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Comparative performance of farming practices in terms of carbon sequestration potential of mulberry and soil organic carbon stock

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Experimentation under the study at Central Sericultural Research and Training Institute, Berhampore (West Bengal, India) was laid out in RBD comprising of seven treatments replicated thrice. The treatments consist of six different farming practices along with a fallow. Mulberry variety, S 1635, spaced at 60 x 60 cm was subjected to those farming practices under irrigated Gangetic alluvial soil. Three years' field experimentation revealed that yield attributes, carbon sequestration potential (CSP) and NPK uptake by mulberry was varied significantly with respect to farming practices as well as seasons. Mulberry growing under moderate tillage with grass cover registered the highest leaf productivity and CSP of 38.72 t ha^{-1} $year^{-1}$ and 6.90 t ha^{-1} $year^{-1}$, respectively in comparison to the existing farming practice (intensive tillage without grass) registering the same two parameters as 38.16 t ha^{-1} $year^{-1}$ and 6.54 t ha^{-1} $year^{-1}$, respectively. It shows that the former is capable of earning an annual carbon credit of 0.36 t from one hectare of land in comparison to the existing farming practice and of course without any compromise with the leaf productivity. Furthermore, the particular farming practice, moderate tillage with grass cover, registered 40.16 Mg ha^{-1}soil organic carbon stock (SOCS) estimated after completion of the field experimentation and the same was significantly higher than the existing farming practice registering the value of 35.25 Mg ha^{-1}. Thus, in terms of SOCS also, the same farming practice is capable of earning carbon credit to the tune of 4.91 Mg ha^{-1} in comparison to the existing farming practice over a time period of three years. It is also worthy to mention that the particular altered farming practice as mentioned can even earn a carbon credit of 1.14 Mg ha^{-1} in terms of SOCS in comparison to the fallow land over the same period of time.

Key words: Carbon sequestration potential, farming practice, mulberry, soil organic carbon stock.

INTRODUCTION

Environmental globalization through the participation of each country in terms of their every activity is the utmost

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need of the present day, as its consequences will sooner or later reach all. Global warming is increasing at an alarming rate of 0.2°C per decade with an estimated average rise in global temperature of 3°C by 2100, which is believed to be caused by rising level of atmospheric CO_2 (Lavania and Lavania, 2009). Ability of the terrestrial biosphere to sequester and store atmospheric CO_2 has been recognized as an effective and low-cost method of offsetting carbon emissions (Koul and Panwar, 2008). Wise use of plants is good but when they are destroyed without thinking of future, the consequences are extremely complex like global warming and climate change (Parmesan and Yohe, 2003; Lau and Tiffin, 2009). Inversely, halting the destruction activities can cut the same proportion of GHGs emission which would be beneficial, thereby bringing the reducing emission from deforestation and forest degradation (REDD+) mechanism into existence (Latham et al., 2014; Greg and Donna, 2015). Different plant species have different capacity to sequestrate carbon during photosynthesis. Slow growing plant species like *Shorea robusta*, *Terminalia tomentosa* and *Adina cordifolia* sequestrate carbon slowly (Mandal et al., 2016).

On the other hand, carbon sequestration potential (CSP) is reported to differed with variation in land-use/ farming system (Kundu et al., 2008; Chauhan et al., 2010) and the same will not only fulfil the requirements of food, fodder and timber but render environmental benefits too. Carbon farming is a new way to describe a collection of eco-friendly farming techniques like use of cover crops, conservation tillage, pasture cropping, mulching etc., which increases soil organic carbon stock (SOCS) (http://www.reuters.com/article/ idUSTRE55G01B20090617?pageNumber=2&virtualBran...). Mulberry is an important leaf crop of India, occupying an area of 2.03 lakh hectares, grown as sole food of silkworm, *Bombyx mori* L. Higher concentration of CO_2 can have a positive influence on photosynthesis under optimal growing condition of light, temperature, nutrient and moisture supply and thus, biomass production can be increased, especially of plant with C_3 photosynthetic metabolism (Sombroek and Gommes, 1996). Mulberry being a C_3 plant promises to be capable of storing carbon in its above-ground components through enzymatic regulation of photosynthetic CO_2 fixation (Woodrow and Berry, 1988). Besides, modification of agricultural practices is a recognized method of carbon sequestration as soil can act as an effective sink offsetting as much as 20% of CO_2 emission annually (http://en.wikipedia.org/wiki/CO2_sequestration). In mulberry farming, information on extent of carbon sequestration in terms of CSP and SOCS is scanty and hence, the present study has been initiated to assess the CSP of mulberry growing under varying farming practices with an extension to SOCS too for evaluation of comprehensive carbon sequestration within the system. The very object of the study is nothing but to match the current Global agenda for terrestrial sequestration of carbon with mulberry-culture in terms of its social value.

