Sequestering Of Atmospheric Carbon through Fodder Cultivation- A Measure for Mitigating Global Warming

T. Sivakumar, S. Meenakshi Sundaram, V.M. Sankaran, and J.S.I. Rajkumar

Abstract**—**Southern districts of Tamil Nadu, India were selected as the study area for carbon sequestration potential during 2011-13 by cultivation of fodder crops of both annual and perennial in origin. Fodder crops such as, fodder maize, fodder cowpea, hedge lucerne and hybrid napier were cultivated in Seevanallur and Ramayanpatti regions of Tirunelveli district and Srivilliputhur and Rajapalayam regions of Virudhunagar district, Tamil Nadu, India. The soil organic carbon estimated pre-cultivation process varied from 0.35 to 0.38 per cent. The percentage of soil organic carbon sequestered by the fodder crops was found to be higher in black soils than in red soils. Hybrid napier sequestered higher amounts of carbon when compared with hedge lucerne, fodder cow pea and fodder maize. The rate of carbon sequestered by hybrid napier ranged from 0.84 to 1.16 per cent. Hedge lucerne sequestered 0.81 to 1.01 per cent. The rate of carbon sequestered by fodder maize and fodder cowpea was 0.11 to 0.56 and 0.13 to 0.45 per cent respectively. This carbon enhancement was significant ($P<0.05$) with soil collection depth, soil bulk density and soil pH. The crops cultivated had enhanced the carbon content in soil and formed the feed for livestock in the land owned farmers. The organic carbon content in the fodder crops was higher in hybrid napier (59.02 per cent) and hedge lucerne (58.60 per cent) when compared with fodder maize (54.17 per cent) and fodder cowpea (53.46 per cent) (R^2 =0.88). Chemical and physical properties of the soil, difference in the climate variability and plant root density also play a major role in carbon sequestration. Application of scientific advancement combined with organic farming, including no-tillage or minimal tillage will enhance the reduction of carbon dioxide in the atmosphere, a strategy for combating global warming.

Keywords**---**Climate change, desmanthus, global warming, hybrid napier, organic farming, soil organic carbon

I. Introduction

THE atmospheric concentrations of carbon dioxide have increased to exceptional levels in the last 800,000 years. Forty per cent increase in carbon dioxide concentrations have been recorded since pre-industrial times, and emissions from fossil fuel and land use change. Continued emissions of greenhouse gases will cause further warming and changes in all components of the climate system. Limiting climate change will require substantial and sustained reductions of greenhouse gas emissions [1]. Alterations in total rainfall and temperature have lead to changes in water availability and demand due to higher rates of evapotranspiration and many areas will endure a decline in water resources due to climate change [2]. Acting as carbon sinks, the marine and terrestrial ecosystems have absorbed 60 per cent of emissions while the remaining 40 per cent has resulted in increase of atmospheric carbon dioxide concentration [3]. Agriculture plays a major role in economic development and in reducing poverty. Agriculture is the most vulnerable sector to climate change and will leave its impacts on Indian agriculture in various direct and indirect ways. This obviously means an impact on the livelihoods of Indian farmers [4]. Soils are the largest terrestrial sink for carbon on the planet [5]. Carbon sequestration with respect to agriculture sector refers to the capability of agriculture lands to remove CO_2 from the atmosphere. Forests and stable grasslands are referred to as carbon sinks, since they can store huge amounts of carbon in their vegetation and root systems for long period of time. The ability of agriculture lands to store or sequester carbon depends on several factors, including climate, soil type, type of crop or vegetation cover and different management practices [6] and agriculture has a dramatic capacity to sequester carbon dioxide and worldwide, farmers have the opportunity to offset their own emissions and those of other industries.

Contribution towards environmental sustainability depends upon the different methods focused in the storing of soil carbon in soil. Improved soil's agronomic capabilities increases the organic matter content of soil, which in return produces better soil and better crops, improves water conservation and reduces erosion [7]. Soil organic carbon (SOC) play a major role in the soil's biological, chemical and physical properties and aggregation between soil particles largely may help in preventing soil structural degradation thereby increasing the physical stability [8]. Maintaining optimum levels of SOC is vital for soil quality, increased water retention capacity, nutrient enrichment, and soil faunal activity, thereby increasing soil fertility and crop productivity. Increasing carbon sequestration in agricultural soils and making soil a net sink for atmospheric carbon can be achieved by adoption of the scientific management practices [9]. Long-term experiments related to field have been conducted to study changes in the sustainability of crop production in relation with physical, chemical, and biological properties of soils, and to establish the effects of mineral manure and fertilizers

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application on the SOC [10] and on carbon sequestration [11]. Hence, in the present study, cultivation of forage crops viz. fodder cowpea, fodder maize, hybrid napier and hedge lucerne was assessed for the rate of soil carbon sequestration in Seevanallur and Ramayanpatti regions of Tirunelveli district and Srivilliputhur and Rajapalayam regions of Virudhunagar district, Tamil Nadu, India during 2011-13.

