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Assessment of Carbon Sequestration Rate and System Productivity under Complementary Bio-Intensive Cropping Systems in an *Inceptisol* of Southern Telangana Zone

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ABSTRACT

Depletion of soil organic carbon (SOC) is the major cause of the decline in soil productivity and degradation for sustainable crop production arising from elevated CO_2 emissions. The adoption of different cropping systems (CSs) is an alternative strategy for soil carbon storage (SCS). Keeping these factors in mind, the current study was conducted in 2019–2020 and 2020–21 to examine the impact of (CSs) on C– sequestration capabilities in the continuing long-term field trial started in 2017. It was conducted at an experimental farm at the College of Agriculture, Rajendranagar. Our findings showed that the impact of effective CSs improved SOC stock above the initial status (7.53 Mg ha^{-1}) in both years. The following cropping order showed a noticeably higher build-up of SOC stock: CS_1: Rice - Maize and CS_2: Bt cotton - Fallow, respectively, had the lowest values (0.66 Mg ha^{-1}) and (0.60 Mg ha^{-1}) whereas CS_5: Maize + Pigeon pea - Groundnut (1.25 Mg ha^{-1}) and CS_4: Pigeon pea + Green gram (1:3) - Sesame (1.22 Mg ha^{-1}) had the highest values. The level of SOC in one of the CSs, CS_{10}: Bhendi, Marigold, and Beetroot, demonstrated a detrimental impact on the study's findings, with depletion (-0.13 Mg ha-1) falling below the original value. Interestingly, the build-up of SOC was more prominent in 2020-2021 in all the CSs as compared to 2019-2020, and SOC accumulation (1.44 Mg ha^{-1}) was more pronounced in CS_4 maintaining the same trend as in 2019-2020. However, the higher carbon sequestration rate (CSR) in 2019-2020 was recorded in CS_5 (0.42 Mg ha^{-1} yr^{-1}) and CS_4 (0.41 Mg ha^{-1} yr^{-1}) while a positive increment in CSR in 2020-2021 was observed in all the CSs with higher (2.15 Mg ha^{-1} yr^{-1}) being under CS_7: Fodder sorghum + Fodder cowpea. System productivity in terms of RGEY (40818 kg ha^{-1}) was significantly higher under CS_{10} after the third year and declined by 18.80% at the end of fourth year. CSR and RGEY reported a negative significant correlation (r= -0.755) and non-significant correlation in 2019-2020 and 2020-2021, respectively. The salient findings have indicated that CSs involving cover crops (legumes and cereals) had sequestered higher SOC, thus bridging the gap to the farmers towards soil carbon loss by elevated CO_2 through the adoption of these complementary bio-intensive CSs mechanisms.*

Keywords: *SOC, Carbon Sequestration rate (CSR), RGEY, soil productivity, Soil Organic Carbon (SOC) and Bio- intensive Cropping systems (CSS)*

1. INTRODUCTION

According to current projections [1] the concentration of carbon dioxide in the atmosphere might reach 418 ppm. For agricultural production, the fact that India's soil organic carbon (SOC) concentration has decreased from 1% to 0.3% over the previous 70 years is a big problem [2]. One method of capturing carbon is to adopt various cropping techniques. An essential part of a farming system is the cropping system, which refers to the cropping pattern used on a farm and is intended to maintain and improve soil health. Cropping systems and pastures make up a third of the arable land on the planet, and they can remove a sizable amount of atmospheric CO_2 for the storage of SOC and improvement of the SOC budget [3].

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Total soil organic carbon (TSOC), total soil inorganic carbon (SIC), and total carbon (TC) were calculated to be 0.47, 0.71, and 1.18 Pg for black soils and 0.33, 0.50, and 0.83 Pg for red soils, which cover 15 million acres in India's semi-arid tropics (SAT). Black soils used for cotton farming have an average SOC concentration of 6.85 g kg-1 in the top 30 cm of the soil [4,5,6]. After 25–30 years under the specified agricultural regimes, [7] showed a general build-up tendency in SOC stock. Although different climatic regions' soils have higher SOC stocks overall, the database shows that SOC in hot, arid, and semi-arid climatic zones is generally deficient. Compared to the global average of 4%, India's plains and hills have soil carbon contents of less than 1% and roughly 2%, respectively [8]. Low organic content (OC) soils are more susceptible to sodification than high OC soils [9]. According to [10], there is a significant opportunity for organic carbon sequestration in arid and semi-arid climate zones through the implementation of effective cropping systems.

