 2). Treatment involving RTG, CRM and INM resulted in an increase in WHC by 4.3%, 5.3% and 6.6% over the initial values, respectively at the end of 5th cropping cycle (Table 4). The WHC increased significantly with intensive cropping system (1.1 %), mulching (3.1 %) and INM practice (5.6 %) over the years. The practice of RTG with mulch and INM registered the highest WHC of 43.2%, after 5 years of study.A strong positive correlation is existed between SOC and WHC (R^2 = 0.899**, Fig. 3).

Soil BD and WHC are important physical parameters significantly influenced by texture, organic matter, residue inputs, cropping systems, tillage type and intensity. More is the organic matter in soil; less would be the BD as SOM helps tame the soil assembly and aggregation [33-34]. Reduction of BD in the soils of RTG with mulch and FYM, in the present study, has better soil aggregation resulting in greater soil porosity with more external organic inputs and root biomass [35-36]. The negative correlation may be due to the mineralization of SOM in soils with high BD [37]. Additionally, research has suggested that BD can be affected by root architecture and development as well as soil microbial activities, and it tends to decrease with higher nutrient levels due to the creation of larger and more pores in the soil [38]. WHC is controlled by its texture, composition, tillage practices and the amount of organic matter content. The WHC of the soil is mostly influenced by the amount of clay particles and organic matter present in it. In this study, the addition of vegetative mulch and FYM and more root biomass in RTG over the years considerably increased the SOM contents, thereby improving the soil WHC [39]. It has also been reported that as the crop residue mulch decomposes gradually and the humus is added to the soil with time, increasing its water holding capacity significantly [40].

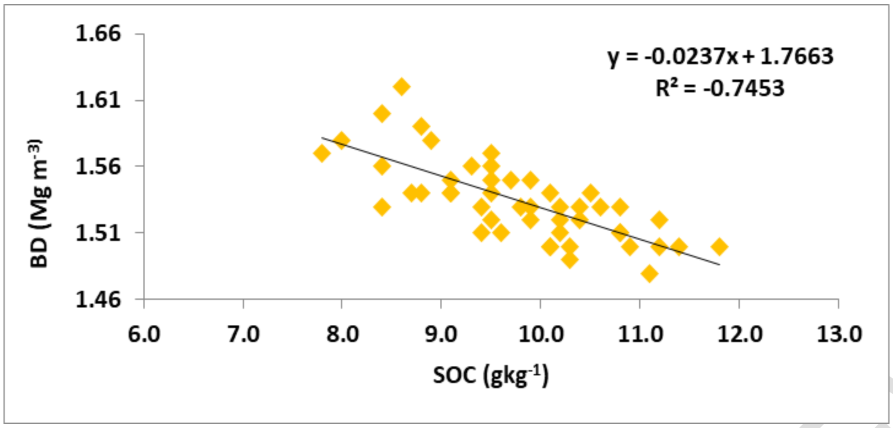

Fig. 2. Correlation of soil organic carbon (SOC) with soil bulk density (BD)

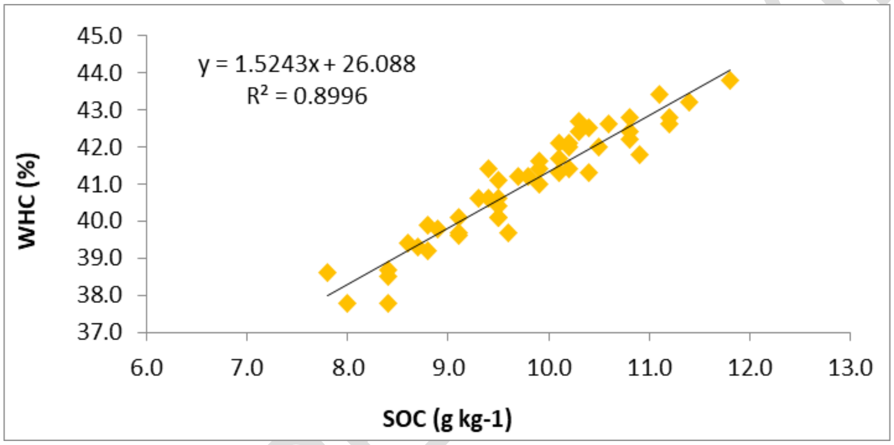

Fig 3. Correlation of soil organic carbon (SOC) with water holding capacity (WHC)

