Range Mgmt. & Agroforestry 40 (1) : 83-88, 2019
ISSN 0971-2070

# Soil organic carbon sequestration potential and economic profitability of perennial forage crops under different mulching environments

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Received: 29th July, 2018 Accepted: 7th March, 2019

**Abstract**
A study was conducted to investigate the soil organic carbon sequestration potential and economic profitability of perennial forage crops under different mulching practices. Based on the field experiment and analysis, forage crop *Setaria anceps* was found as an economically viable crop as well as provided an efficient carbon sequestration system. Green forage productivity was 10.31-17.67% higher with live mulching during first year and 12.66-18.31% during second year when compared with no mulching and soil dust mulching. There was an improvement in soil organic carbon sequestration rate (4.15-12.37% higher over other treatments) and a decrease in bulk density with live mulching. Higher economic benefit was also obtained with live mulched plot. Live mulching also increased uptake of N, P and K by perennial forage crops significantly. It was concluded that live mulching with legumes in *Setaria anceps* was superior for improving productivity, profitability and environmental sustainability.

**Keywords:** Carbon sequestration, Economics, Mulching, Perennial forage crops

## Introduction
Climate change is the major problem globally and its adverse effects on environment, economy and food production require a good scientific solution based on sustainable development. Contribution towards environmental sustainability depends upon the different methods focused in the storing of soil carbon in soil sinks. Agriculture has a remarkable capacity to store carbon dioxide ($CO_2$) and worldwide soil is one of the largest reservoirs, where carbon could be restored. One of several management practices proposed to sequester atmospheric $CO_2$ as soil organic matter is to expand the area of crops such as perennial forages that increase the annual crop residue carbon inputs to the soil (Sundaram *et al*., 2012). This is partly explained by the more important root biomass production of perennial forage crops and the reduction or absence of tillage compared to annual crops. Adoptions of improved agricultural practices have great potential to increase the amount of carbon in soils by enhancing the amount of soil organic carbon and to mitigate carbon dioxide emission and effects on climate change. Mulching is one of the most sustainable approaches in sequestering carbon (Bajoriene *et al*., 2013; Blanco-Canqui and Lal, 2007) and has potentiality of reducing greenhouse gas emissions from soil by increasing soil organic matter content (Mulumba and Lal, 2008; Jordan *et al*., 2010). Livestock contributes livelihood of 70% population in rural areas (IGFRI, 2011). A total of 14.9 million workers were engaged in farming of animal in rural and urban areas. Among which 13.6 million is only from rural areas (DADF, 2011-12). But the scenario of productivity of livestock is not satisfactory due to shortage in green forage availability (Hazra, 2014). At present, the country faces a net deficit of 36% green fodder (DADF, 2014-15). Adequate availability of feed and fodder to livestock is vital for increasing the productivity. Therefore, a very realistic approach is needed towards increasing the area under forage production. Thus present study was conducted to investigate the soil organic carbon sequestration potential and economic profitability of perennial forage crops under different mulching practices.

## Materials and Methods
***Study area***: The experiment was carried out at the Central Research Farm, Bidhan Chandra Krishi Viswavidyalaya, Nadia, West Bengal ($22^0$ 58' N latitude, $88^0$ 31' E longitude and at an elevation of 9.75 m above mean sea level) during 2012-13 and 2013-14. Initial basic chemical properties of the surface soil (0-150 mm) were pH 7.20, available N, $P_2O_5$ and $K_2O$ as 190.39, 12.50 and 145.61 kg/ha, respectively. Soil textural status, bulk density and

organic carbon contents were also recorded (Table 1). Average annual rainfall of the experimental region was 1608 mm and 85% of it was received during June to September.

**Table 1.** Initial soil properties of the experimental field

| Soil layers (mm) | Particle size distribution (%) | | | Bulk density (g/cc) | Organic carbon (g/kg) |
|---|---|---|---|---|---|
| | Sand | Silt | Clay | | |
| 0-150 | 60.19 | 20.73 | 19.08 | 1.49 | 5.10 |
| 151-300 | 64.55 | 19.09 | 16.36 | 1.51 | 4.80 |
| 301-450 | 62.41 | 21.25 | 16.34 | 1.51 | 4.50 |
| 451-600 | 69.91 | 17.24 | 12.85 | 1.54 | 3.70 |