II. Materials And Methods

Seevanallur and Ramayanpatti regions of Tirunelveli district and Srivilliputhur and Rajapalayam regions of Virudhunagar district of Tamil Nadu, India were selected for studying the rate of carbon sequestered by different fodder crops. The land use types were identified in the area with local agricultural officers and local farmers. Sites were selected randomly within each land use type. General site characteristics were recorded. The land use history of each site was documented by interviewing with the owner of the study area. The study was conducted during the year 2011-13. The field plot was divided into 12 blocks with 3 replicates in each block as a randomized complete block design with split plot method. Field plots measuring 1200 m^2 were used for the four crops (two leguminous and two non-leguminous) at each study area. Standard agronomic practices including farm yard manure, manure treatment techniques and application of inorganic fertilizers were followed in cultivation of these crops [12]. Hedge lucerne and hybrid napier was of perennial group and fodder maize and fodder cowpea were annual crops. Crops were harvested at random periodically (farmers harvest option) up to 240 days to study biomass accumulation pattern and for carbon analysis. The crops were harvested as: one harvest of fodder maize (50 days); fodder cowpea (55 days); hedge lucerne (30, 60 and 90 days consecutively) and hybrid Napier (30, 60 and 90 days consecutively).

Soil was taken from each section of the pit and placed in a large basin, thoroughly mixed, and a 500 g subsample of soil was collected. Auger cores were taken within the pit to collect a sample for depth of 30 cm. Bulk density samples were taken at each depth using a known volume metal container. Only one set of bulk density samples were taken per site. Soil samples for the bulk density estimation were oven dried at 100°C for two days. Soil samples were sieved to 2 mm soaked in 10 per cent HCl to remove any carbonates from the soil and then put in a 45°C oven until dry. Soils were then grounded with pestle and mortar and analyzed for carbon using Analytikjena multi N/C 2100S carbon analyzer, with furnace temperature of 950°C, NDIR detector and oxygen as carrier gas. The available total carbon pre cultivation of crops and amount of carbon captured at the time of harvest were estimated. For each sample, the elemental analysis was repeated three times and the average C values used in the analysis. One-way ANOVA (multiple comparison tests) was performed to analyze significant difference in the rate of carbon sequestered. Soil Bulk Density (Mg/m^3) was calculated by dividing the dry weight of the soil with the volume of the soil. Tonnes carbon per hectare was calculated by the following formulae: Tonnes carbon per hectare (t C/ha) = SOC (%) x Soil Bulk Density (Mg/m^3) x Soil Sampling Depth (cm). Carbon values were log transformed for all future statistical tests in order to meet normality assumptions of statistical tests. One-way ANOVA was performed using Graphpad Prism Version 5. Similarity, draftsman plot, principal component analysis and distance method was analysed using primer version 6.

III. Results And Discussion

The SOC is a food source for most soil microbial life, so as it is utilized, the C in the SOC is emitted as CO_2 into the atmosphere. The soil organic carbon estimated prior to cultivation ranged from 0.24 to 0.28 per cent. Hybrid napier sequestered higher amounts of carbon when compared with hedge lucerne, fodder cowpea and fodder maize. The rate of carbon sequestered by hybrid napier ranged from 0.92 to 1.24 per cent. Hedge lucerne sequestered 0.90 to 1.17 percent. The rate of carbon sequestered by fodder maize and fodder cowpea was 0.07 to 1.14 and 0.19 to 0.99 per cent respectively. Hybrid napier and hedge lucerne contain higher amounts of protein, thereby increasing the growth and milk yield properties of livestock in the land owned farmers of the villages.