Table 4. Effect of stand establishment techniques, cropping systems, mulching and nutrient management practices on bulk density (BD), water holding capacity (WHC),soil organic carbon (SOC) and soil total carbon (STC) of soil

Particular	BD (Mg m^{-3})	WHC (%)	SOC (g kg^{-1})	STC (g kg^{-1})
Method of rice establishment				
SRI	1.52	41.17	9.9	11.8
CMT	1.53	40.84	9.68	11.52
SEm (±)	0.003	0.12	0.07	0.09
CD (0.05)	NS	NS	NS	NS
Cropping system				
RGF	1.54	40.79	9.54	11.36
RTG	1.52	41.22	10.04	11.96
SEm (±)	0.003	0.12	0.07	0.09
CD (0.05)	0.013	0.42	0.26	0.32
Mulching				
WoM	1.54	40.37	9.31	11.09
CRM	1.52	41.64	10.27	12.23
SEm (±)	0.004	0.15	0.08	0.1
CD (0.05)	0.012	0.44	0.25	0.3
Nutrient management				
RDF	1.54	39.9	9.15	10.9

INM	1.51	42.12	10.43	12.42
SEm (±)	0.004	0.15	0.08	0.1
CD (0.05)	0.012	0.44	0.24	0.3
Initial	1.55	39.5	7.3	9.2

(SRI: “System of Rice Intensification”; CMT: “Conventional method of transplanting”; RGF: “rice-groundnut-fallow”; RTG: “rice-toria-greengram”; WoM: “No mulching”; CRM: “Crop residue mulch to *rabi* and summercrops only”; RDF: “100% recommended dose of fertilizer”; INM: “75% RDF + 25% N through FYM to all the crops”

3.2 Soil Organic Carbon (SOC) and Soil Total Carbon (STC)

The SOC was substantially higher under RTG (5.2%), CRM (10.3%) and INM (13.9%) compared to RGF, WoM and RDF, respectively (Table 4). Inclusion of toria and greengram in the cropping system, mulching with the crop residues and integrated use of FYM along with RDF elevated the SOC status by 34.0 %, 37.9 % and by 36.6 % over the initial, respectively. Even though the crop establishment practices did not exhibit any significant changes in the SOC contents, the SRI soils have slightly higher SOC than CMT soils. The STC followed a similar trend to that of SOC. After 5th years of continuous cropping, RTG with CRM and INM considerably increased the STC contents by 30 %, 32.9 % and 35 %, respectively over the initial STC. Inclusion of greengram in the sequence, application of crop residue mulch in toria and greengram crops and similarly, INM increased the STC remarkably and the gain was in the tune of 5.3 %, 10.3 % and 13.9 % over RGF, WoM and RDF, respectively (Table 4).