***Experimental details*:** The experiment was conducted in a split-plot design with three replications. Different forage crops were kept in the main plots ($P_1$ - *Brachiaria brizantha*, $P_2$ - *Panicum maximum* and $P_3$ - *Setaria anceps*) and mulching practices ($M_1$ - No mulching, $M_2$ - Soil dust mulching and $M_3$ - Live mulching with legume) were assigned to the sub-plots. This experiment was started in an experimental field of two years aged perennial grass. During establishment of this experiment a spacing of 50 cm x 50 cm (plant x row) was maintained for each treatment. As live mulching berseem (@ 20 kg/ha), cowpea (@ 30 kg/ha) and ricebean (@ 30 kg/ha) were sown by opening of furrow with *tyne* in between two lines of perennial grass at the same time soil dust mulch was made by loosening of surface layer. Live mulching was cut after 45 days of sowing and spread over the soil surface in between lines of perennial grasses. Cutting intervals in three seasons were different. In winter season, cutting was made once (only single cut was possible due to slow growth rate) and in summer and rainy seasons it was done at two times. The plants from the net plot area were cut at 15 cm above the ground level at the time of each cut and fresh weights were recorded. Based on this green forage yield (t/ha) was calculated.

***Soil and plant analysis*:** Soil bulk density was determined using core sampler method (Piper, 1950). Organic carbon content at the soil depths of 0-150, 151-300, 301-450 and 451-600 mm was determined using potassium permanganate method as suggested by Walkley and Black (1934) and soil organic carbon (SOC) stock was calculated for each sampling depth by the following formula as suggested by Hoyle (2013) and sum of all depths (0-600mm) were presented.

$$\text{SOC stock (Mg/ha)} = \frac{A \times SOC \times BD \times D}{100}$$

Where, A is area ($m^2$), SOC is soil organic carbon content (%), BD is soil bulk density (g/cc) and D is soil sampling depth (m). Difference between initial and final stock was considered as total amount of soil organic carbon sequestered. Carbon sequestration rate (Mg/ha/year) was calculated by the following formula suggested by Kumara *et al.* (2014).

$$\text{SOC sequestration rate (Mg/ha/year)} = \frac{\text{Final SOC stock - Initial SOC stock}}{\text{Duration/Years}}$$

Total N, P and K uptake was calculated for each treatments separately using following formula:

$$\text{Nutrients uptake (kg/ha)} = \frac{\text{\% Nutrient concentration x Dry biomass yield (kg/ha)}}{100}$$

For nutrients concentration, total nitrogen, phosphorus and potassium content were estimated by modified Kjeldhal method, vanadomolybdate yellow colour method and photometric method, respectively (Jackson, 1967).

***Economic and statistical analysis*:** Economic parameters such as cost of production, gross return, net return and benefit cost ratio were calculated by considering all inputs and outputs. Data were statistically analyzed using analysis of variance (ANOVA) as split-plot design (Gomez and Gomez, 1984). Further significant differences between the treatments were compared with the critical difference at ±5% probability level.

**Results and Discussion**

***Bulk density of soil*:** Soil bulk density was reduced by cultivation of different forages with mulching practices (Fig 1-2). Among the different forage crop plots, initial (before winter season of 2012-13) bulk density (g/cc) ranged from 1.49 to 1.50 and 1.53 to 1.51 at 0-150 and 151-300 mm depth of soil, respectively (Fig 1). This was reduced to 1.43 -1.44 g/cc and 1.43 - 1.46 g/cc at 0-150 and 151-300 mm depth of soil at last observation (after rainy season of 2014). Reduction in bulk density with cultivation of perennial forage crops might be due to increase in soil organic carbon content. During the start of experiment the mean value of bulk density (g/cc) under different mulching treatment ranged from 1.47 to 1.52 and 1.50 to 1.53 at 0-150 and 151-300 mm soil depth. This experiment was started in a two years old plot that was the reason for variation in initial bulk density within mulch treatment. At final observation bulk density reduced to 1.41, 1.44 and 1.45 g/cc under live mulching, soil dust mulching and no mulching treatment, respectively in 0-150 mm soil depth (Fig 2). Incorporation of live mulch added biomass to the soil, it ultimately add some carbon and also increased SOC content, which might be the reason for lower bulk density with live mulching treatment. Bulk density decreased due to enrichment in SOC was also reported earlier by Sharma *et al*. (2010a). Many workers reported that there was inverse relationship between soil organic matter content and bulk density (Acharya *et al*., 1998; Sharma and Acharya, 2000) in mulch treated plots.

