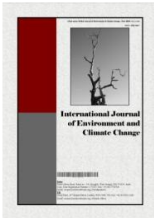

International Journal of Environment and Climate Change

10(10): 24-34, 2020; Article no.IJECC.60269
ISSN: 2581-8627
(Past name: British Journal of Environment & Climate Change, Past ISSN: 2231–4784)

Response of Conservation Agriculture on System Productivity and Carbon Sequestration in Rice-Based Cropping Systems

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Authors' contributions

This work was carried out in collaboration among all authors. Authors AKB and SC designed the study and wrote the experimental protocol. Author TP conducted the field trial and carried out the majority of the data analyses. Authors TP and SC performed the statistical analysis. Author TP wrote the first draft of the manuscript. All authors critically reviewed the results, contributed to the discussions and improved the manuscript. All authors read and approved the final manuscript.

Article Information

DOI: 10.9734/IJECC/2020/v10i1030244
Editor(s):
(1) Dr. Arjun B. Chhetri, Dalhousie University, Canada.
Reviewers:
(1) Norhidayah Abd Manan, Universiti Malaysia Terengganu (UMT), Malaysia.
(2) Dlnya Abdalla Mohammad, University of Sulaimani, Iraq.
Complete Peer review History: http://www.sdiarticle4.com/review-history/60269

Original Research Article

Received 20 June 2020
Accepted 24 August 2020
Published 03 September 2020

ABSTRACT

Low crop yields due to constant monocropping systems and deteriorating soil health in a smallholder farmers' field of Indo-Gangetic plains of India have led to a quest for sustainable production practices with greater resource use efficiencies. The aim of the study was to elucidate the short term effects of conservation agricultural systems on productivity, soil health and carbon sequestration rate of soils in three different diversified cropping systems. The treatments consisted of two different tillage systems (conventional and reduced tillage), two mulch levels (no and straw mulch) and two levels of fertility (100 and 75% RDF) were compared in three rice-based cropping systems (rice-wheat; rice-vegetable pea-greengram; and rice-potato-maize sequences) for two years on an experimental field (clay loam) located at Norman E Borlaug Crop Research Center, Pantnagar, India. The resource conservation technologies (RCT) i.e. reduced tillage, mulch, and 100% RDF had recorded 2.5 and 3.0% higher system productivity and relative production

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efficiency in rice-vegetablepea-greengram and rice-potato-maize sequences, respectively in two consecutive years. Conservation tillage had sequestered three times higher carbon than conventional tillage while mulching acted four times higher than non-mulched condition in agricultural soils. Even though cropping system not significant significantly influenced on carbon sequestration, rice-vegetablepea-greengram sequence had recorded higher carbon sequestration rate and higher soil organic carbon stock noted in surface plough sole layer than any other cropping systems. Therefore, our results suggested that Indo-Gangetic farmers should consider adopting resource conservation practices together in indogangetic area because of benefits to soil health, carbon sequestration and system productivity.

Keywords: Cropping system; C-sequestration; mulch; reduced tillage; rice; soil health.

1. INTRODUCTION

Agriculture is a keystone of the Indian economy. Tillage has particularly, been an important aspect of technological development in the evolution of Indian agriculture, in meticulous in food production. Soil tillage is one of the fundamental agro-technical operations in agriculture because of its influence on soil properties (physical, chemical and biological), environment and crop growth [1]. Tillage creates soil environment favourable for plant growth. Though the continuous use of conventional tillage operations makes the soil more compact and a hardpan is usually developed underneath the plough layer which hinders the movement of water and air, inhibits root growth, and reduces crop yield [2]. Additionally, the soils are generally unproductive and the condition is aggravated by the limited use of external nutrient inputs [3,4]. Therefore, restoring and retaining soil productivity remains a key challenge for smallholder agriculture in the Indo-Gangetic plains of India.