MATERIALS AND METHODS

The study was undertaken on a sandy clay loam soil (*Typic ustochrept*) at the experimental farm of the Institute as mentioned above (24°4/ N – 88°9/ E) and the same is confined to the Bengal-Assam plain, hot sub-humid eco-geographic region with alluvium derived soils. Bulk density, organic carbon, available N, P_2O_5 and K_2O content of the experimental soil at the initiation of the experimentation were 1.38 Mg m^{-3}, 5.80 g kg^{-1}, 271 kg ha^{-1}, 34 kg ha^{-1} and 355 kg ha^{-1}, respectively. Maximum temperature of the experimental site varied between 27 to 43°C while minimum temperature varied between 14 to 30°C. The annual rainfall was varying between 1093 mm to 1420 mm with rainy days of 141-173 days per year.

Experimentation under the study was laid out in RBD comprising of seven treatments replicated thrice. The treatments were: T1, Intensive tillage (IT); T2, IT + Grass cover; T3, IT + Grass Cover + Cover crop; T4, moderate tillage (MT); T5, MT + Grass cover; T6, MT + Grass Cover + Cover crop; T7, Fallow. Mulberry variety, S 1635, spaced at 60 x 60 cm was subjected to six (T1 to T6) different farming practices under irrigated Gangetic alluvial soil. Intensive tillage refers to deep digging of ~30 cm depth of soil while moderate tillage refers to single-surface digging of ~10 cm depth of soil. *Cyperus rotundus* and *Cynodon dactylon* were naturally grown as grass cover while *Vigna umbellata* was used as cover crop. The coverage of grass crop and grass crop + cover crop was 420 and 485 g m^{-2}, respectively.

Soil organic carbon stock (SOCS) before initiation of the experimentation was computed based on the estimated values of bulk density (BD) of the same and its organic carbon (OC) content. 'Core cutter' method (Blake and Hartage, 1986; Kar et al., 2013) was employed to determine BD and OC content was estimated by following the method of chromic acid digestion (Black, 1965; Kar et al., 2018). Ultimately, computation of SOCS was made with the help of the following equation:

$$S = \rho. C. d \qquad (1)$$

Where, S = SOCS, ρ = BD, C = OC content, d = depth of soil.

Rearing waste compost @ 20 t/ ha/ year along with soil test-based NPK fertilizers were applied to the mulberry plantation under different farming practices.

Yield parameters of mulberry under different farming practices were recorded season wise for three years (2012 to 2013 to 2014 to 2015). Mulberry has been cultivated as bush for supply of its leaf to silkworm as feeding material. Annually five leaf crops was harvested during five different seasons followed by pruning of the plant at ~15 cm height and the shoot samples were subjected to composting after suitable chopping along with rearing waste. Age of the mulberry plantation during initiation of the experimentation was seven years. Carbon sequestration potential (CSP) and NPK uptake by mulberry for the same were also estimated season wise. Unlike trees, promotional increment of carbon stock in mulberry-biomass in terms of CSP over the years cannot be computed and thus, study on difference of carbon stock between the years does not appear to be pragmatic. Annual CSP of mulberry is computed by cumulating the contribution of five crops. CSP means potential of a plant to withdraw carbon from atmosphere as CO_2 through photosynthetic metabolism to store the same in its biomass (Lewandrowski et al., 2004). For estimation and calculation of the same, mulberry leaf and shoot samples were oven dried at 70°C and dry weights of the same were calculated using moisture content. The ash contents of the oven-dried leaf and shoot samples were determined by igniting 1 g of powdered sample at 550 °C for 6

Table 1. Season wise yield attributes of mulberry under different farming practices.