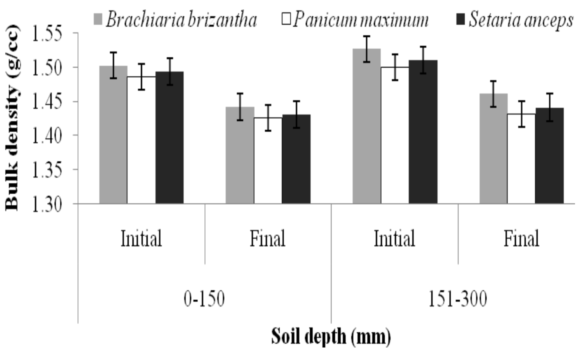


**Fig 1.** Effect of forage crops on soil bulk density at 0-150 and 151-300 mm soil depth (error bars indicate standard error)

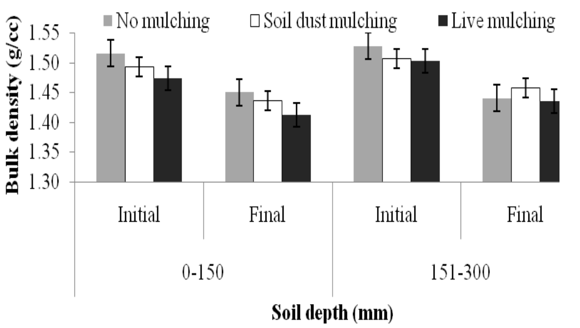


**Fig 2.** Effect of mulching practices on soil bulk density at 0-150 and 151-300 mm soil depth (error bars indicate standard error)

***Soil organic carbon (SOC)*:** SOC stock, amount of SOC sequestered and sequestration rate did not vary significantly with different forage crops but highest values were obtained with *Setaria anceps* (Table 2). At the end of experiment, SOC stock for 0- 600 mm soil depth was 50.95 Mg/ha under live mulching ($M_3$), 49.34 Mg/ha under soil dust mulching ($M_2$) and 47.37 Mg/ha under no mulching ($M_1$) as against initial value of 42.41, 41.14 and 39.76 Mg/ha for $M_3$, $M_2$ and $M_1$, respectively. Legume based mulching improved soil health (Sharma *et al*., 2010b) and resulted in better root and shoot growth as well as some of biomass also added from mulch plant, so there were more chances of biomass decomposition and increase in amount of SOC stock with live mulching treatment. As the amount of SOC sequestered was more (8.54 Mg/ha in two years) with live mulching ultimately had higher sequestration rate (4.27 Mg/ha/year) with this treatment. The increase in SOC with live mulch might be attributed to more production of roots and their subsequent decomposition increased organic carbon content of soil (Narwal and Antil, 2005) due to legume effect. At the same site, an experiment was conducted by Mandal *et al*. (2007) in long term cropping systems with rice-mustard-sesamum and rice-fallow-berseem sequences and found that in first system total amount of carbon sequestered was 1.88 to 2.89 Mg/ha in different treatment combinations in seven years and in second sequence it was about 1.23 to 5.69 Mg/ha in twenty years. The carbon sequestration in case of general cropping system was found low as compared to forage system and this might be due to fibrous rooting system of grasses as compared to tap rooted mustard, sesamum and berseem of the experimented cropping system conducted by Mandal *et al*. (2007). Powlson *et al*. (2008) suggested that increases in SOC should normally be termed ‘accumulation’ and that ‘sequestration’ be reserved for situations where there is an additional transfer of carbon from the atmosphere and thus a genuine contribution to climate change mitigation. Removing some land from annual cropping and converting to forest, grassland or perennial forage crops will remove carbon from atmospheric carbon dioxide and genuinely contribute to climate change mitigation. There was no significant interaction between forage crops and mulching practices for SOC.