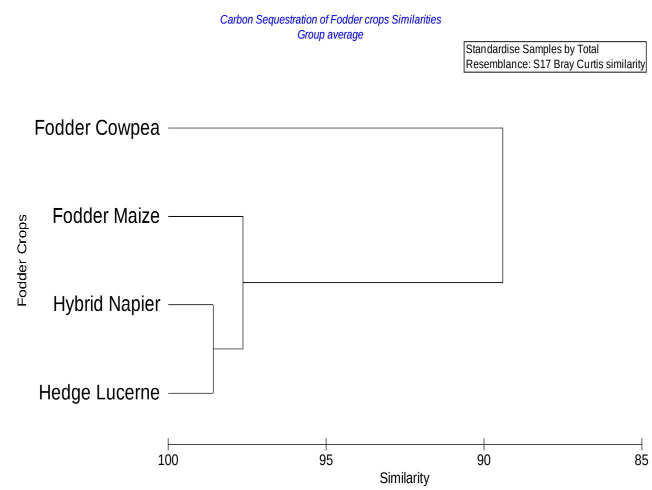
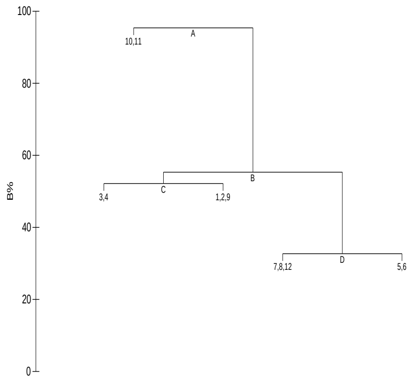


Fig. 1 Rate of carbon sequestered by the four different fodder crops at selected villages

The organic carbon content was high in hybrid napier and hedge lucerne when compared with fodder maize and fodder cowpea. The soil bulk density ranged from 1.44 to 1.56 mg/m^3, the calculated soil bulk density showed positive correlation with the soil organic carbon sequestered by the forage crops. It is evidently clear from the Figure 1 and 2, that hybrid napier, 98 per cent similarity has the maximum potential of sequestering carbon in the soil followed by hedge lucerne 98 per cent similarity, fodder maize 97 per cent similarity and fodder cowpea 89 per cent similarity.



A: R=0.89; B%=95; Hybrid Napier>27.9(<27.5)
B: R=0.61; B%=55; Fodder Cowpea<21.2(>21.2) or Hybrid Napier>26.8(<26.7)
C: R=0.83; B%=52; Hedge Lucerne>26.7(<26.3) or Fodder Cowpea<20.6(>20.9) or Hybrid Napier<27(>27.1)
D: R=1.00; B%=33; Fodder Maize<25.5(>25.9) or Fodder Cowpea>21.5(<21.3) or Hedge Lucerne>26.3(<26.3)

Fig. 2 Percentage of carbon sequestered by fodder crops, dominated by hybrid napier and hedge lucerne followed by fodder maize and fodder cowpea

Increasing the soil organic carbon content in soil is a good idea in any situation to generate or maintain healthy soils [13]. It will benefit the farm economy of those farmers who sequester the carbon with cultivation of fodder crops, and anyone can participate without a regional bias. Intercropping can be regarded as the next important tool in sequestering carbon, stimulated by the primer, the Figure 3 illustrates the intercropping potential of hybrid napier with fodder cowpea has a positive correlation (R^2=0.89) and hedge lucerne with fodder maize with R^2=0.65.

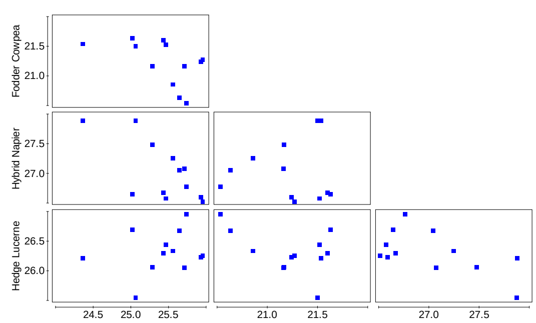


Fig. 3 Draftsman plotted for intercropping facilitated carbon sequestration in four villages

The rate of soil organic carbon sequestration with adoption of recommended technologies depends on soil texture and structure, rainfall, temperature, farming system, and soil management. The influence of fodder crops at different plots varied significantly (P<0.05) due to difference in management, dispersal of manure, application of farm yard manure, position of trees, slope and disturbances caused by animals (Fig 4). Variability of top soil carbon between sites in the present study is also likely due to differences between sampling locations, past site history, termite mounds and intensity of livestock grazing intensity. Strategies to increase the soil carbon pool include no-till farming, cover crops, nutrient management, manuring, efficient irrigation and growing energy crops on spare lands. According to Ravindranath et al. [14] the standing biomass in India is estimated to be 8,375 million tons for the year 1986, of which the carbon storage would be 4,178 million tones. An increase of 1 ton of soil carbon pool of degraded cropland soils may increase crop yield by 20 to 40 kg ha^{-1} for wheat, 10 to 20kg/ha for maize, and 0.5 to 1kg/ha for cowpeas [13]. Estimates of the total potential of C sequestration in world soils vary widely from a low of 0.4 to 0.6Gt C/ year [15] to a high of 0.6 to 1.2Gt C/ year [9].