Resource conservation technologies like reducing soil tillage, mulching with crop residues and appropriate crop rotation when applied all together have the potential to halt and reverse some of the challenges the smallholder farmers are facing. Reduced tillage (RT), mulching and crop rotation have the potential of reversing physical, chemical and biological degradation of soils [5] under different climatic conditions and soil types [6]. Significant changes in soil organic carbon (SOC), bulk density and soil moisture status have been recorded on smallholder farms and research stations where conservation agriculture practices have been implemented [7,8]. In general, conservation tillage provides the best opportunity for improving soil quality and enhancing crop productivity [9]. Soil water content was increased due to RT that improved water infiltration, reduced surface runoff and decreased evaporation [10]. Additionally, the replacement of conventional tillage (CT) with conservation tillage improves crop yields and reduces production cost among other economic benefits [11,12]. Reduced tillage has also been reported to reduce greenhouse gas emissions [13]. CT mixes soil organic matter in the surface layers and may increase its decomposition and hence gaseous emissions of COx and NOx.

Soil organic matter is an important indicator of soil fertility and productivity because of its chemical, physical and biological impacts on other soil properties. Many researchers have reported that retaining crop residue can improve several soil characteristics [14,15], reduce soil erosion and runoff [16], affect the quantity of rainwater entering the soil and evaporation [17] and promote soil stability. Soil organic matter can be increased by either increasing C input or decreasing SOC loss and decomposition and these can be achieved through adopting residue management and reduced tillage. Mulching combined with reduced tillage is effective in reducing surface runoff, maintaining soil structure, conserving soil water and adding organic matter to the soil [18,19].

In some areas, nutrient imbalances have been reported and attributed to the use of suboptimal fertilizer rates and consequent nutrient mining and extreme acidity [20,21]. Nutrient deficiencies and imbalances are more acute in the fields of resource-poor farmers who do not have access to in-situ field resources and mineral fertilizer. Besides general infertility, the soils exhibit spatial fertility variability large enough to affect response to fertilization and targeted application of the often limited nutrient resources to preferred portions of the farm has further increased the fertility gradients [22].

Therefore, the aptness of any conservation agricultural practices should be evaluated locally before they are adopted in any particular region.

Although numerous experiments have been conducted on the effects of conservation agricultural systems, only a few experiments have been made involving all the components of conservation agriculture together i.e. crop diversification, residue cover and minimum disturbance of soil in the irrigated ecosystem of Indo-Gangetic plains. In the study, system productivity, total soil organic carbon (SOC), bulk density, soil moisture content, carbon stock in the soil over the experimental period were measured from fields that had been exposed to conservation agricultural practices.

2. MATERIALS AND METHODS

2.1 Site Description and Experimental Design

The study was conducted from 2011 to 2013 at a site on the Norman E. Borlaug crop research centre, G.B. Pant University of Agriculture and Technology, Pantnagar, (29°N latitude 79.3°E longitude and 243.8 m AMSL) in Uttarakhand state, India. The average annual precipitation of the site is 1350 mm, with 80 per cent falling between July and September. The annual maximum temperature in summer and minimum in winter season may record up to 43.5°and -0.5°C, respectively. The soil at the study site had a loam texture according to the USDA texture classification system. Soil organic carbon content, available nitrogen, available phosphorus, available potassium and bulk density at 0-20 cm depth were 0.7%, 196 kg ha^{-1}, 21.57 kg ha^{-1}, 169.2 kg ha^{-1} and 1.24 g cm^{-3}, respectively.

In this experiment, a fixed plot field experiment was established during kharif season in 2011-12. The field was divided into two main plots with each plot having 259.2m^2 as two different tillage systems. These main plots of each tillage strip were again equally sub divided into two plots as M0 and M1 treatments. These whole main plots were divided across into six subplots (21.6m^2) to possess three different cropping systems and two fertility levels. The experiment comprised all 24 factorial combinations of two tillage systems, two mulch treatments in main plots and three different diversified rice-based cropping systems and two fertility levels in sub-plots.