According to [11], soil carbon sequestration is a strategy for restoring degraded soils, increasing land productivity, enhancing biodiversity, safeguarding the environment, and reducing atmospheric CO_2 enrichment. According to reports, the historic soil organic carbon loss (about 66–90 Pg C) from the soil can be recovered through C–sequestration for 25–50 years with the implementation of suitable crop management practices [12].
Regardless of the bioclimatic systems, pigeon pea introduction in CS improves SOC in soils, with or without other leguminous crops [13]. Addition of huge amount of C inputs to the soil can also helps in enhancing the C storage in our soils. . According to research by [3,14], adding cover crops (CC) and pulses to cropping systems as well as avoiding fallow winter periods can increase carbon stock, sequester carbon, reduce carbon footprint, improve soil biodiversity, and thus be another way to offset atmospheric CO_2 emissions. In addition, the use of cover crops (CC) is a desirable management technique for boosting SOC reserves [15]. A promising strategy for enhancing soil health has been suggested by the potential for C sequestration in croplands. This strategy, though, is dependent on cropping systems. To effectively sequester carbon dioxide, cropping systems should generate and hold onto large amounts of biomass or organic carbon in the soil. By increasing biomass output and lowering nitrogen input as chemical fertilizer, crop rotation with legumes or pulses and cover crops increases soil carbon sequestration [16,17]. Therefore, it is essential to enhance the intake of plant biomass residues by incorporating cover crops and legumes between primary crops in growing seasons, minimizing the amount of time that land is fallow during the winter, crop rotations, and intercropping systems to improve C sequestration. Without paying more attention to management practices and soil organic carbon retention, growers frequently adopt management practices that tend to boost crop production. Numerous studies have shown that, despite the promise, research on the evaluation of carbon sequestration and agricultural output under various cropping systems is lacking. To better understand how different cropping strategies affect system productivity and carbon sequestration capacity in an *Inceptisol*, the current study has begun.

2. MATERIALS AND METHODS

2.1 Location

The study was carried out in the *Kharif-Rabi* seasons of 2019–2020 and 2020–21 at the college farm under All India Coordinated Research Project on Integrated Farming Systems, Professor Jayashankar Telangana State Agricultural University, Rajendranagar, Hyderabad.

2.2 Weather and Climate

Rajendranagar is classified as being in the Semi-arid zone agro climatically, which is characterised by having a maximum temperature of 32.33 °C and a minimum temperature of 18.46 °C, as well as an annual rainfall of 797 millimeters, the majority of which (about 80%) is obtained from June to September. December through February sees winter showers. Figure 1 shows the mean monthly maximum, minimum, and precipitation meteorological data that were collected at the ARI meteorological observatory for the crop seasons in the years 2019, 2020, and 2021.

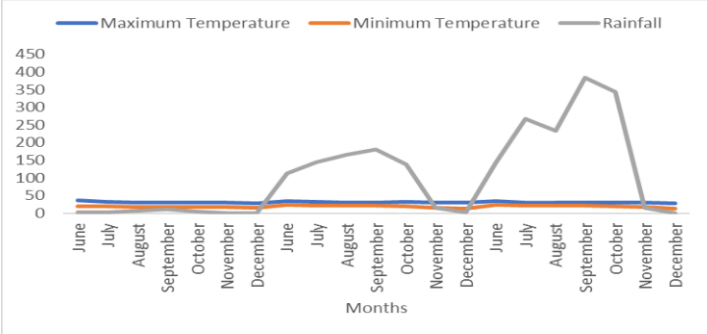

Figure 1. Mean monthly temperature (minimum and maximum) and rainfall for the year 2019-2021 meteorological data during the crop cycle.

2.3 Soil characteristics

The experimental field's soil belongs to the *Inceptisols* soil order. Due to the presence of lime concretion in the lower horizon, this soil has a sandy loam texture, is red chalk in color, and has a neutral to alkaline soil reaction (pH 7.68). At the end of the experiment (2020–2021), the available N status of the experimental field was low (191.65 kg ha^{-1}), medium in available P (38.50 kg ha^{-1} P_2O_5), available K status was in medium range (194.79 kg ha^{-1} K_2O), soil organic carbon was in low range (4.1 g kg^{-1}), and electrical conductivity was also in low range (0.40 dSm^{-1}). Table 1 provides some key physical, chemical, and physico-chemical properties of the surface soil (0–15 cm) of the experimental location at the start of the experiment.

Table1. Soil physicochemical characteristics at the initiation of the experiment

S. No	Soil property	Value
i.	Soil type	Red soil
ii	**Mechanical separates (%)**	
	Sand	62.3
	Silt	25.2
	Clay	12.5
	Texture	Sandy loam
iii.	Bulk density (mg/m3)	1.41
iv.	Soil pH (1:2) soil water suspension	7.81
v.	EC (dS/m) (1:2.5) Soil water suspension)	0.11
vi	Organic carbon (g/kg)	0.39
vii	**Available nutrients (kg ha^{-1})**	
	Nitrogen	112.2
	Phosphorus	23.4
	Potassium	170.3