SOC and STC are influenced most by tillage regimes, cropping systems, soil types, mulching, nutrient management practices and climate. SOC is often regarded as the most imperative indicator of soil health and quality because it’s the raw material for all the process in the soil and its restoration represents a potential sink for atmospheric CO2. Long-term management practices like crop establishment technique, crop rotation, residue recycling and organic inputs profoundly affect SOC contents' alteration. The practice of RTG rotation over the years, in the present study, significantly elevated the SOC contents because of the accumulation of more root residues and above ground litter input in the form of shredded leaves of toria and greengram [41] (Hiremath and Usha, 2019).Fallowing the soil in RGF reduced the SOC by diminishing the volume of non-harvested plant residues reimbursed to the soil [42-43]. Higher SOC in legume allow it to be included in several crop rotation due to its faster and easier decomposition by variety of microbial arena because of its lower C: N ratio residues and root nodules [44]. Continuous mulching with previous crop residues in dry seasons for five years helped build soil organic matter, resulting in higher SOC contents. As the amount of different crop residues (approximately 8 t ha-1 yr-1) returned to the soil is amplified, SOC build up is expected to upsurge in situation if the residue C is not lost as CO2 to the atmosphere because of faster decomposition [45]. Weighty upsurge in SOC was ascertained due to long term application of vegetative mulch [46-47]. The higher SOC contents due to mulching is also related to wider C:N ratio of rice straw (50:1) and mustard straw (76:1) leading to slower decomposition and turnover of SOM [48]. In the present study, the addition of FYM to rice straw and through INM practices in dry season crops each year exhibited remarkable improvement in the SOC contents of the soils, which could be ascribed to the supply and obtainability of additional mineralizable C input. It can be presumed that the use of FYM coupled with higher extent of resistant organic constituents like lignin and polyphenol which are not easily degradable by microbes, led to the creation of organic complexes and render it further to more resistant to microbial mediated disintegration [49]. STC is composed of SOC and Soil inorganic carbon (SIC). In the present study, SOC was the dominant fraction of STC as the soils belong to Inceptisols showing rare presence of carbonates in the soils that account for most of the SIC. As agricultural management practices can significantly influence STC, the same can be employed as a potential indicator of CSR than SOC [50]. Long term addition of residue inputs due to mulching and decomposed organic inputs (FYM) due to INM practice significantly enhanced the STC contents of the soil under SRI rice-toria-greengram system, which was in corroborated with the findings revealed by Rasmussen et al [51]. Incorporation of rice and mustard straw mulch with high N concentration (0.5-0.9 %), amplified turnover degree of plant C into soil C, increased the SOC contents and as the SIC under study is negligible, most of the STC can be considered as SOC [50].

3.3 Water stable aggregates (WSA) and water stable aggregate associated carbon (WSAC)

Under the practices of mulching and INM, a significant increase in the share of macro-aggregates (> 0.25 mm) was observed and the gain was in the tune of 5.2 % and 9.2 % over WoM and RDF, respectively (Table 5). The increment of macro-aggregates was spectacular in CRM and INM, as the values were higher by 9.9 % and 11.9 % over the initial status. Rice CEM and different cropping patterns did not secure any substantial effect on the proportion of soil macro-aggregates. RGF was documented with a reduced proportion of micro-aggregates (9.1%) over the soils under RTG containing 11 % micro-aggregates. CRM and INM, on the other hand, exhibited an increase of micro-aggregates in the soils by 14.8 % and 15.7 % over WoM and RDF, respectively. Various rice establishment practices had no significant changes in the proportion of micro aggregates among treatments. The positive impact of SOM on soil aggregation is defensible by the strong correlation of SOC with macro-aggregates and micro-aggregates across the treatments. The rice establishment and cropping systems method could not influence the macro-aggregate and micro-aggregate C significantly (Table 5). Residue inputs through mulching and INM have a positive consequence on macro-aggregate C status, thereby recording an improvement of 8.3 % and 11.8 % over WoM and RDF, respectively. CRM and INM, over the years, remarkably elevated the macro-aggregate C (13.9 % and 15.7 %) over the initial contents (10.2 g kg-1). Similarly, INM elevated the micro aggregate C to 5.9 % and 8.4 % over no mulch and RDF treatments and by 22.5 % and 23.9 % over the initial value, respectively, irrespective of stand establishment techniques and cropping systems.