The two tillage treatments were (i) conservation tillage i.e., direct seeded in rice (DSR), zero tillage (ZT) in wheat and reduced tillage (RT) in vegetable pea, potato, greengram and maize crops. (ii) Conventional tillage (CT) i.e. soil was puddled after water stagnated up to three days followed by rice was transplanted as transplanted rice (TPR) into the main field from nursery during kharif season; whereas, the soil was ploughed to a 30 cm depth up to fine tilth using a rotary cultivator for all the other crops as farmers practised locally during rabi and summer season. The two mulch treatments were: no mulch (M_0) where the field was kept as barren land and application of sundry paddy straw mulch was retained in the soil surface (M_1) during rabi and summer season crops. No mulch materials were applied for rice crops during kharif season. Three different cropping systems were rice-wheat (CS_1); rice-vegetablepea- greengram (CS_2) and rice-potato-maize (CS_3). Two levels of fertility were: 100% RDF (F_1) and 75% RDF (F_2). During rabi season, after kharif rice crop followed by wheat, vegetablepea and potato were grown as conservation and CT. while during summer, greengram and maize were grown under CS2 and CS3 as conservation tillage and CT. Plots had left as fallow after wheat harvested under CS1.

Rice was shown on first fortnight of June for the year of 2011 and 2012 followed by wheat, vegetable pea and potato were sown on the second fortnight of October and Maize and greengram were sown on the first week of March for the year of 2011 and 2012. Each treatment was replicated three times and each plot was 6m long and 3.6m wide in a factorial split design. The crop was irrigated uniformly to bring the soil moisture near to field capacity. All the agronomical management practices were followed according to crops.

2.2 Measurement and Data Collection

2.2.1 Yield and system productivity

Each plot was harvested mechanically to determine economic yield at maturity; total system productivity is usually calculated by summation of rice equivalent yield in a specified cropping system. Cropping system productivity (CSP) was calculated by using the following formula [23],

$$CSP = \frac{\text{Total system productivity}}{\text{Duration of crops (days) in sequence}}$$

Relative production efficiency (RPE) was determined with the help of the following formula as described by Katyal and Gangwar [24].

$$\text{RPE (\%)} \quad \frac{\text{(EYD-EYE)}}{\text{EYD}} \times 100$$

Where EYD denotes the equivalent yield under improved/diversified system while EYE denotes the existing system yield.

2.2.2 Soil sampling and measurements

Soil samples from the upper 30 cm depth for each plot were collected during the period from post harvest season of *kharif*, *rabi* and summer season in all the cropping systems to determine the soil bulk density and soil moisture content.

The concentration of carbon accumulated in an experimental field was examined before and after cropping period during 2011-12 and 2012-13. In addition, soil organic carbon concentration during initial period of the experiment (2010-11) was taken to a comparison of carbon stock dynamics in the experimental field. The field was dug out up to 0.45 meter depth and soil samples were collected from three different depth at 0-15 cm, 15-30 cm and 30-45 cm interval by using core sampler with 5cm dia and 7.7cm height. Then soil samples were analyzed in the laboratory after finding out bulk density. Data on bulk density and carbon concentrations are used to compute amounts of carbon per unit area [25]. For the mineral soil, amounts of carbon per unit area are given by:

C (Mg ha^{-1}) = [soil bulk density (g cm^{-3}) × soil depth (cm) × % C] × 100

In this equation, % C should be articulated in a decimal fraction; for instance, 2.2 % C is expressed as 0.022. In the following example, the mass of soil carbon per unit area is calculated.

2.3 Statistical Analysis

All the data were subjected to statistical analysis and the means were tested by the least significant difference (LSD) at 5% level of significance.

3. RESULTS AND DISCUSSION

3.1 System Productivity

Production efficiency of system viz. total system productivity (TSP), cropping system productivity (CSP) and relative production efficiency (RPE) had significantly influenced by RCT practices. TSP was significantly higher under RT as compared to CT for both years indicated that improved soil conditions reflected by the increases in SOC as a result of decomposing stubbles residue, decrease in bulk density and improved soil hydraulic properties over the plough sole layer. Overall, RT produced 9.8% more TSP than CT (Table 1). The higher system productivity of RT in the field can be attributed to the improved soil condition reflected by the increase in SOC as a result of biomass always remained in the soil surface, decrease bulk density. A similar finding was also corroborated by Sarkar *et al*., [26]. These results are in agreement with those of Husnjak and Kousutic [27], who concluded RT provide more favourable soil physical environment for crop growth than CT. In a three years experiment, Arshad and Gill [28] found greater productivity in RT and lowest in CT. The yield increase was correlated with an increase in water contents in the soil due to reduced evaporation. Loss of soil organic matter is less under RT relative to CT, influences the soil physical, chemical and biological properties and creates a favourable medium for biological reactions. Regarding mulching treatments, M_1 significantly improved system productivity by 25.5% over the M_0 system. It might be owing to the beneficial effect of mulch on soil moisture content for a longer period which affects the physiological process of the crop growth and productivity. These results are in agreement of Liu [29] who concluded that crop residue on the soil increased soil temperature and soil water contents, improved the ecological environment of the field and increased the yield of crops. Similar results were reported by Duncan *et al*., [30]. In contrast to the cropping system, the TSP of the system was significantly greater for treatment following CS_3 followed by CS_2. The lowest TSP of the system was recorded with CS_1 during both the years. Higher system productivity in the above sequence was owing to higher quantum in terms of yield and price. The TSP of CS_3 and CS_2 were significantly increased by 156% and 91.6% higher than CS_1, respectively.