***Green forage yield (GFY)*:** Significant variation in green forage yield (GFY) among different perennial grasses was found in both years (Table 3). *Setaria anceps* recorded significantly higher green forage yield in both the years (71.55 t/ha in 1st year and 67.92 t/ha in 2nd year). In terms of GFY forage crop *Brachiaria brizantha* positioned second during both years. Variation in GFY within different species was due to differences in growth habit of perennial grasses and their response to environments (Langer, 1979). Significantly higher green forage yield was obtained in live mulching (72.85 t/ha in 1st year and 68.80 t/ha in 2nd year) followed by soil dust mulching, and no mulching recorded the lowest GFY (Table 3). GFY increased by 10.31 and 17.67% in first year and 12.66 and 18.31% in second year with live mulching treatment as compared to soil dust mulching and no mulching. Nodulation under live mulch improved

**Table 2.** Effect of forage crops and mulching practices on SOC stock, sequestration and sequestration rate (0-600 mm soil depth)

| Treatments | SOC stock (Mg/ha) | | SOC sequestered (Mg/ha) | SOC sequestration rate (Mg/ha/year) |
|---|---|---|---|---|
| | Initial | Final | | |
| Forage crops | | | | |
| $P_1$ | 41.28 | 49.16 | 7.88 | 3.94 |
| $P_2$ | 40.27 | 48.34 | 8.06 | 4.03 |
| $P_3$ | 41.75 | 50.16 | 8.41 | 4.20 |
| SEm± | 0.41 | 0.45 | 0.22 | 0.11 |
| CD (P<0.05) | NS | NS | NS | NS |
| Mulching practices | | | | |
| $M_1$ | 39.76 | 47.37 | 7.61 | 3.80 |
| $M_2$ | 41.14 | 49.34 | 8.19 | 4.10 |
| $M_3$ | 42.41 | 50.95 | 8.54 | 4.27 |
| SEm± | 0.59 | 0.64 | 0.22 | 0.11 |
| CD (P<0.05) | 1.83 | 1.97 | 0.69 | 0.34 |

$P_1$: *Brachiaria brizantha*; $P_2$: *Panicum maximum*; $P_3$: *Setaria ancep*; $M_1$: No mulching; $M_2$: Soil dust mulching; $M_3$: Live mulching; NS: Non significant

**Table 3.** Effect of mulching practices on yield and economics of forage crops

| Treatments | Green forage Yield (t/ha) | | Cost of cultivation (Rs./ha) | | Gross return (Rs./ha) | | Net return (Rs./ha) | | Benefit cost ratio | |
|---|---|---|---|---|---|---|---|---|---|---|
| | 1st year | 2nd year | 1st year | 2nd year | 1st year | 2nd year | 1st year | 2nd year | 1st year | 2nd year |
| Forage crops | | | | | | | | | | |
| $P_1$ | 67.43 | 62.46 | 37083 | 39813 | 80920 | 78076 | 43837 | 38263 | 2.18 | 1.96 |
| $P_2$ | 61.82 | 57.63 | 37083 | 39813 | 74180 | 72043 | 37097 | 32230 | 2.00 | 1.81 |
| $P_3$ | 71.55 | 67.92 | 37083 | 39813 | 85860 | 84899 | 48777 | 45086 | 2.31 | 2.13 |
| SEm± | 0.94 | 0.98 | - | - | - | - | - | - | - | - |
| CD (P<0.05) | 3.70 | 3.83 | - | - | - | - | - | - | - | - |
| Mulching practices | | | | | | | | | | |
| $M_1$ | 61.91 | 58.15 | 34168 | 36623 | 74293 | 72687 | 40125 | 36064 | 2.17 | 1.98 |
| $M_2$ | 66.04 | 61.07 | 36913 | 39693 | 79247 | 76334 | 42334 | 36641 | 2.15 | 1.92 |
| $M_3$ | 72.85 | 68.80 | 40168 | 43123 | 87420 | 85998 | 47252 | 42875 | 2.18 | 1.99 |
| SEm± | 0.44 | 0.56 | - | - | - | - | - | - | - | - |
| CD (P<0.05) | 1.36 | 1.72 | - | - | - | - | - | - | - | - |

$P_1$: *Brachiaria brizantha*; $P_2$: *Panicum maximum*; $P_3$: *Setaria ancep*; $M_1$: No mulching; $M_2$: Soil dust mulching; $M_3$: Live mulching

soil nutrient status (Sharma *et al*., 2010a; Sharma *et al*., 2010b) and cutting the intercropped legume plants and using it as mulch after 45 days helped in suppressing weed growth, and led to checking evaporation losses (Narain and Singh, 1997) which resulted in maximum green forage yield under live mulching. In no mulched plot there might be more evaporation loss of moisture leading to lower green forage yield.