2.4 Specifics of an experiment

Ten cropping systems were used as treatments in the experiment, which was set up using a Randomised Block Design (RBD) with three replications. The eight cropping sequence combinations that were evaluated were CS_1: Rice - Maize, CS_2: Bt cotton – Fallow, CS_3: Bt cotton plus Greengram (1:3) inter row crops- groundnut, CS_4: Pigeon pea plus Greengram (1:3) followed by Sesame, intercrop Maize plus pigeon pea (1:3) - Groundnut in CS_5, CS_6 row intercrop: Pigeon pea + Groundnut (1:7) intercropping rows – Ragi, CS_7: Fodder cowpea plus fodder sorghum (1:2) - Horsegram and Sunhemp in a row-intercrop, CS_8: Fodder maize followed by Lucerne, Sweet maize and vegetables (tomato) makeup CS_9, and bhendi, marigold and beetroot make up CS_{10}. Initial allocation of each treatment was random, and each replication was done three times. All of the crops were grown using the approved set of techniques across all cropping systems. Crop sequencing for *Rabi* was started as soon as the crops from the previous *Kharif* had been harvested in the corresponding areas.

2.5 Soil sampling and standard methodology

For the chemical analysis, composite soil samples were taken from each plot at a depth of 0–20 cm. The following standardized protocols were used to conduct a soil organic carbon analysis on the processed soil samples. After the harvest of the Rabi crops in the third and fourth years of the cropping system, carbon stocks and carbon sequestration calculations were made based on the results of the soil organic carbon analysis. [18] Calculated soil organic carbon (%) using the method outlined by [19].

2.6 Crop yield

For each crop in the cropping schemes, biological yield was independently recorded. The yields of all the crops were translated into rice grain equivalent yields on a pricing basis so that different crop sequences could be compared. After each growing season, crop yields were noted, and the rice equivalent yield (REY) was calculated after the cropping system cycle. By combining REY of the component crops, system yield was derived.

2.6.1 Rice equivalent yield (REY) was calculated as follows:

REY (kg ha^{-1}) = Economical yield Price (Rs kg^{-1}) of same crop
e.g. wheat of a crop *e.g.*, wheat x

(kg ha^{-1}) Price (Rs. kg^{-1}) of rice

2.6.2 Productivity as follows:

Productivity (kg ha^{-1} day^{-1}) = Rice equivalent yield (REY) of cropping system (kg ha^{-1})

Actual duration of cropping system

2.7 Calculation of the Soil Carbon Stocks:

By using the techniques outlined by [20,21] (Table 2), the soil carbon store was calculated.

2.7.1 Organic carbon (Mg ha^{-1}): The bulk density of the soil (1.41 Mg m^{3}), which was measured at the start of the experiment at a soil depth of 0 to 15 cm, was multiplied by the OC content (%) to calculate the SOC stock.

SOC Stock (Mg ha^{-1}) = Percentage of SOC content (%) x Bulk Density (Mg m^{3}) x soil depth (cm)

2.7.2 Carbon that is organic Build-up or Depletion: This was calculated as the difference in final organic carbon levels compared to initial organic carbon levels for soil depths of 0 to 15 cm, and it was expressed as Mg ha^{-1}. Final SOC - Initial SOC = Build-up or Depletion (Mg ha^{-1})

2.7.3 Rate of Carbon Sequestration: According to [22], it was estimated by dividing the carbon build-up or depletion by the experiment's age in years. The result was expressed as Mg ha^{-1} yr^{-1}.

Rate of CS (Mg ha^{-1} yr^{-1}) = Depletion/ Build-up (Mg ha^{-1})
Experiment's age (Years)

2.8 Analysis of Data and Statistics

With the aid of the RBD statistical tool and the operational statistics (OP STAT) software designed for agricultural research, the experimental data were examined. The analysis of variance was carried out using the Duncan Multiple Rank Test (DMRT).

3. RESULTS AND DISCUSSION

3.1 Cropping practises' Impact on soil carbon stores and rate of carbon sequestration

3.1.1 Stocks of carbon (Mg ha^{-1}): The data compiled on the soil organic carbon supply under study is shown in table 2 as well as Figure 2.

Table 2. Different farming practices impact on soil organic carbon stock (Mg ha^{-1}) after Rabi 2019 – 2020 and 2020- 2021[a,b]

Treatment (Cropping system: *Kharif* – R*abi*)	2019-2020	2020-2021
CS_4: Pigeon pea + Green gram– Sesame (1:3)	9.52^{a}	9.73^{a}
CS_6: Pigeon pea + Groundnut (1:7)	9.24^{ab}	9.31^{ab}
CS_8: Fodder maize – Lucerne	9.14^{abc}	9.31^{ab}
CS_5: Maize + Pigeon pea (1:3)	9.02^{abc}	9.09^{ab}
CS_7: Fodder sorghum + Fodder cowpea (1:2)	8.66^{abcd}	9.73^{a}
CS_3: Bt cotton + Green gram (1:3)	8.47^{abcd}	9.09^{ab}
CS_9: Sweet corn – Vegetables (Tomato)	7.91^{abcd}	8.46^{ab}
CS_1: Rice – Maize	7.51^{bcd}	8.67^{ab}
CS_2: Bt cotton – Fallow	7.24^{cd}	8.25^{b}
CS_{10}: Bhendi – Marigold – Beetroot	6.77^{d}	8.25^{b}
Initial SOC	7.53	