Uptake of nutrient by plants is kinematic in nature and is significantly influenced by different factors. It is a function of climate, soil properties, amount and method of fertilizer application and cultural practices adopted [31]. Moderate favourable temperature laying in top soil promoted metabolic process Lavahun *et al*., [32] which increased nitrogen, phosphorus and potassium absorption and ultimately resulted in higher productivity. Moreover, higher productivity of system is also known to be governed by the total dry matter production. Therefore, higher system productivity by 100% RDF led to higher NPK uptake.

The above similar trends had been reflected in the cropping system productive and relative production efficiency with higher in RCT practices and lower in conventional methods.

3.2 Carbon Sequestration Rate (C Stock)

Soil is an ideal reservoir for storage of organic C since soil organic C has been depleted due to land misuse and inappropriate management under conventional methods through the long history. The great potential of C sequestration in cropland has provided a promising approach to reducing the atmospheric concentration of CO_2 for mitigating climate change. To optimize the efficiency of C sequestration in agriculture, tillage system, residue management and cropping systems play a critical role by influencing optimal yield, total increased C sequestered with biomass, and that remained in the soil.

In our study, the profile soil organic carbon (SOC) stock differed significantly among the treatments. Significantly, the highest three years mean carbon stock of 13.6 Mg ha^{-1} was observed in the RT and the lowest in the CT (12.9 Mg ha^{-1}). In this result, SOC under both the tillage systems was increased annually but the relatively higher annual rate of carbon sequestration was 0.76 Mg C ha^{-1} per year in RT, which is corresponded 2.8 times higher SOC stock compared to conventionally tilled treatments, CT (Table 2). There was significantly higher C stock (13.2, 13.5 and 14.0 Mg C ha^{-1}) in RT as compared to 12.8, 12.9 and 13.1 Mg C ha^{-1} in CT system during 2010-11, 2011-12 and 2012-13, respectively. CT accelerates organic C oxidation to CO_2 by improving soil aeration, increasing contact between soil and crop residues and exposing aggregate-protected organic matter to microbial attack [33]. Therefore, organic matter content decreased when soils are tilled. However, the minimum tillage and zero tillage helped the soil to restore more organic matter content and prevent the exposure to external factors; this led to the accumulation of organic carbon on soil [34]. In this experiment also found that SOC was concentrated near the surface, while in tilled soils it was distributed deeper in the profile. Similar findings were also reported by Carter [35]; Baker *et al.,* [36]. On the other hand, the net change in SOC depends not only on the C loss as CO_2 emissions but also on the C input by residue retention or manure addition [37].

Table 1. Total system productivity (kg ha^{-1} in ×10^{3}), Cropping system productivity (kg ha^{-1} day^{-1}) and relative production efficiency (%) as influenced by different RCT,s practices in rice based cropping system

