RESEARCH ARTICLE Agricultural Reviews, Volume 43 Issue 2: 249-254 (June 2022)

Long-term Effect of Different Cropping Systems on Carbon Sequestration in a Sandy Loam Soil of Telangana

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10.18805/ag.R-2301

ABSTRACT

Background: Rice, maize and Bt cotton are the predominant crops which are either grown solely or in rotation with other crops in Telangana state. As all these crops are exhaustive, non leguminous in nature and may lead to fast soil degradation. Therefore, a major agricultural research priority is needed to sustain soil productivity through carbon sequestration by including legume component in cropping systems. The present study was undertaken to investigate effect of cropping systems on carbon sequestration in the ongoing long-term field trial.

Methods: This field investigation was initiated during the year 2017 at an experimental farm located at College of Agriculture, Rajendranagar, Hyderabad. The surface soil samples were collected at 0-15 cm depth in various treatments within different cropping systems after harvest of *Kharif* and *Rabi* crops, 2019-2020 at the completion of third year of the experiment and analysed for soil organic carbon (SOC) and soil inorganic carbon (SIC) status by following standard procedures. Data were subjected to statistical analysis by adopting RBD statistical tool and analysis of variance was worked by adopting operational statistics (OP STAT) software programme.

Result: The results indicated the improvement in soil organic carbon over the initial status due to the effect of efficient cropping systems. Significantly highest build-up of organic carbon was noticed in the following cropping sequence: CS_5: maize + pigeon pea (1:3) (1.25 Mg ha^{-1}) and CS_4: pigeon pea + green gram (1:3) - sesame (1.22 Mg ha^{-1}) but the lowest value of SOC was recorded in CS_1: rice-maize (7.51 Mg ha^{-1}) and CS_2: Bt cotton-fallow (7.24 Mg ha^{-1}), respectively. During the study, it was also observed that in one of the cropping systems *i.e.*, CS_{10}: bhendi-marigold-beetroot showed the negative impact on the level of SOC stock (6.77 Mg ha^{-1}) fell below the initial value (7.53 Mg ha^{-1}) after third year of trial. However, the highest carbon sequestration rate was recorded in CS_5: maize + pigeon pea (0.42 Mg ha^{-1} yr^{-1}) and CS_4: pigeon pea + green gram (1:3) - sesame (0.41 Mg ha^{-1} yr^{-1}). The salient findings of this study showed that cropping systems involving legumes and fodder crops had improved soil organic carbon on long term basis.

Key words: Carbon sequestration, Cropping system, SIC, SOC.

INTRODUCTION

Total soil organic carbon (TSOC), soil inorganic carbon (SIC) and total carbon (TC) were estimated as 0.47, 0.71 and 1.18 Pg for the black soils and 0.33, 0.50 and 0.83 Pg in red soils which covers 15 million area in the semi-arid tropics (SAT), India. It was further reported that there was overall build-up trend in soil organic carbon stock after 25-30 years under identified cropping systems (Battacharyya *et al*., 2006). Despite the higher SOC stock in soils of different climatic regions, the database indicates that hot arid and semi-arid climatic regions have overall poor soil organic carbon (SOC). Carbon content in soil is less than 1 per cent in plains and around 2 per cent in hills States in India, compared with the world average of 4 per cent. It has been documented that soils with low OC are more prone to sodification than high OC soils (Poonia,1998). There is an enormous scope for sequestration of OC in arid and semi-arid climatic regions through adoption of efficient cropping systems (Velayutham *et al*., 2019). Soil Carbon sequestration is a multiple purpose strategy that can restore degraded soils, enhances the land productivity, improves the diversity, protects the environment and reduces the enrichment of atmospheric CO_2 (Wang *et al*., 2010). The historic soil organic carbon loss (about 66-90 Pg C) from the soil can be restored *via* C sequestration for 25-50 years through adoption of appropriate crop management practices (Lal *et al*., 2004). An average value of 6.85 g kg^{-1} SOC in first 30 cm depth of soil seems to be a quasi-equilibrium concentration of SOC in black soils used for cotton cultivation (Saikh *et al*. 1998 a, b, Naitam and Bhattacharyya, 2004).

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How to cite this article: Nthebere K., Sharma, S.H.K., Kumari, C.P. and Qureshi, A.A. (2022). Long-Term Effect of Different Cropping Systems on Carbon Sequestration in a Sandy Loam Soil of Telangana. Agricultural Reviews. 43(2): 249-254. DOI: 10.18805/ag.R-2301.