[a] *NB: a-e letters denote significance at 5% level, using Duncan's new multiple range test.*
[b] *Means with the same letter are not significantly different.*

3.1.2 Organic Carbon in Soil (SOC) stock (Mg ha^{-1}): After harvesting of *Rabi* (Winter) crops in 2020, the cropping systems with the greatest concentration of SOC stock were CS_4: Pigeon pea + Green gramme (1:3), CS_6: Pigeon pea + Groundnut (1:7), and CS_8: Fodder maize - Lucerne (9.14 Mg ha^{-1}) in comparison to CS_5: Maize + Pigeon pea (1:3) (9.02 Mg ha^{-1}), the remaining cropping systems were statistically equivalent to one another (Table 2 and figure 2). Possible explanations for the rise in SOC stock include pigeon pea's persistent effects. Nevertheless, CS_2: Bt cotton - Fallow and CS_{10}: Bhendi - Marigold - Beetroot caused a drop in SOC stock above all other cropping systems, which may be related to CS_2: Bt cotton - Fallow's Rabi (winter) fallow and CS_{10}: Bhendi - Marigold - Beetroot's exhausting nature of vegetables.

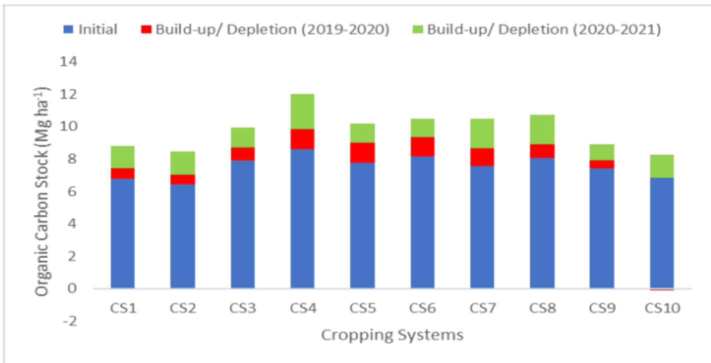

Fig 2. Different farming practices' impact on organic carbon stock after Rabi, 2019-2020 and 2020-2021

Following the harvest of Rabi (Winter) crops in 2021, a similar trend in SOC stock was seen compared to 2021, with the highest levels under CS_4: Pigeon pea + Green gram (1:3) and CS_7: Fodder sorghum - Fodder cow pea (1:2) (9.52 Mg ha^{-1}) followed by CS6: Pigeon pea + Groundnut (1:7) and CS_8: Fodder maize – Lucerne (9.31 Mg ha^{-1}). However, when legume crops were taken into account, were statistically comparable to other cropping systems, whilst all other of the cropping systems remained statistically comparable to one another. There was an overall improvement in SOC stock (8.25 Mg ha^{-1}) under cropping techniques *viz.*, CS_{10}: Bhendi – Marigold – Beetroot and CS_2: Bt-cotton – Fallow over the initial value (7.53) (Table 2 and Figure 2). SOC stock has significantly increased in *Rabi* (winter) post-harvest, 2021 across all cropping systems indicating a positive impact in different systems of cropping upon SOC stock (Table 2). That might be ascribed to crop diversification over the years.

3.1.3 The equilibrium of organic carbon: All farming systems had a favorable impact on soil organic carbon in *Rabi* (winter), 2019-2020 and 2020-2021 after harvest with the exception of CS_{10}, CS_1, and CS_2, all of which had reduced organic carbon in Rabi, 2019-2020 post-harvest. The farming strategies that relied on the production of dry fodder and legumes had the greatest favorable impact such as CS_4: Pigeon pea plus Green gram (1:3) (CS_4) and dry fodder production system in fodder sorghum and fodder cowpea (CS_7) in a 1:2 ratio, respectively. That might be due to plant residue accumulation, massive quantity of litter falls and canopy cover to the soil brought about by those cropping systems. [26] confirmed similar findings, observing that cover crops like legumes and summer cover crops such as Sunhemp improve carbon sequestration through the enhancement of soil structure and the addition of large quantity of soil organic matter.