Table 5: Effect of stand establishment techniques, cropping systems, mulching and nutrient management practices on WSA, Macro and micro-aggregate associated carbon (MaAC and MiAC) and rice equivalent yield (REY)

Particular	WSA % (Macro)	WSA % (Micro)	MaAC (g kg-1)	MiAC (g kg-1)	REY (kg ha^{-1})
Method of rice establishment					
SRI	66.3	10.51	11.41	9.51	9187
CMT	63.2	10.39	10.94	9.34	8116
SEm (±)	1.91	0.19	0.27	0.16	185
CD (0.05)	NS	NS	NS	NS	640
Cropping system					
RGF	65.8	9.95	11.54	9.53	8466
RTG	63.7	10.95	10.81	9.31	8836
SEm (±)	1.91	0.19	0.27	0.16	185
CD (0.05)	NS	0.66	NS	NS	NS
Mulching					
WoM	63.1	9.73	10.73	9.15	8263
CRM	66.4	11.17	11.62	9.69	9039
SEm (±)	0.73	0.24	0.17	0.15	159
CD (0.05)	2.14	0.7	0.51	0.43	464
Nutrient management					
RDF	61.9	9.69	10.55	9.04	8494
INM	67.6	11.21	11.8	9.8	8809
SEm (±)	0.73	0.24	0.17	0.15	159
CD (0.05)	2.14	0.7	0.51	0.43	NS
Initial	60.4	11.8	10.2	7.91	

(SRI: “System of Rice Intensification”; CMT: “Conventional method of transplanting”; RGF: “rice-groundnut-fallow”; RTG: “rice-toria-greengram”; WoM: “No mulching”; CRM: “Crop residue mulch to *rabi* and summercrops only”; RDF: “100% recommended dose of fertilizer”; INM: “75% RDF + 25% N through FYM to all the crops”)

Aggregates are often used as surrogates of the soil interrelationships and complex soil matrices and quite helpful in ascertaining the SOM dynamics. Soil structure is very narrowly allied with water stable aggregates. Any change in these aggregates is often related to the land use pattern and varying degrees of soil management practices. Aggregates shield the SOM, regulate water and air flow, and curtail run-off and erosion. Soil aggregation is one of the important processes of stabilizing SOM pools and water stable aggregate carbon (WSAC). This slow SOM pool is often delineated as a key soil quality indicator [52]. SOM is the foremost binding mediator in which the primary particles and clay domains are tiled into aggregates. Marginal increase in macro-aggregates in RGF and concomitant decrease in micro-aggregates are related to residue input and lower turnover as the soils are undisturbed during the fallow period [53]. Over the years, the addition of residue inputs in the form of mulch and organic inputs in the form of FYM elevated the share of both aggregates in the soil as the soil aggregation process is controlled largely by SOC dynamics [54]. SOM being acted upon by the diverse microflora in soil system resulted in higher synthesis of polysaccharides, natural acids, mucilage, and microbial gum. Those decomposition products acted as binding agents helping in soil aggregation [55-56]. Enhanced carbon concentrations in WSA are the main mechanism of SOC protection. Mulching and adding FYM through INM continuously for four years significantly affected the macro and micro-aggregated carbon in the soil. As Prasad et al. [57] discussed, WSAC has been viewed as a transitional fraction of SOC between the dynamic and sluggish that alter quickly in response to changes in agricultural management practices. In the current study, the higher WSAC in the soils under mulching and INM were ascribed to greater build-up of SOM, resulting in more organic matter binding micro aggregate [58]. The elevated concentration of carbon in macro-aggregates of these soils is also related to the conversion of SOM binding to both aggregates [53].