Submitted: 10-06-2021 **Accepted:** 17-02-2022 **Online:** 15-03-2022

Introduction of pigeon pea, with or without other leguminous crops, aid towards improving SOC in soils irrespective of bioclimatic systems (Bhattacharyya *et al*., 2008). Inclusion of pulses in the cropping systems consisting of intercropping, mixed cropping, relay cropping and sequential cropping aid in high carbon sequestration, low carbon footprint, fixation of atmospheric nitrogen in the soil and improvement of soil biodiversity (Adarsh *et al*., 2019).

The scope for C sequestration in croplands has provided a promising approach for improving soil quality. However, this approach depends on cropping systems, which may be defined as an operating system for growers to follow in their practices for crop production. An ideal cropping system for C sequestration should produce and retain the abundant quantity of biomass or organic C in the soil. Crop rotation with legumes or pulses improves soil C sequestration through biomass production and reduction in nitrogen input as chemical fertilizer (Zentner *et al*., 2001. Zentner *et al*., 2004). The organic C concentration in the surface soil (0-15 cm) is dependent on the total input of crop residues incorporated into the soil. Therefore, to improve C sequestration, it is critical to increase the input of plant biomass residues by including cover crops between main crop in growing seasons, reducing fallow period of land, crop rotations and intercropping systems. Biomass retention to the soil can be improved by maintaining a dense vegetation cover on the soil surface, which in turn prevent soil erosion against SOC losses. Row intercropping is commonly practiced in India with cereals *viz*. sorghum intercropped with pigeon pea which efficiently utilize the time and space for an optimal productivity of both crops (Willey, 1983). Therefore, the present study was undertaken with the view to investigate the effect of different cropping systems on carbon sequestration ability in sandy loam soil.

MATERIALS AND METHODS

The study was conducted at college farm of All India Coordinated Research Project on Integrated Farming Systems, Professor Jayashankar Telangana Sate Agricultural University, Rajendranagar in *Kharif-Rabi* session, 2019-2020. The soil of the experimental field comes under the soil order *Inceptisols*. This soil is sandy loam in texture, red chalk in colour, neutral to alkaline in soil reaction (pH 7.68) due to presence of lime concretion in lower horizon. The N status of the experimental field was low (191.65 kg ha^{-1}) and 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}) while electrical conductivity was also in low range (0.40 dSm^{-1}).

The experiment was laid out with ten cropping systems as treatments in randomized block design (RBD) with three replications. The ten combinations of cropping sequence tested were CS_1: Rice-maize, CS_2: Bt cotton-fallow, CS_3: Bt cotton + green gram (1:3) row inter crop -groundnut, CS_4: Pigeon pea + green gram (1:3) inter crop - sesame, CS_5: Maize + pigeon pea (1:3) row inter crop-groundnut, CS_6 : pigeon pea + groundnut (1:7) row intercrop-ragi, CS_7: Fodder sorghum + fodder cowpea (1:2) row inter crop - horsegram-sunhemp, CS_8: Fodder maize-lucerne, CS_9: Sweet corn-vegetables (tomato) and CS_{10}: Bhendi-marigold-beetroot. Each treatment was allocated randomly initially and replicated three times. All the crops in different cropping systems were raised in accordance with recommended package of practices. Crop sequences during *Rabi* were taken up as and when the preceding *Kharif* crops were harvested in the respective plots. Composite soil samples were collected from each plot at a depth of 0-15 cm and used for the chemical analyses. The processed soil samples were analysed for soil organic carbon and soil inorganic carbon by adopting the following standard procedures. Based on the results of soil organic carbon and inorganic carbon, carbon sequestration was worked out at the end of third year of the cropping system after harvest of *Rabi* crops. soil organic carbon (%) was estimated by Walkley and Black (1934) and soil inorganic carbon by adopting the procedure as described by Richards *et al.* (1954).

Quantification of soil carbon stock (s)

The soil carbon stock was done by adopting the methods as described by Batjes (1999) and Battacharya *et al.* (2000) (Table 1).

Organic carbon (Mg ha^{-1})

Calculation of SOC stock was done by multiplying OC content (%), bulk density of soil (1.41 Mg m^3) determined at the initiation of the experiment at 0-15 cm of soil depth.

SOC stock (Mg ha^{-1}) =
SOC content (%) × B.D (Mg m^3) × Depth of soil (cm) of soil

Inorganic carbon (Mg ha^{-1})

Similarly, for SIC the calculation was derived as 12% values of the estimated $CaCO_3$ percentage.