Farming practices	Leaf yield (t ha^{-1}) in different seasons					Shoot yield (t ha^{-1}) in different seasons				
	May	July	Sep	Nov	Feb	May	July	Sep	Nov	Feb
Intensive Tillage (IT)	7.74	9.10	8.84	7.09	5.39	4.62	5.80	7.44	3.02	3.58
IT + Grass	7.04	8.39	8.87	7.30	5.76	3.92	5.30	7.74	3.34	4.23
IT + Grass + Cover crop	6.45	7.69	7.82	6.62	4.96	3.67	4.86	6.26	2.98	3.29
Moderate Tillage (MT)	6.83	8.49	8.47	6.98	5.45	3.67	5.12	7.23	3.24	3.70
MT + Grass	7.73	8.96	8.84	7.41	5.78	4.37	5.91	7.43	3.49	4.30
MT + Grass + Cover crop	6.39	7.80	8.02	6.95	5.13	3.65	5.07	6.72	3.35	3.52
$CD^*_{\text{farming practice}}$			0.32					0.36		
CD^*_{season}			0.29					0.33		

h in a muffle furnace. A total of 50 % of the ash-free mass was taken as the carbon content (Nath and Das, 2011; Majumder et al., 2014). CSP of mulberry was calculated on hectare basis utilizing the dry weights of leaf and shoot as follows:

$$CSP = y.\ C.\ (100 – m).\ 10^{-4} \qquad (2)$$

Where, y = leaf/ shoot yield, C = leaf/ shoot carbon%, m = leaf/ shoot moisture%. Further, N, P and K contents of the oven-dried (70°C) leaf and shoot samples were determined by following the standard analytical protocols, namely, Kjeldahl, Vanadomolybdate – spectrophotometry and Flame Photometry, respectively (Jackson, 1973; Kar et al., 2017). NPK uptake by mulberry was calculated on hectare basis utilizing the dry weights of leaf and shoot.

After completion of the field experimentation for three years, soil samples were collected replication wise from each of the treatment. SOCS under different treatments were estimated by adopting the method as described earlier and changes in SOCS due to induction of altered farming practices were enumerated in comparison to the existing one (T1) as well as fallow (T7).

Based on the mulberry productivity, CSP and SOCS, the most efficient farming practice for the mulberry vegetation under irrigated Gangetic alluvial plain was identified.

RESULTS AND DISCUSSION

Initial SOCS

Soil sample collected before initiation of the experimentation was analyzed for estimation of bulk density and organic carbon content following the methodology as mentioned above. Bulk density of the sample was estimated as 1.38 Mg m^{-3} and that of organic carbon content was 5.80 g kg^{-1}. Considering standard conversion factor of 1.33 for incomplete oxidation under Walkley-Black method (Batjes, 1996; Kar et al., 2013), SOCS of the sample was computed as 31.94 Mg ha^{-1}upto 0.30 m depth of soil.

Yield attributes of mulberry

Season wise leaf and shoot yield of mulberry under different farming practices has also been pooled for three years and presented in Table 1.