3.1.4 Accumulation or decline (Mg ha^{-1}): In the winter season after harvest in 2019–2020, the highest carbon buildup (1.25 Mg ha^{-1}) was noted in CS_5: Maize + Pigeon pea (1:3), followed by CS_4: Pigeon pea + Green gram (1:3) (1.22 Mg ha^{-1}) and CS_6: Pigeon pea + Groundnut (1:7) (1.18 Mg ha^{-1}) and it was statistically comparable to CS_7: Fodder sorghum + Fodder cowpea (1:2) and CS_8: Fodder maize – Lucerne (1.08 Mg ha^{-1}) cropping systems (Table 3 and figure 2). This could be as a result of the addition of more plant wastes to the soil brought about by the inclusion of legume crops. Similar findings were made by [27] Prasad et al. (2004), who found that the accumulation of organic carbon was higher in legume-incorporated grassland than in natural grassland. The stability of the SOC increment, which is influenced by vegetable cultivation patterns as well as the exhaustive extent of vegetable crop production for nutrients that are accessible in the soil, may be the cause of the observed depletion of organic carbon in CS_{10}: Bhendi, Marigold, and Beetroot cropping systems.

In *Rabi*, 2020-2021 after harvest, it was noticed that there was a build-up in SOC by all the cropping systems over the initial value and 2019-2020 post- harvest in comparison. Significantly higher SOC accumulation (2.15 Mg ha^{-1}) was recorded in CS_7: Fodder sorghum + Fodder cowpea (1:2) of the several cropping techniques. System *viz.*, CS_2 and CS_1 which have recorded lower SOC in the year 2019-2020 post-harvest of *Rabi* (winter) crops, were observed to have accumulated abundant SOC (1.83 Mg ha^{-1} and 1.82 Mg ha^{-1}) accordingly. Similar to CS_9: Sweet corn - Vegetables (Tomato), CS_{10}: Bhendi - Marigold - Beetroot proved system recovery through the formation of SOC (8.25 Mg ha^{-1}) after depletion.

Table 3. Organic carbon stock accumulation or depletion and soil carbon sequestration as an outcome of various cropping systems after the fourth year

Treatment (Cropping system: (*Kharif* – *Rabi*)	Initial SOC	2019-2020			2020-2021		
		Final SOC	Build-up or depletion of SOC	C sequestration rate	Final SOC	Build-up or depletion of SOC	C sequestration rate
	(Mg ha^{-1})			(Mg ha^{-1} yr^{-1})	(Mg ha^{-1})		(Mg ha^{-1} yr^{-1})
CS_5: Maize + Pigeon pea (1:3)	7.77	9.02	1.25^{a}	0.42^{a}	9.09	1.40^{ab}	0.35^{ab}
CS_4: Pigeon pea + Green gram– Sesame (1:3)	8.36	9.52	1.22^{a}	0.41^{ab}	9.73	1.44^{ab}	0.36^{ab}
CS_6: Pigeon pea + Groundnut (1:7)	8.16	9.24	1.18^{a}	0.39^{ab}	9.31	1.22^{ab}	0.31^{ab}
CS_7: Fodder sorghum + Fodder cowpea (1:2)	7.58	8.66	1.08^{a}	0.36^{b}	9.73	2.15^{a}	0.54^{a}
CS_8: Fodder maize – Lucerne	8.07	9.14	1.08^{a}	0.36^{b}	9.31	1.17^{ab}	0.29^{ab}
CS_3: Bt cotton + Green gram (1:3)	7.93	8.47	0.78^{b}	0.26^{c}	9.09	1.16^{ab}	0.29^{ab}
CS_1: Rice – Maize	6.77	7.51	0.66^{bc}	0.22^{cd}	8.67	1.83^{ab}	0.46^{ab}
CS_2: Bt cotton – Fallow	6.43	7.24	0.60^{bc}	0.20^{d}	8.25	1.82^{ab}	0.45^{ab}
CS_9: Sweet corn – Vegetables (Tomato)	7.42	7.91	0.50^{c}	0.17^{d}	8.46	0.97^{b}	0.24^{b}
CS_{10}: Bhendi – Marigold – Beetroot	6.83	6.77	-0.13^{d}	-0.05^{e}	8.25	1.42^{ab}	0.35^{ab}

3.1.5 Rate of carbon sequestration (Mg ha^{-1} yr^{-1}): Cropping systems that retain the residues and yield root exudates have the potential to undergo soil organic matter decomposition process very rapidly. Through the adoption of such cropping systems, about 1.1 to 2.2 Pg carbon can be sequestered in the agricultural soils in the next 50 years [28]. Our findings in 2019-2020 (winter season) post-harvest have indicated **a** greater rate of carbon sequestration (0.42 Mg ha^{-1} yr^{-1}) was achieved by CS4: Pigeon pea + Green gramme (1:3), followed by CS5: Maize + Pigeon pea (1:3)- Groundnut (0.42 Mg ha^{-1} yr^{-1}) and CS6: Pigeon pea + Groundnut (1:7)- Ragi (0.39 Mg ha^{-1} yr^{-1}), which was statistically comparable to CS7: Fodder sorghum + Fodder cowpea (1:2) and CS8: Fodder maize - Lucerne (0.36 Mg ha^{-1} yr^{-1}) (Table 3 and figure 3). In CS_{10}, there was a decrease in the rate of C sequestration (-0.05 Mg ha^{-1} yr^{-1}): Beetroot, Marigold, and Bhendi which might be due to low biomass or crop residues retained by vegetable crop production.