SIC Stock (Mg ha^{-1}) =
SIC content (%) × B.D (Mg m^3) × Depth of soil (cm) × 12% ($CaCO_3$)

Total carbon (Mg ha^{-1})

The sum of SOC + SIC was produced as total carbon (TC) content for a particular soil depth and was expressed in Mg ha^{-1}.

TC Stock (Mg ha^{-1})= SOC + SIC

Organic carbon build up or depletion

This was deduced as the difference between the final organic carbon and initial organic carbon for 0-15 cm soil depth and expressed as Mg ha^{-1}.

Build-up or depletion (Mg ha^{-1}) = Final SOC - Initial SOC

Carbon sequestration rate

It was calculated by dividing the carbon build-up or depletion with the age of the experiments in years and expressed as Mg ha^{-1} yr^{-1} (Srinivasarao *et al*., 2009).

$$\text{CS rate (Mg ha}^{-1}\text{ yr}^{-1}) = \frac{\text{Build-up or Depletion (Mg ha}^{-1})}{\text{Age of experiment (years)}}$$

Data analysis and statistics

The experimental data were analysed by adopting RBD statistical tool and analysis of variance was worked out using Duncan multiple rank test (DMRT) in operational statistics (OP STAT) software for agricultural research.

RESULTS AND DISCUSSION

Effect of cropping systems on soil carbon stocks and carbon sequestration rate

Carbon stocks (Mg ha^{-1})

The data on soil organic carbon stock, soil inorganic carbon stock and total carbon stocks studied has been presented in (Table 1 and Fig 1).

Soil organic carbon (SOC) stock (Mg ha^{-1})

Highest content of SOC stock (9.52 Mg ha^{-1}) at harvest of *Rabi* (Winter) crops was observed under CS_4: Pigeon pea + green gram (1:3) followed by CS_6: Pigeon pea + groundnut (1:7) (9.24 Mg ha^{-1}) and CS_8: Fodder maize-lucerne (9.14 Mg ha^{-1}) which were statistically on par with CS_5: Maize + pigeon pea (1:3) (9.02 Mg ha^{-1}) whereas the rest of the cropping systems were statistically on par with each other. The increase in SOC stock might be attributed to massive litter fall from pigeon pea. However, CS_2: Bt cotton-fallow and CS_{10}: Bhendi-marigold-beetroot resulted in decline in SOC stock over all other cropping system which might be due to fallowing in CS_2: Bt cotton-fallow and exhaustive nature of vegetables CS_{10}: Bhendi-marigold-beetroot (Table 1 and Fig 1). Similar results were reported by Yeasmin *et al.* (2020) who observed that fallow lands or fields depleted OC which in turn resulted in biomass reduction in Bangladesh. Bhattacharyya *et al.* (2008) also reported that monocropping of cotton appear to have exhausted SOC.

Data in Table 1 indicate that cropping systems had significant effect on soil organic carbon stock. Diekow *et al.* (2005) reported increased soil C stocks by 26% in maize-pigeon pea cropping systems for a long-term trial in Brazil after 17 years of cropping. Tolanur and Badanur (2003) also reported a significant increase in soil C after one year of pigeon pea-cereal (pearl millet) cropping in India.

Table 1: Effect of different cropping systems on soil organic carbon, inorganic and total carbon stock after *Rabi* 2019 -2020.

Treatment (Cropping system: *Kharif-Rabi*)	SOC (Mg ha^{-1})	SIC (Mg ha^{-1})	TC (Mg ha^{-1})
CS_4: Pigeon pea + Green gram (1:3)	9.52^{a}	2.46^{bc}	12.05^{a}
CS_6: Pigeon pea + Groundnut (1:7)	9.24^{ab}	1.79^{de}	11.12^{ab}
CS_8: Fodder maize - Lucerne	9.14^{abc}	2.71^{bc}	11.86^{ab}
CS_5: Maize + Pigeon pea (1:3)	9.02^{abc}	1.80 ^{de}	10.84^{abc}
CS_7: Fodder sorghum + Fodder cowpea (1:2)	8.66^{abcd}	1.79^{de}	10.45^{bc}
CS_3: Bt cotton + Green gram (1:3)	8.47^{abcd}	2.38^{bcd}	11.09^{ab}
CS_9: Sweet corn - Vegetables (Tomato)	7.91^{abcd}	2.97^{b}	10.88^{abc}
CS_1: Rice - Maize	7.51^{bcd}	2.12^{cde}	9.55^{cd}
CS_2: Bt cotton - Fallow	7.24^{cd}	1.70^{e}	8.73^{d}
CS_{10}: Bhendi - Marigold - Beetroot	6.77^{d}	5.57^{a}	12.27^{a}
Initial SOC		7.53	