***Economics***: Total cost of cultivation for soil dust mulching and live mulching was higher than no mulching due to additional cost involved in making soil dust and sowing of live mulching. Cost of cultivation was higher in second year due to increase in labour price (Table 3). Among the different forage crops, highest gross return (Rs. 85860 and 84899 per ha in first and second year, respectively), net return (Rs. 48777 and 45086 per ha in first and second year, respectively) and benefit cost ratio (2.31 and 2.13 in first and second year, respectively) were obtained with *Setaria anceps* ($P_3$) followed by *Brachiaria brizantha* ($P_1$). Forage crop *Panicum maximum* ($P_2$) recorded the least value during both years (Table 3). This might be due to higher total green forage yield recorded with $P_3$ followed by $P_1$ and $P_2$, but there was no difference for cost of production among the different forages. In case of mulching, gross return was recorded higher (Rs. 87420 and 85998 in first and second year, respectively) with live mulching followed by soil dust mulching and no mulching recorded the least value (Table 3). Higher net return and benefit cost ratio were recorded with live mulching

**Table 4.** Effect of forage crops and mulching practices on nutrients uptake

| **Treatments** | **Nitrogen(kg/ha)** | | **Phosphorus(kg/ha)** | | **Potassium(kg/ha)** | |
|---|---|---|---|---|---|---|
| | **1st year** | **2nd year** | **1st year** | **2nd year** | **1st year** | **2nd year** |
| Forage crops | | | | | | |
| $P_1$ | 190.41 | 174.08 | 40.25 | 37.03 | 297.22 | 276.54 |
| $P_2$ | 164.31 | 144.19 | 35.13 | 31.21 | 274.09 | 238.81 |
| $P_3$ | 185.76 | 165.48 | 38.98 | 34.72 | 284.19 | 259.95 |
| SEm± | 4.50 | 2.46 | 1.04 | 0.44 | 5.89 | 4.57 |
| CD (P<0.05) | 17.67 | 9.64 | NS | 1.71 | NS | 17.94 |
| Mulching practices | | | | | | |
| $M_1$ | 161.51 | 146.81 | 34.01 | 30.93 | 254.80 | 229.06 |
| $M_2$ | 180.17 | 159.23 | 38.09 | 33.93 | 287.33 | 254.35 |
| $M_3$ | 198.80 | 177.70 | 42.26 | 38.09 | 313.37 | 291.89 |
| SEm± | 3.27 | 2.91 | 0.66 | 0.62 | 5.90 | 5.39 |
| CD (P<0.05) | 10.06 | 8.96 | 2.02 | 1.90 | 18.16 | 16.62 |

$P_1$: *Brachiaria brizantha*; $P_2$: *Panicum maximum*; $P_3$: *Setaria ancep*; $M_1$: No mulching; $M_2$: Soil dust mulching; $M_3$: Live mulching; NS: Non significant

because of increase GFY by 17.67 and 18.31% during 1st year and 2nd year, whereas, increase in cost of cultivation was less *i.e.* 17.56 and 17.75% during 1st year and 2nd year as compared to no mulching. Irrespective of every treatment gross return, net return and benefit cost ratio were recorded lower during 2nd year of experimentation due to abridged GFY and rise of cultivation cost due to higher labour price during this year.

***Nutrients uptake***: The higher amount of uptake for N, P and K was recorded by *Setaria anceps* and the lowest uptake was recorded in case of *Panicum maximum* (Table 4). The variation in uptake might be due to differential growth habit of different grasses. The sequence of GFY and nutrients uptake did not match, might be due to variation in percent dry matter production within different species. In both years, among the mulching management nutrients uptake recorded more with mulched plots. This was due to the higher yields of the crops following application of the mulching materials, which led to enhanced moisture conservation and greater nutrient availability in the soil (Sharma *et al*., 2010b). The maximum nutrients uptake was recorded when the crop was cultivated with live mulching (Table 4). Live mulching with legumes improved soil health due to addition of biomass and increased nutrients availability with better uptake. Higher nutrients uptake by live mulch plot was reported earlier by Sharma *et al*. (2010a) and Singh *et al*. (2011). Mulching significantly influenced NPK uptake in forage crops was also recorded by Gill and Tiwana (2018).

**Conclusion**

It is implied that Conservation Agriculture practice is more relevant towards better carbon conservation and soil bulk density. Incorporation of live mulching with legumes resulted in reduction of soil bulk density and augmenting SOC stock. Live mulching enhanced carbon sequestration rate. Taking up of perennial forages may be a profitable proposition and farmers will definitely be benefited upon getting forages at moderate price. Considering yield, economic return and environmental sustainability farmers of the adjoining areas can be advised to cultivate forage crop *S. anceps* with live legume mulching.

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