3.4 Total carbon stock (TCS) and carbon sequestration rate (CSR)

Soils under various types and degrees of management practices under SRI exhibited higher TCS (27.2 % to 64.1 %) as compared to the corresponding practices under CMT (23.6 % to 55.2 %) over the initial TCS (Table 6). The highest TCS was observed in the RTG with mulching and INM practice under SRI (61.91 Mg ha-1) followed by the same treatment under CMT (58.56 Mg ha-1). The CSR followed a similar trend as that of total C stock ranging from 2.22 to 5.0 Mg ha-1 under SRI based practices and 1.94 to 4.33 Mg ha-1 in CMT based practices. The robust linear association found between C sequestration rate and cumulative C inputs (R^2 = 0.675**, Fig. 4) corroborates these findings. The maximum C sequestration was detected in the soils under SRI-RTG with mulching and INM practices followed by the same system under CMT.

Table 6. Effect of stand establishment techniques, cropping systems, mulching and nutrient management practices on TCS and CSR

Treatments		TCS (Mg ha^{-1})	CSR (Mg ha^{-1} yr^{-1})
SRI	RGF-WOM-RDF	48.01	2.22
	RGF-WOM-INM	52.3	3.08
	RGF-CRM-RDF	53.47	3.31
	RGF-CRM-INM	61.42	4.9
	RTG-WOM-RDF	48.6	2.33
	RTG WOMINM	55.13	3.64
	RTG-CRM-RDF	55.97	3.81
	RTG-CRM-INM	61.91	5
CMT	RGF-WOM-RDF	46.62	1.94
	RGF-WOM-INM	50.71	2.76
	RGF-CRM-RDF	53.01	3.22
	RGF-CRM-INM	57.86	4.19
	RTG-WOM-RDF	46.88	1.99
	RTG WOMINM	53.09	3.23
	RTG-CRM-RDF	53.93	3.4
	RTG-CRM-INM	58.56	4.33
Initial		37.73	

(SRI: “System of Rice Intensification”; CMT: “Conventional method of transplanting”; RGF: “rice-groundnut-fallow”; RTG: “rice-toria-greengram”; WoM: “No mulching”; CRM: “Crop residue mulch to *rabi* and summercrops only”; RDF: “100% recommended dose of fertilizer”; INM: “75% RDF + 25% N through FYM to all the crops”)