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

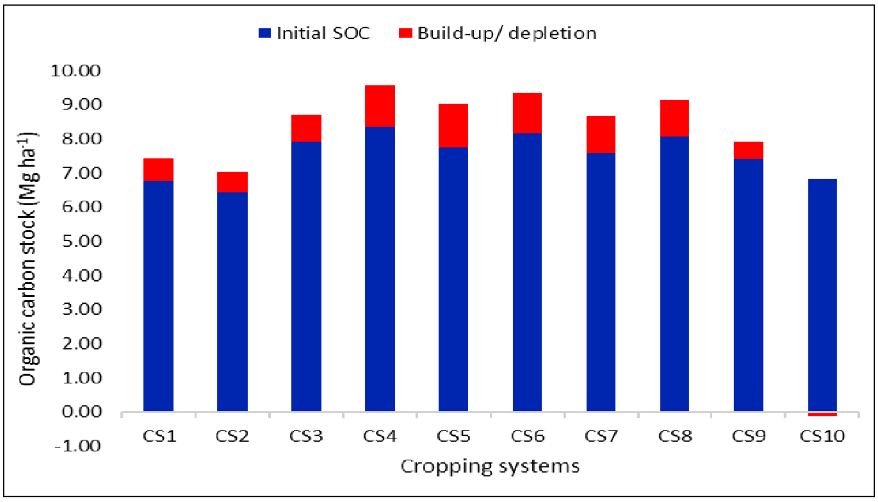

Fig 1: Effect of different cropping systems on organic carbon stock at third year after *Rabi,* 2019-20.

Table 2: Build-up or depletion in organic carbon stock and carbon sequestration in soil due to different cropping systems.

Treatment (Cropping system: (*Kharif-Rabi*)	Final SOC ($Mg\ ha^{-1}$)	Initial SOC ($Mg\ ha^{-1}$)	Build-up or depletion of SOC ($Mg\ ha^{-1}$)	C sequestration rate ($Mg\ ha^{-1}\ yr^{-1}$)
CS_5: Maize + Pigeon pea (1:3)	9.02	7.77	1.25^a	0.42^a
CS_4: Pigeon pea + Green gram (1:3)	9.52	8.36	1.22^a	0.41^{ab}
CS_6: Pigeon pea + Groundnut (1:7)	9.24	8.16	1.18^a	0.39^{ab}
CS_7: Fodder sorghum + Fodder cowpea (1:2)	8.66	7.58	1.08^a	0.36^b
CS_8: Fodder maize - Lucerne	9.14	8.07	1.08^a	0.36^b
CS_3: Bt cotton + Green gram (1:3)	8.47	7.93	0.78^b	0.26^c
CS_1: Rice - Maize	7.51	6.77	0.66^{bc}	0.22^{cd}
CS_2: Bt cotton - Fallow	7.24	6.43	0.60^{bc}	0.20^d
CS_9: Sweet corn - Vegetables (Tomato)	7.91	7.42	0.50^c	0.17^d
CS_{10}: Bhendi - Marigold - Beetroot	6.77	6.83	-0.13^d	-0.05^e

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

Soil inorganic carbon (SIC) stock ($Mg\ ha^{-1}$)

Highest content of SIC stock (5.57 $Mg\ ha^{-1}$) at harvest of *Rabi* crops was recorded in, followed by CS_9: sweet corn-vegetables (Tomato) with SIC stock (2.97 $Mg\ ha^{-1}$) over all cropping systems except CS_2: Bt cotton - fallow which resulted in lowest SIC stock (1.70 $Mg\ ha^{-1}$) (Table 1 and Fig 1). The highest SIC stock in CS_{10}: Bhendi-marigold-beetroot and CS_9: sweet corn-vegetables (Tomato) might be due to high soil inorganic carbon initially which can remain constant for a long period of time in the soil following cultivation practices and fertilization. Similar results were reported by Mikhailova *et al.* (2006) in their experiment that increase in inorganic carbon stock in continuous cropped field was attributed to initial cultivation and fertilization.