Data pertaining to yield attributes of mulberry as presented in Table 1 reveals significant variations for farming practices and seasons with respect to leaf as well as shoot productivity. Three years' pool data highlighted the farming practice involving moderate tillage with grass cover in terms of maximum leaf (38.72 t ha^{-1} $year^{-1}$) as well as shoot (25.50 t ha^{-1} $year^{-1}$) productivity. In terms of seasonal influence, September crop corresponded to maximum leaf (8.48 t ha^{-1}) as well as shoot (7.14 t ha^{-1}) productivity. Such seasonal variation of mulberry productivity has already been reported to be correlated with seasonal variation of nutrient uptake (Majumdar et al., 2003) and the same has been furnished in the following part of elaboration (Table 3). However, the order of leaf productivity under different farming practices are as follows:

Leaf productivity (t ha^{-1} $year^{-1}$)

MT + grass (38.72) > IT (38.16) > IT + grass (37.36) > MT (36.22) > MT + grass + cover crop (34.29) > IT + grass + cover crop (33.55)

Comparative advantage of moderate tillage (MT) over intensive tillage (IT) may be postulated in terms of reduction in carbon reversion from soil to atmosphere and subsequent conversion of soil inorganic carbon (SIC) to soil organic carbon (SOC) resulting in improvement of soil organic ambience (Singh et al., 2005; Bhattacharya et al., 2009; Kar et. al. 2013). On the other hand, incorporation of grass and cover crops while digging is supposed to improve the soil organic ambience, in turn (Setua et al., 2012) but, competition between mulberry and cover crop in terms of nutrient assimilation exerted declining effect on mulberry yield attributes and the situation is worse in case of cover crop than grass crop. The resultant of these two reverse tendencies highlighted the treatment (MT + grass) in terms of better yield attributes of mulberry in comparison to others.

CSP and NPK uptake by mulberry

CSP of mulberry growing under different farming

Table 2. Season wise CSP of mulberry under different farming practices.

Farming practices	CSP of leaf (t ha^{-1}) in different seasons					CSP of shoot (t ha^{-1}) in different seasons				
	May	July	Sep	Nov	Feb	May	July	Sep	Nov	Feb
Intensive Tillage (IT)	0.712	0.892	0.930	0.721	0.501	0.497	0.661	0.923	0.372	0.329
IT + Grass	0.671	0.802	0.922	0.748	0.535	0.436	0.591	0.950	0.394	0.389
IT + Grass + Cover crop	0.618	0.747	0.788	0.669	0.460	0.420	0.540	0.735	0.335	0.306
Moderate Tillage (MT)	0.668	0.811	0.904	0.725	0.504	0.425	0.592	0.901	0.375	0.340
MT + Grass	0.755	0.896	0.941	0.777	0.559	0.476	0.694	0.945	0.419	0.435
MT + Grass + Cover crop	0.634	0.777	0.844	0.702	0.477	0.416	0.574	0.832	0.396	0.330
CD* $_{\text{farming practice}}$			0.038					0.040		
CD* $_{\text{season}}$			0.035					0.037		

practices has been estimated season wise in terms of its above-ground components, namely, leaf as well as shoot and three years' pool data of the same is presented in Table 2. Season wise NPK uptake by leaf and shoot samples of mulberry has also been estimated separately. Further, NPK uptake by mulberry biomass has been computed by cumulating the both and three years' pool data of the same is presented in Table 3.

CSP of mulberry leaf and shoot both has been varied significantly among farming practices as well as seasons (Table 2). Three years' pool data on CSP revealed that mulberry growing under moderate tillage with grass cover registered an annual CSP of 3.93 t and 2.97 t by leaf and shoot, respectively from one hectare of land followed by intensive tillage (existing practice) and other farming practices as follows:

CSP of leaf (t ha^{-1} year^{-1})

MT + grass (3.93) > IT (3.76) > IT + grass (3.68) > MT (3.61) > MT + grass + cover crop (3.43) > IT + grass + cover crop (3.28).

CSP of shoot (t ha^{-1} year^{-1})

MT + grass (2.97) > IT (2.78) > IT + grass (2.76) > MT (2.63) > MT + grass + cover crop (2.55) > IT + grass + cover crop (2.34).