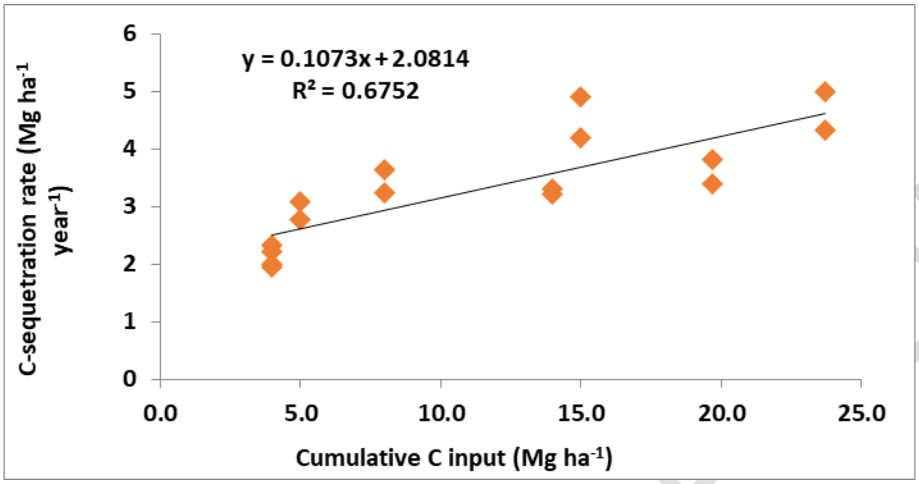

Fig 4. Correlation of C sequestration rate with cumulative C inputs

In agriculture, CSR implies the ability of agricultural areas to absorb CO2 from the atmosphere and depends on the temperature, type of soil, kind of crop or vegetation cover, and management techniques. The balance of carbon addition from organic sources, such as the unharvested crop fraction, and carbon loss, mostly from SOM decomposition, determine how much carbon is stored in soils. SOC stock retorts linearly to growing rate of residue C generated by crop biomass or addition in both short term and LTE [59]. Regarding CSR potential, the robust linear relationship between C input and rate of C sequestration specifies that the soils under this study were not C saturated [60]. The elevated SOC stock and CSR under SRI system is related to more unaccounted C inputs from roots and weed biomass due to weeding (three times) by cono weeder. The RGF sequestered less C as compared to RTG sequence because of less C inputs from the above ground biomass (less mulch and FYM addition) as well as below ground biomass (roots) [61]. The type and time of vacating the field affect the amplitude of SOC stock as the alteration in intensities of undertaking crops as implied by component crops and location and climate specific practices. The higher CSR under mulching and FYM application is related to the external C inputs from these sources [62]. Besides C loading, aggregate soil dynamism also firmly interacts with CSR and C-cycling [63]. Micro-aggregate C is a pool with sluggish turnover than coarse POM or silt-clay size C fractions. Micro-aggregate C is a superlative indicator of long-term SOC sequestration.

3.11 System yield (Rice equivalent yield, REY) and economics

Adopting rice establishment methods and mulching practices significantly influenced the system yield regarding REY (Table 5). Adopting the cropping systems and the nutrient management practices produced almost similar system yield. Among the establishment methods, SRI method recorded more system yield (9187 kg REY ha-1) than the conventional system of rice establishment (8116 kg ha-1). Mulching in rabi and summer crops recorded a system yield of 9039 kg REY ha-1, 9.4 % higher than no mulch application (8263 kg REY ha-1). The cost of cultivation ranged from Rs. 93011 to 104702 ha-1 for different cropping systems. The SRI method of rice establishment incurred less cost of cultivation (by Rs. 2000) than CMT method. RTG, CRM, and INM required more investment of Rs. 4058 ha-1, Rs.1200 ha-1 and Rs. 1481 ha-1 than RGF, WoM and RDF, respectively (Fig. 5). SRI, CRM and INM fetched Rs. 14849 ha-1 and Rs. 16849 ha-1, Rs. 10967 ha-1and Rs. 9768 ha-1 and Rs. 4467 ha-1 and Rs. 2986 ha-1 more gross returns and net returns than CMT, WoM and RDF, respectively. The SRI, RTG, CRM, and INM registered higher B:C of 1.36, 1.28, 1.32 and 1.31 over CMT, RGF, WoM and RDF, respectively.