Total carbon (TC) stock ($Mg\ ha^{-1}$)

Highest content of total carbon stock (12.27 $Mg\ ha^{-1}$) *i.e.*, (SOC + SIC) was recorded in CS_{10}: Bhendi-marigold-beetroot and CS_4: Pigeon pea + green gram (1:3) (12.05 $Mg\ ha^{-1}$) whereas lowest TC stock (8.73 $Mg\ ha^{-1}$) was registered in CS_2: Bt cotton - fallow cropping system (Table 1 and Fig 1). The highest TC stock in CS_{10} might be attributed to high soil inorganic carbon initially which remain constant for a long period of time in the soil while the highest TC stock in CS_4: Pigeon pea + green gram (1:3) might be due to build up in soil organic carbon as a result of that cropping system effect.

Organic carbon balance

There was a positive effect on soil organic carbon by all the cropping systems except CS_2: Bt cotton-fallow, CS_1: Rice-Maize and CS_{10}: Bhendi-marigold-beetroot cropping systems which had depleted organic carbon. Highest positive effect was observed in cropping system involving legume based cropping systems for improving soil health *i.e.*, CS_4: Pigeon pea + green gram (1:3) and dry fodder production system *i.e.,* CS_7: Fodder sorghum + fodder cowpea (1:2). Similar results were reported by Nair *et al*. (2015).

Build-up or depletion ($Mg\ ha^{-1}$)

Highest carbon build-up (1.25 $Mg\ ha^{-1}$) after third year was observed 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 $Mg\ ha^{-1}$) which was statistically on par with CS_7: Fodder sorghum + fodder cowpea (1:2) and CS_8: Fodder maize - lucerne (1.08 $Mg\ ha^{-1}$) cropping systems (Table 2 and Fig 1). This might be due to inclusion of legume crops which result in addition of more plant residues to soil. Similar results were reported by Prasad *et al.* (2004) in which build-up of organic carbon was higher in legume incorporated grassland than the natural grassland. However, depletion of organic carbon was observed in CS_{10}: Bhendi -marigold-beetroot cropping systems which might be due to exhaustive crops for nutrients in the soil.

Carbon sequestration rate ($Mg\ ha^{-1}\ yr^{-1}$)

The results of the study indicated that highest carbon sequestration rate *i.e.*, 0.42 $Mg\ ha^{-1}\ yr^{-1}$ was recorded in CS_4: Pigeon pea + Green gram (1:3), followed by CS_5: Maize + Pigeon pea (1:3) (0.42 $Mg\ ha^{-1}\ yr^{-1}$) and was followed by CS_6: Pigeon pea + Groundnut (1:7) (0.39 $Mg\ ha^{-1}\ yr^{-1}$) which was statistically on par with CS_7: Fodder sorghum + Fodder cowpea (1:2) and CS_8: Fodder maize - Lucerne (0.36 $Mg\ ha^{-1}\ yr^{-1}$) (Table 2 and Fig 1). Depletion in C sequestration rate (-0.05 $Mg\ ha^{-1}\ yr^{-1}$) was observed in CS_{10}: Bhendi-marigold-beetroot. Inclusion of legumes and fodder production systems contributed in storing carbon on a long-term basis which in turn results in soil sustainability. The results of this study are in line with those of (Korner, 2003) who reported that grasslands are unique because besides being most sensitive and vulnerable to changes due to their extensive soil carbon reserves, they are also promising targets for long-term carbon uptake (Schimel, 1995). Lugato *et al.* (2014) determined potential net carbon sequestration in cropping systems and carbon sequestered was found to be the highest by all leguminous crops and fodder cropping systems *viz*., hybrid napier, hedge lucerne, fodder cowpea and fodder maize in comparison with other crops.

Rochester, (2011) reported higher rates of carbon sequestration observed in cropping systems that included legume crops.

CONCLUSION

Diversification of existing cropping systems with legume based cropping systems and fodder production systems have improved Soil carbon stock as compared to initial value. Continuous omission of legume and fodder production systems had depleted soil organic carbon which in turn showed negative effect on carbon sequestration rate among other crops within the system. Recommended management practices include conversion from Conventional tillage to no-tillage or minimum tillage, incorporation of legume, cover crops and fodder and or forage crop rotation. Therefore, different cropping systems are essential to improve soil health.

ACKNOWLEDGMENT

The authors are extremely thankful to All India Coordinated Research Project (AICRP), IFS for the Indian Council of Agricultural Research with financial help and technical guidance to carry out this research work at Professor Jayashankar Telangana State Agricultural University, Rajendranagar, Telangana (India) under the aegis of "All India Coordinated Research Project on Long Term Experiment."

Conflict of interest: None.

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