Treatments	Total system productivity		Cropping system productivity		Relative production efficiency	
	2011-12	2012-13	2011-12	2012-13	2011-12	2012-13
Tillage system (T)						
Reduced tillage (RT)	20.17	205.3	70.9	73.9	105.6	104.0
Conventional tillage (CT)	18.52	185.3	65.1	66.5	96.9	91.7
SEm.±	0.62	0.65	0.22	0.24	0.64	0.73
LSD (P=.05)	1.76	1.87	0.62	0.69	1.83	2.08
Mulch (M)						
No- mulch	17.53	173.9	61.6	62.4	85.7	79.2
Straw mulch	21.16	216.6	74.4	77.9	115.7	115.3
SEm.±	0.62	0.65	0.22	0.24	0.64	0.73
LSD (P=.05)	1.76	1.87	0.62	0.69	1.83	2.08
Cropping system (CS)						
Rice-wheat	10.57	104.3	38.1	37.0	8.8	4.20
Rice-Veg. pea- Greengram	20.57	213.5	76.8	81.5	109.7	112.2
Rice-Potato-Maize	269.1	267.9	89.1	92.1	174.3	166.3
SEm.±	0.76	0.80	0.27	0.30	0.79	0.90
LSD (P=.05)	2.16	2.29	0.76	1.12	2.24	2.55
Fertilizer levels (F)						
100% RDF	20.31	205.1	71.4	73.7	110.9	107.3
75% RDF	18.39	185.5	64.6	66.7	82.6	79.9
SEm.±	0.62	0.65	0.22	0.24	0.64	0.73
LSD (P=.05)	1.76	1.87	0.62	0.69	1.83	2.08

Table 2. Effect of RCT, s practices influencing on carbon sequestration as carbon stock (Mg ha^{-1}) under rice based cropping system from 2010-11 to 2012-13

Treatments	Carbon stock			Mean	C stock difference between years
	2010-11	2011-12	2012-13		
Tillage operation (T)					
Reduced tillage (RT)	13.2	13.5	14.0	13.6	0.76
Conventional tillage (CT)	12.8	12.9	13.1	12.9	0.27
SEm.±	0.03	0.04	0.05	0.04	0.07
LSD (P=.05)	0.10	0.12	0.14	0.11	0.21
Mulch (M)					
No mulch	12.9	12.9	13.1	13.0	0.19
Straw mulch	13.1	13.5	13.9	13.5	0.84
SEm.±	0.03	0.04	0.05	0.04	0.07
LSD (P=.05)	0.10	0.12	0.14	0.11	0.21
Cropping system (CS)					
Rice-wheat	12.8	13.0	13.3	13.0	0.47
Rice-Veg. pea- Greengram	13.4	13.8	14.1	13.8	0.69
Rice-Potato-Maize	12.8	12.9	13.1	12.9	0.32
SEm.±	0.04	0.05	0.06	0.04	0.08
LSD (P=.05)	0.13	0.15	0.17	0.12	0.24
Soil depth (cm) (D)					
0-15	15.1	15.6	16.1	15.6	0.96
15-30	13.8	14.1	14.5	14.1	0.47
30-45	9.91	9.9	9.95	9.9	0.04
SEm.±	0.04	0.05	0.06	0.04	0.08
LSD (P=.05)	0.13	0.15	0.17	0.12	0.24

Mulching followed a similar trend to tillage. The SOC sequestration in M_1 plot showed that sequestration rate was significantly highest (0.84 Mg ha^{-1} $year^{-1}$) which was corresponded to four times higher compared to M_0 field. In general, crop residue applied soils had a significantly higher amount of SOC stock at all soil depths than soil without crop residue during three years and average sequestration rate of three years was 13.5 Mg ha^{-1} in M_1 as compared to 13.0 Mg ha^{-1} in M_0. This might be due to incorporation and decomposition of paddy straw which increased the total SOC on topsoil.

The cumulative mean carbon stocks, rate of change in carbon stock and comparison from initial carbon stocks (carbon stock difference) were followed the similar trend to SOC. Reduction in tillage intensity and use of crop residues leads to accumulating more soil organic matter [38]. The results also partially corroborate with several previous studies of Six *et al.*, [39]; West and Post [40] that higher SOC sequestration might be due to the role of crop residues, among others, in conserving soil moisture and protecting carbon from oxidation and mineralization [41]. Therefore, from above the results in our study, conservation tillage and residue management can provide a constant build-up of soil organic carbon and together constitute an agronomic practice that does not only produce a crop but also reduces greenhouse gas emissions by preventing carbon from transforming into carbon dioxide through decomposition.