In 2020- 2021 after harvest, C-sequestration rate is much greater (0.54 Mg ha^{-1} yr^{-1}) was recorded in CS_7: Fodder sorghum + Fodder cowpea (1:2), followed by CS_1: Rice – maize (0.46 Mg ha^{-1}) it was statistically comparable to CS_2: Cotton – fallow (0.45 Mg ha^{-1}) (Table 3 & Figure 3).

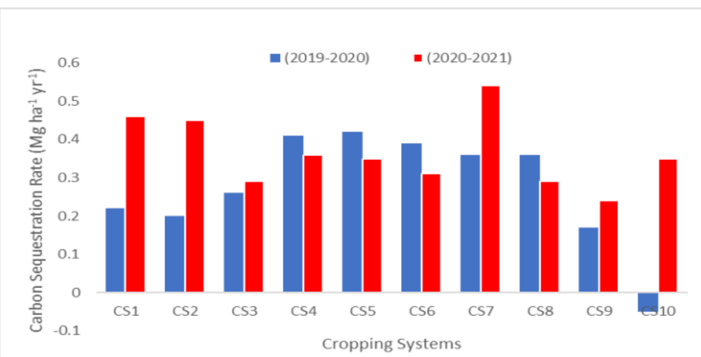

Fig 3. Various cropping systems impacts on rate of carbon sequestration after Rabi, 2019-2020 and 2020-2021

All other cropping systems were statistically on par with one another except CS_9:Sweet corn – Vegetables (Tomato) which has sequestered low rates of carbon (0.24 Mg ha^{-1}) in contrast to other cropping techniques.

The trend was found different in 2020-2021 as opposed to 2019- 2020 in terms of C- sequestered by cropping systems in which cereals (Rice – maize) and predominant crop (cotton) – fallow followed fodder and legume crops (Fodder sorghum + Fodder cowpea). In general, there was an overall improvement in carbon sequestration rate by all the cropping systems over the ones which have been recorded by cropping systems in 2019-2020 harvest which might be due to high rainfall during those monthly periods of the cropping cycles. Our results have confirmed that cropping systems that involves cover crops *viz*., legumes, cereals and cotton followed by short winter fallow after the fourth year of the experiment have the ability to sequester more carbon.

3.2 Various cropping Systems's impact on System Productivity (RGEY)

A cropping system's productivity depends on its potential output as well as the variety of the crops being tried out there. The crops that are being examined have an impact on agricultural yield, either positively or negatively [29,30]. Because vegetable crops have a high yield potential, CS_{10}: Bhendi - Marigold - Beetroot cropping sequence had the highest system productivity within regards of rice grain equivalent yield (RGEY) of any cropping system (40818 kg ha^{-1}). This system's productivity was significantly higher than that of other cropping systems and was followed by CS_9: Sweet corn - Vegetables (Tomato) (23962 kg ha^{-1}). Increased vegetable crop yields were also documented by [31,32] in their meta-analyses. Significantly lowest RGEY (5868 kg ha^{-1}) was observed in Bt cotton followed by Fallow cropping sequence (CS_2) after the third year, 2019-2020 which might be due to a lower build-up of SOC. In 2020-2021, a significant increase in RGEY was observed in Fodder maize – Lucerne, Bt cotton + Greengram (1:3)- Groundnut, CS_2: Bt cotton – Fallow and Pigeon pea +Maize (1:3)-Groundnut by 17.13%, 9.52 %, 7.75% and 3.65% respectively whereas significant reduction was in the cropping sequence *viz*., CS_{10}: Bhendi – Marigold – Beetroot, Pigeon pea + Groundnut (1:7) – Ragi, CS_1: Rice – Maize, CS_4: Pigeon pea + Greengram– Sesame (1:3), Fodder sorghum + Fodder cowpea (1:2): CS_7 and CS_9: Sweet corn – Vegetables (Tomato) by 18.80%, 8.84%, 7.80%, 4.53%, 3.49%, and 1.78% respectively (Table 4).