CSP of mulberry leaf and shoot under different farming practices had good bearing with the biomass production of mulberry under different treatments as discussed earlier and the same is very much correlated with enzymatic regulation of photosynthetic CO_2 fixation (Woodrow and Berry, 1988; Lavania and Lavania, 2009). It is reported (Koul and Panwar, 2008; Mandal et al., 2016) that carbon sequestration depends upon biomass production capacity, which in turn depends upon interaction between edaphic, climatic and topographic factors of an area. Besides, seasonal fluctuation of CSP highlighted September crop further as the most capable one for capturing carbon by leaf (0.89 t ha^{-1}) and shoot (0.88 t ha^{-1}) both. The finding indicates its bearing with yield attributes of mulberry during the particular season.

NPK uptake by mulberry biomass was also affected similarly as that of CSP of mulberry under different farming practices and seasons (Table 3).

The variation of NPK uptake under farming practices and seasons was found significant. Based on the three years' pool data, the order of NPK uptake by mulberry biomass under different farming practices is as follows:

N uptake by mulberry (kg ha^{-1} year^{-1})

MT + grass (430.34) > IT (391.81) > IT + grass (391.20) > MT (379.64) > MT + grass + cover crop (362.31) > IT + grass + cover crop (323.79).

P uptake by mulberry (kg ha^{-1} year^{-1})

MT + grass (56.70) > IT + grass (51.40) > IT (51.00) > MT (49.92) > MT + grass + cover crop (47.94) > IT + grass + cover crop (44.16).

K uptake by mulberry (kg ha^{-1} year^{-1})

MT + grass (291.26) > IT (275.37) > IT + grass (273.50) > MT (258.51) > MT + grass + cover crop (250.88) > IT + grass + cover crop (236.68).

The trend of NPK uptake by mulberry under different farming practices and seasons almost matches with the finding of CSP and thus, is supposed to be linked with the variation of yield attributes of mulberry under the same. The role of soil organics on nutrient mobilization into mulberry from soil has already been reported (Kar et al., 2012a, 2012b) and the same may, further, be correlated with SOCS under different farming practices (Table 4) as discussed later. Similar reports are also quite available in agricultural crops (Hati et al., 2008; Swarup and Singh, 2009). However, September crop is again highlighted in terms of uptake parameters registering 96.56, 13.60 and 67.26 kg ha^{-1} N, P and K uptake, respectively, which matches with the biomass production of mulberry (Table

Table 3. Season wise NPK uptake by mulberry biomass under different farming practices.

Farming practices	N uptake (kg ha^{-1}) in different seasons					P uptake (kg ha^{-1}) in different seasons				
	May	July	Sep	Nov	Feb	May	July	Sep	Nov	Feb
Intensive Tillage (IT)	72.76	91.02	101.25	68.17	58.61	8.81	11.11	13.80	9.69	7.58
IT + Grass	71.75	82.17	101.10	72.70	63.48	8.23	10.03	14.30	10.11	8.73
IT + Grass + Cover crop	63.99	68.85	81.91	58.96	50.08	7.87	9.18	11.16	8.75	7.19
Moderate Tillage (MT)	70.82	83.00	99.38	69.41	57.02	8.09	9.98	13.99	9.93	7.94
MT + Grass	79.71	93.58	107.58	79.40	70.08	9.52	11.72	15.30	10.43	9.72
MT + Grass + Cover crop	65.41	80.17	88.13	69.89	58.72	7.78	9.96	13.02	9.31	7.86
CD* $_{\text{farming practice}}$			5.12					0.67		
CD* $_{\text{season}}$			4.67					0.61		
	K uptake (kg ha^{-1}) in different seasons									
	May	July	Sep	Nov	Feb					
Intensive Tillage (IT)	49.08	67.24	70.16	48.83	40.07					
IT + Grass	45.58	60.10	71.25	51.54	45.03					
IT + Grass + Cover crop	41.81	54.93	58.99	43.72	37.23					
Moderate Tillage (MT)	43.88	59.54	67.10	48.41	39.57					
MT + Grass	50.55	67.80	71.73	53.16	48.02					
MT + Grass + Cover crop	42.99	57.28	64.30	46.12	40.20					
CD* $_{\text{farming practice}}$				3.71						
CD* $_{\text{season}}$				3.38						

Table 4. SOCS and its components under different treatments.