However, there was no significant variance of SOC stock in rice-based cropping system. A trend was apparently suggesting that CS_2 sequence could result in higher annual rate of SOC stock (0.69 Mg ha^{-1} $year^{-1}$) followed by CS_1 sequence (0.47 Mg C ha^{-1} $year^{-1}$) and lowest C rate was noted in CS_3 cropping system (0.32 Mg C ha^{-1} $year^{-1}$). When evaluated across cropping system, the three years mean of the SOC sequestration stock in CS_2 was about 1.06 and 1.05 times higher than in CS_3 and CS_1, respectively. During the experimental period, the cropping system of CS_3 sequestered significantly lower rate in both the tillage system. Higher rate of C sequestration in CS_2 was due to two crops being legumes fixed biological N in soil and increasing the soil organic matter. This result was corroborated with the findings of Amado *et al.*, [42] that more carbon could be stored by adding leguminous cover crops to the rotation cycle in conservation agriculture. Whereas, C sequestration rate was higher in the rice-wheat system than in rice-potato-maize system is due to the soils being under a unique aquic (flooded) moisture regime for 3–4 months under rice crop and utilizing soil moisture to succeeding crop of wheat in zero tilled condition. Secondly, it was due to higher biomass production in rice and wheat crops as compared to maize. This results in a net accumulation of organic matter in soils that remain for several years. Witt *et al.,* [43] also reported 11–12% greater C sequestration in soils continuously cropped with rice for 2 years than in the maize-rice rotation with the higher amounts sequestered in N-fertilized treatments. Increased cropping frequency can lead to more annual overall production of residues and roots thereby increasing soil C stock [44].

Considering the change of total SOC sequestration rate down to a specific depth, when three years data were pooled together, on average, adoption of different management practices increased SOC stock in the surface 0-15cm (15.6 Mg ha^{-1}) of soil followed by 15-30 cm (14.1 Mg ha^{-1}) of soil. When deeper layers of soil were included, the total SOC stocks recorded lower in 30-45 cm (9.94 Mg ha^{-1}) of soil layer. As data shown in relation to the point of C stock difference between three years, sequestration of carbon stock kept almost stable and was insignificant between 0-15cm and 15-30 cm layers of soil. Another interesting point revealed in this study that increasing rate of SOC stock between three years was almost absent in a deeper layer of 30-45 cm soil layer. Further, it showing that plough sole layer of 0-15 cm soil deeper layer had significantly increased the soil organic carbon stock (15.6 and 16.1 Mg C ha^{-1}) followed by 14.1 and 14.5 Mg ha^{-1} in 15-30 cm deeper soil layer during 2011-12 and 2012-13, respectively. As compared to above 0-15 and 15-30 cm soil layer, there was steadily declined carbon stock in 30-45cm soil layer during three years. The relatively near surface higher water content and the favourable temperature of no-tillage soils during the growing season might have provided a favourable environment for SOC accumulation in the surface soil.

3.3 Depth Distribution of Organic Carbon

The soil organic carbon concentration differed considerably among the treatments and depth. The highest total mean of SOC concentration of 15.64 g kg^{-1} soil was observed in the surface layer (0-15cm) followed by 15-30 cm. Then SOC concentration was sharply declined in 30-45 cm soil layer.

The soils under RT recorded (13.94 g kg^{-1}) consistently higher concentration of organic carbon than under CT (13.19 g kg^{-1}) systems (Table 3). Among the depthwise organic carbon concentration data showed that RT increased soil organic carbon i.e. were 16.32, 14.73 and 10.81g kg^{-1} compared to 14.59, 14.29 and 10.69 g kg^{-1} under CT system soils in 0-15, 15-30 and 30-45 cm deeper layer, respectively and which was 11.86, 3.08 and 1.12 per cent higher over the depthwise as compared to soils of CT.

Comparison of organic carbon with the initial value that when the experiment was initiated during 2010-11, indicates SOC concentration had increased up to 30cm soil depth layer in RT thereafter, SOC concentration decreased in 0-15 cm layer compared to an initial value. This was due to the surface layer of soil has most of the C and ploughing in CT moves the crop residue and surface soil C into deeper soil layers. Ploughing also loosens the soil down to the depth of 15-45 cm, changes the soil physical conditions and promotes more crop root growth in those loose layers thereby increasing C input through root senescence at corresponding soil layer. In case of RT /ZT, leads to increased soil cover, reduced soil disturbance and increase soil strength. It does not only discourage root growth into deeper soil layer but also reduced the downward movement of surface soil C [45]. The present study also found this similar finding that higher SOC concentration in surface soil under RT and in deeper soil layer under CT.