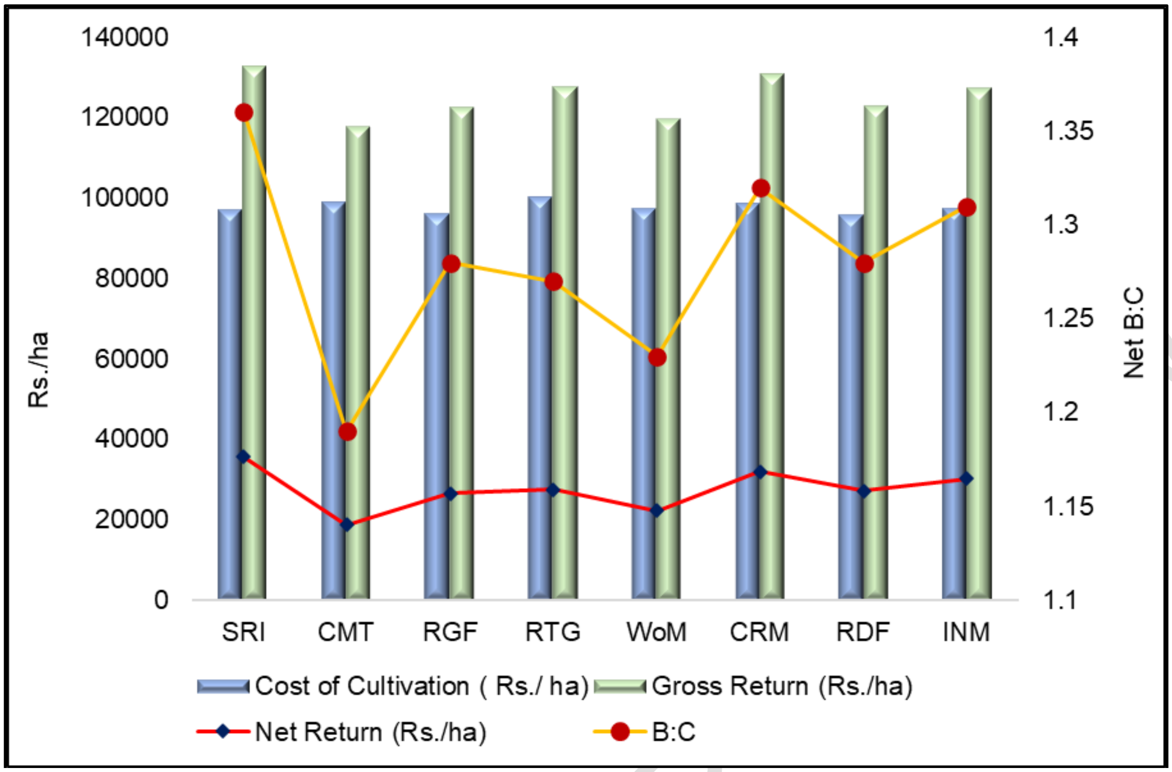

Fig. 5. Effect of stand establishment techniques, cropping system, mulching and nutrient management practices on economics of rice-based cropping systems

In the current study, system yield, reported as rice equivalent yield (REY), depends on the component crops' productivity, efficiency, and current market price. Crop production variations between different systems may result from interactions between biological and environmental variables that alter a plant's ability to express itself. The REY, net and gross returns of the SRI system were the highest with the lowest cost of cultivation because of improved soil quality due to luxuriant root growth leading to a nutrient-rich environment. The higher REY and net returns under mulching practice indicated the steady improvement in the productivity of the soils through build-up of SOM and its labile pools, favorably influencing the ecosystem functions. Even though the cropping systems and nutrient management could not influence the REY after 5th cropping year, marginally higher values under rice-toria-greengram system and under INM practice to dry season crops are related to improving overall soil qualities in these management practices. Kachroo et al. [64-65] illustrated that adding pulses and oilseed crops to cropping systems can boost agricultural productivity, resource use efficiency, profitability, sustainability, and acceptability. Furthermore, the winter crop dominated the yield in cropping systems based on rice because of higher productivity. Adding organic manure increased rice's development, yield characteristics, and yield. This increase was ascribed to an adequate supply, elevated acquisition, and better recovery of nutrients applied [66]. Organic materials, such as FYM, are advantageous in lowering the fixation or precipitation with those of the soil components of supplied or mineralized nutrients and perform a complementary role in elevating crop output [67].

4. CONCLUSIONAND RECOMENDATION

From the present study it has been concluded that the increasing SOC is a key process in both mitigation and adaptation strategies to climate change. The ability of agricultural land to store or sequester carbon depends on climate, soil type, type of crop and management practices. The SRI based farming practice, in the present investigation, though did not influence the SOC, STC, WSA and associated carbon of the soils significantly after 7 years, exhibited the potential to store large amounts of carbon, and exhibit higher carbon sequestration rate because of additional C inputs from root and incorporated weed biomass. The SRI system, mulching @ 5t/ha of rice straw in toria and 3t/ha of toria biomass to green gram and INM practices has been identified as the most suitable climate resilient farming practice in the coastal agro-ecosystem of Odisha because of its higher C storage potential, and thus synergizing effects for favorable soil ecosystem functioning. Further study on quantification of soil non-labile C fractions and methane emission, an important factor of C cycle in soils, can substantiate the present findings.

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