Table 4. Different cropping systems impacts on system productivity (RGEY) in kg ha-1 for the year 2019-2021

Cropping systems-*(Kharif-Rabi)*	2019- 2020	2020-2021
CS1: Rice – maize	12240	11285
CS2: Bt Cotton – fallow	5886	6342
CS3: Bt cotton + Greengram (1:3) – Groundnut	13926	15252
CS4: Pigeon pea + Greengram (1:6) – Sesame	8829	8429
CS5: Pigeon pea+Maize (1:3) – Groundnut	14947	15492
CS6: Pigeonpea + Groundnut (1:7) – Ragi	11998	10937
CS7: Fodder sorghum + Fodder cowpea (1:2) – Horsegram – Sunhemp	6754	6518
CS8: Fodder maize – Lucerne	7231	8470
CS9: Sweetcorn – Vegetables (Tomato)	23962	23535
CS10: Bhendi – Marigold – Beetroot	40818	33145
SEm±	456.51	779
CD (0.05)	1368.5	2334

Note: RGEY= Rice grain equivalent yield

3.3 Relationship between carbon sequestrations in addition to system productivity measured by rice grain equivalent yield (RGEY):

It is evident that RGEY increased with a decrease in carbon sequestration rate (CSR) under cropping sequence *viz*., Bhendi – Marigold – Beetroot (CS_{10}), Sweet corn – Vegetables such as Tomato (CS_9) and in some of the cropping systems especially those without legume component and decreased with increase in CSR in cropping systems with legume crops after third and fourth year of the cropping systems (Figure 4a and 4b). The decline in CRS with increase in system productivity in CS_{10} and CS_9 might be ascribed to the exhaustive nature of vegetable crops for the removal of available nutrients in the soil for assimilation. The increase in CSR with decrease in system productivity in cropping systems that involve legume crops might be attributed addition and retention of the biomass by leguminous crops which in turn decompose adding a specific amount of soil organic matter.

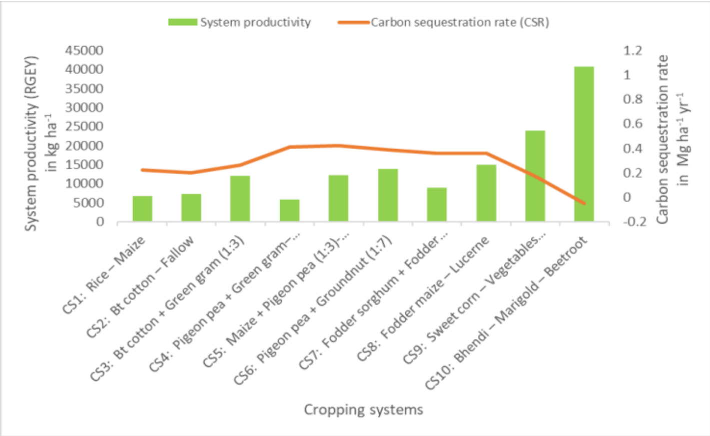

Figure 4a. Relationship between carbon sequestration rate and system productivity (RGEY) of different cropping systems after the third year (2019-2020)

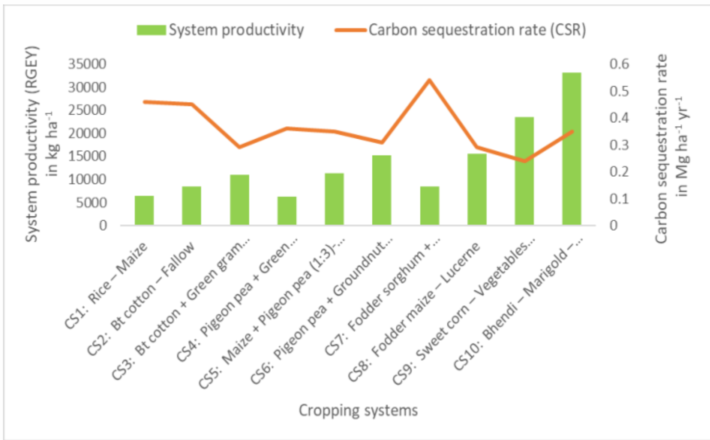

Figure 4b. Relationship between carbon sequestration rate and system productivity (RGEY) of different cropping systems after third year (2020-2021)

Pearson correlation indicated a significant negative correlation (r = -0.755*) between CSR and system productivity (RGEY) (Figure 5a) after third year of the cropping system, *i.e.*, 2019-2020 and no significant correlation was observed between system productivity and CRS after the fourth year of the trial *i.e.*, 2020-2021 (Table 5b).

Table 5ab. Pearson correlation between system productivity in terms of rice grain equivalent yield (RGEY) and carbon sequestration rate (CSR) after third and fourth year of the cropping system.

a. 2019- 2020

Correlations			
		System productivity (RGEY)	Carbon sequestration rate (CSR)
System productivity (RGEY)	Pearson Correlation	1	**-.755***
	Sig. (2-tailed)		**.012**
	N	10	10
Carbon sequestration rate (CSR)	Pearson Correlation	**-.755***	1
	Sig. (2-tailed)	**.012**	
	N	10	10
*. Correlation is significant at the 0.05 level (2-tailed).			

b. 2020-2021

Correlations			
		System productivity (RGEY)	Carbon sequestration rate (CSR)
System productivity (RGEY)	Pearson Correlation	1	-0.493
	Sig. (2-tailed)		0.147
	N	10	10
Carbon sequestration rate (CSR)	Pearson Correlation	-0.493	1
	Sig. (2-tailed)	0.147	
	N	10	10
*. Correlation is significant at the 0.05 level (2-tailed).			