Paddy straw mulch, M_1 applied to soil surface had significantly increase SOC (13.68 g kg^{-1}) than M_0 (13.19g kg^{-1}). Application of straw mulch at surface increased SOC in all soil layers and was 16.76, 14.61 and 10.35 g kg^{-1} in 0-15, 15-30 and 30-45 cm soil layer, respectively. As that of tillage system, M_1 was also significantly increased up to 15cm layer i.e. 8.5, 3.4 and 1.2 per cent higher over M_0 plot in 0-15, 15-30 and 30-45 cm soil layer, respectively. The higher SOC under mulched plot was due to straw material can cause a decrease in soil temperature in the top soil during summer, therefore lead to reduced soil C decomposition [46]. It can also increase moisture through reduced evaporation in the topsoil leading to changes in crop root growth and other soil process related to SOC decomposition in the topsoil layer.

Table 3. Changes in SOC concentration (g kg^{-1}) under different treatments over mean initial value (2010-11) and two year experimental period (2011-2012 and 2012-13) in rice based cropping system

Treatment	Soil Depth (cm)						Mean
	Initial value			Two year mean			
	0-15	15-30	30-45	0-15	15-30	30-45	
Tillage operation							
Reduced tillage (RT)	16.26	14.69	10.81	16.32	14.73	10.81	13.94
Conventional tillage (CT)	14.72	14.25	10.62	14.59	14.29	10.69	13.19
Mulch							
No mulch	15.28	13.91	10.17	15.44	14.13	10.23	13.19
Straw mulch	15.49	14.57	10.31	16.76	14.61	10.35	13.68
Cropping system							
Rice-wheat	15.90	14.28	8.92	15.95	14.47	8.97	13.08
Rice-Veg. pea- Greengram	16.11	14.32	10.97	16.46	14.68	11.20	13.96
Rice-Potato-Maize	15.72	14.19	8.96	15.90	14.28	8.99	13.01
Total mean	15.64	14.32	10.11	15.92	14.46	10.19	

Among the cropping system, CS_2 recorded higher SOC concentration (13.96 g kg^{-1}) followed by CS_1 sequence (13.08 g kg^{-1}). The CS3 recorded lower value of SOC concentration. The CS_2 recorded highest SOC of 16.46, 14.68 and 11.20 g kg^{-1} of soil in 0-15, 15-30 and 30-45 cm soil layer, respectively with an average value of 13.96g kg^{-1} of soil over other cropping systems i.e. CS_1 and CS_3. The effects of crop diversity on soil C changes after adopting RCT might have contributed to the variability in the SOC concentration. Our results showed that increasing diversity could increase soil microbial biomass and decomposition rate [47,48] which may help explain the net decline in soil C in CS_3 system. However, another diversified cropping system of CS_2, the inclusion of legumes in this cropping system favoured to increasing SOC rather than declining SOC. The CS_1 system recorded higher SOC after CS_2 system because more annual overall production of residues and roots biomass than CS_3, thereby increasing soil C stock [49].

4. CONCLUSION

In the light of results summarized above, it is clear that resource-conserving technologies applied in isolation have advantages as well as disadvantages. The following findings were synthesized in this study as given below.

- ❖ Combining different resource-conserving technologies synergies can be created to eliminate the disadvantages of single technologies and accumulate the benefits.
- ❖ Different RCTs practices were recorded 2.5 times higher TSP in CS_2 and 3.0 times higher TSP in CS_3 when compared to conventional farmers' practices.
- ❖ RCT practices enhanced 8-12% more carbon sequestration in agricultural soils.
- ❖ The combination of different RCTs practices in diversified cropping system resulted not only benefit in enhancing system productivity and soil health but also in mitigating climate change and successfully could be adopted against vulnerable and extreme climatic conditions.

COMPETING INTERESTS

Authors have declared that no competing interests exist.

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