Treatment	Bulk density (Mg m^{-3})	Organic carbon (g kg^{-1})	SOCS (Mg ha^{-1})
Intensive Tillage (IT)	1.29	6.87	35.25
IT + Grass	1.29	6.97	35.97
IT + Grass + Cover crop	1.30	6.93	35.98
Moderate Tillage (MT)	1.32	6.97	36.62
MT + Grass	1.31	7.70	40.16
MT + Grass + Cover crop	1.30	7.10	36.83
Fallow	1.43	6.83	39.02
CD*	0.06	0.37	2.99

1) in that particular season.

SOCS after field experimentation

After completion of the field experimentation for three years, soil samples were collected replication wise from each of the treatment. SOCS under different treatments were computed on the basis of estimated values of bulk density as well as organic carbon content and the same is presented in Table 4.

Soils subjected to different land use systems for three years have been analysed to compute SOCS up to the depth of 0.30 m based on the estimated values of bulk density and organic carbon content (Table 4). Changes in the soil parameters due to intervention of different farming practices have not only been compared with the fallow land but with the initial condition also. Intervention of farming practices improved the bulk density, organic carbon content and SOCS in comparison to the initial condition registering 1.38 Mg m^{-3}, 5.80 g kg^{-1} and 31.94 Mg ha^{-1}, respectively for the above three soil attributes. But, for fallow land, bulk density was worsened in comparison to the initial condition and reason for the same seems to be enhancement of soil compactness under serene land condition. On the other hand, organic carbon content and SOCS was improved in the fallow land in comparison to initial condition probably due to reduction of CO_2 reversion from soil to atmosphere under composed land (Kar et al., 2013).

Comparing the performances of different farming practices in terms of enhancement of SOCS, it was observed that SOCS under moderate tillage with grass cover was significantly higher than any other farming practices. As variation of bulk density of soil under different farming practices is at par, higher organic carbon content coupled with substantial reduction of CO_2 reversion seems to be the reason for higher SOCS under the particular farming practice. However, SOCS under the fallow land is substantial and comparable with the treatment cited above. Restricted CO_2 reversion from soil to atmosphere under compact soil condition is supposed to be the prime reason for the same.

Conclusion

Among the six farming practices under the study, mulberry growing under moderate tillage with grass cover registered the highest leaf productivity and CSP of 38.72 t ha^{-1} $year^{-1}$ and 6.90 t ha^{-1} $year^{-1}$, respectively in comparison to the existing farming practice (IT) registering the same two parameters as 38.16 t ha^{-1} $year^{-1}$ and 6.54 t ha^{-1} $year^{-1}$, respectively. Thus, mulberry growing under moderate tillage with grass cover is capable of earning an annual carbon credit of 0.36 t from one hectare of land in comparison to that under the existing farming practice (intensive tillage) and of course without any compromise with the leaf productivity.

Moreover, in terms of SOCS as estimated after completion of the field experimentation, moderate tillage with grass cover registered 40.16 Mg ha^{-1} SOCS and the same is significantly higher than existing farming practice (intensive tillage) registering the value of 35.25 Mg ha^{-1}. Thus, in terms of SOCS also, moderate tillage with grass cover is capable of earning carbon credit to the tune of 4.91 Mg ha^{-1} in comparison to the existing farming practice over a time period of three years. It is worthy to mention that the altered farming practice, moderate tillage with grass cover, can even earn a carbon credit of 1.14 Mg ha^{-1} in terms of SOCS in comparison to the fallow land over the same period of time.

In light of the above, suitable modification of existing farming practices in the form of ‘moderate tillage with grass cover’ is recommended for mulberry cultivation to achieve the target of offsetting carbon emission from the atmosphere at an enhanced rate and to store the same subsequently in terrestrial system for further use. The approach matches the current Global agenda for terrestrial sequestration of carbon and promises to act as an agent to save the Globe from warming.

CONFLICT OF INTERESTS

The authors have not declared any conflict of interests.

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