Discussion

Organic Carbon in Soil (SOC) stock (Mg ha^{-1}): According to [23], fallow fields or lands deficient in OC, which led to a decrease in biomass in Bangladesh. According to [13], cotton monoculture appears to have depleted SOC.

After 17 years of cropping, [24] found that soil C stores in maize-pigeon pea cropping systems for a long-term study in Brazil grew by 26%. In India, pigeon pea-cereal (pearl millet) farming was observed to significantly enhance soil C after one year [25].

The equilibrium of organic carbon

The farming strategies that relied on the production of dry fodder and legumes had the greatest favorable impact on organic carbon which is mainly because of plant residue accumulation, massive quantity of litter falls and canopy cover to the soil brought about by those cropping systems. [26] confirmed similar findings, observing that cover crops like legumes and summer cover crops such as Sunhemp improve carbon sequestration through the enhancement of soil structure and addition of large quantities of soil organic matter.

Accumulation or decline (Mg ha^{-1})

Addition of more plant wastes to the soil brought about by the inclusion of legume crops has resulted in more carbon buildup in the soil. Similar findings were made by [27], who found that the accumulation of organic carbon was higher in legume-incorporated grassland than in natural grassland. The stability of the SOC increment, which is influenced by vegetable cultivation patterns as well as the exhaustive extent of vegetable crop production for nutrients that are accessible in the soil, may be the cause of the observed depletion of organic carbon in CS_{10}: Bhendi, Marigold, and Beetroot cropping systems.

Inclusion of vegetables in CS will augment the capacity of the system to enhance SOC, while, also having a higher proportion of active carbon than the reference fields, which could be the indication of quick break down or decomposition of SOC in the soil. . Similar findings were reported by [28], who found that while vegetable cultivation might increase SOC quantity, it had an impact on SOC stability.

Rate of carbon sequestration (Mg ha^{-1} yr^{-1})

[34] observed comparable outcomes from their experiment, while evaluating the state of SOC sequestration under different cropping patterns that the soils under vegetable, vegetable-vegetable, fallow- Jute-T. Am, Fallow-Aus-Vegetable and Rabi-Jute-T. Cropping practices used by Aman were substantially less soil organic matter percent and lower SOC sequestration ability. It is obvious that the rate of C sequestration was greater under legume cover crops and fodder crops which might be due to large canopy for soil cover and plant residues. The inclusion of these crops (legumes and dry fodder crops) have indicated a positive contribution towards organic carbon restoration which could ultimately sustain the soil for crop production. The findings of this study are consistent with those of [35], who noted that grasslands (cover crops) constitute special in that they are particularly sensitive to change and vulnerable to it because of their substantial soil carbon stocks. They are also excellent targets for long-term intake of carbon [36]. According to research by [37], all leguminous crops and fodder-based cropping systems, such as Hybrid Napier, Hedge Lucerne, Fodder cowpea, and Fodder maize, were found to sequester the most carbon in contrast to other crops. Similar outcomes have also been revealed by [38], who found that cropping systems using legume crops saw greater amounts of carbon sequestration.

Higher rates of C- sequestration in cereals (rice – maize) crops and cotton as cover crops might be ascribed to lower water extractable organic C concentration mechanism possessed those crops which in turn aid in reducing the leaching losses of carbon than non-cover crops. In their experiment, [39] reported comparable outcomes indicating that cover crops have potential on long-term C storage and reducing C leaching losses in the long-term experiment. According to [39], the rate of carbon dioxide (CO_2) sequestration with cover crops ranged from 1.1 to 2.2 Mg C ha^{-1} $year^{-1}$ in the top 15 cm.

4. CONCLUSION

The soil carbon stock has increased relative to the initial value as a result of crop diversification using cover crops, specifically legume, fodder, and cereal-based cropping systems. When cover crops were not used, soil organic carbon levels decreased, which had a detrimental impact on how much carbon other crops in the system were able to sequester. Legumes, cover crops, crop rotation, fodder and/or forage production, and limited fallow periods are a few of the management techniques that are advised for carbon storage. Therefore, it is imperative to follow bio-intensive cropping systems in agricultural production systems not only to sequester carbon but also to improve soil quality. Research on C- sequestration in the sub-surface soil profile should be deemed to compute for carbon retention efficiency under different cropping systems.

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