Deeper carbon profile will represent the integration due to biological inputs. Top soil contains the most labile carbon sources decomposed by microbes, if carbon inputs are reduced, the microbes will continue to decompose the existing organic matter until the majority of the carbon will exist as stable, inert complexes. Soil at different depths will generally be old and will not be easily influenced by land practices at the surface level, and hence the variation of SOC at different depths [16]. Evidence on long-term experiments reveals that soil C losses as a result of oxidation and erosion can be reversed through improved soil management such as reduced tillage [17]. Therefore, improved land-management practices to enhance C in soils have been suggested as a viable way to reduce atmospheric C content significantly [18]. In recent years, accumulating evidence suggests that certain fractions of SOC are likely to respond more rapidly than total soil C to land use change and management. It has been shown that C presented in particulate organic matter (POM) can accumulate rapidly under land management systems that minimize soil disturbance and may also provide an early indicator of changes in total soil C under different land use and management practices [19]. Significant differences in SOC between land-use treatments indicate that soil C can increase by converting annual crops to perennial forages. Studies have suggested that land use can have a wide range of effects on soil C but will be influenced by climate, soil texture, nutrient status, and the time periods [20]. A common worldwide practice, when land is converted to agriculture breaking soil aggregates by plowing, increases in bulk density, however significant changes were observed in the present study in relation to soil bulk density and depth of soil sampling (Fig 5). SOC stocks are dependent on soil mineralogy and

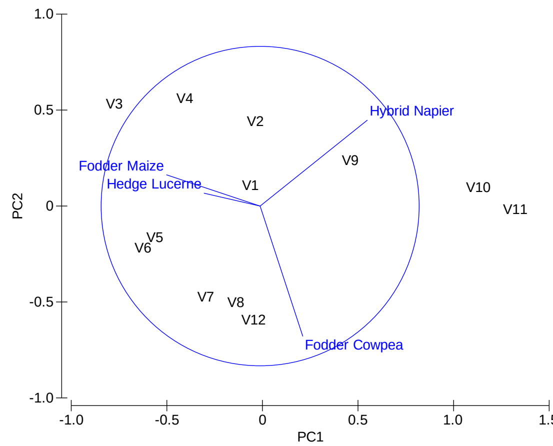


Fig. 4 Principal component analysis in field plots cultivated for four fodder crops, where V1 to V12 are the field plots

texture. Carbon levels tend to increase with increasing clay content [21].

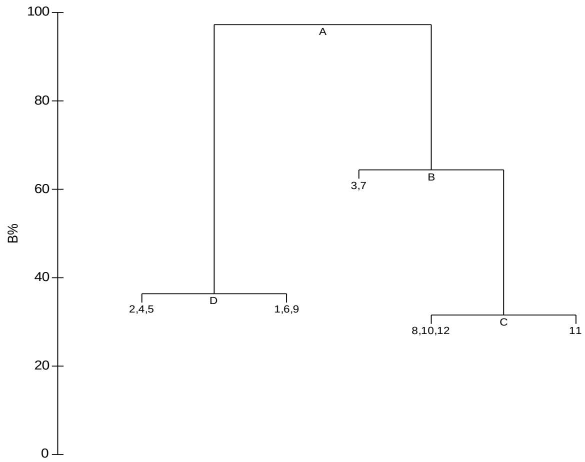


Fig. 5 Link tree for the enhancement of soil organic carbon influenced by soil depth and soil bulk density for carbon sequestration

A: R=0.91; B%=97; Soil Depth>54.2(<50.6) or Tonnes Carbon Per Ha<43.4(>47) or Per cent Soil Carbon<0.674(>0.72) or Soil Bulk Density>1.72(<1.63)

B: R=1.00; B%=64; Soil Depth>50.4(<46.5) or Tonnes Carbon Per Ha<47.2(>51.2) or Soil Bulk Density>1.61(<1.52) or Per cent Soil Carbon<0.729(>0.775)

C: R=1.00; B%=32; Soil Bulk Density<1.44(>1.52) or Per cent Soil Carbon>0.811(<0.775) or Tonnes Carbon Per Ha>53.3(<51.2) or Soil Depth<44.5(>46.5)

D: R=0.93; B%=36; Soil Depth<54.9(>56.4) or Tonnes Carbon Per Ha>42.7(<41.1) or Per cent Soil Carbon>0.657(<0.639) or Soil Bulk Density<1.76(>1.79)

Allen [22] reported that in tropical parent soils, organic C decreased 50 per cent more than in other soil types and bulk density increased significantly more than in other soil types. Davidson and Ackerman [23] found carbon losses of between 20 and 40 per cent due to land use conversion to agriculture at various ecosystems worldwide. Sarah and Desanker, [16] recorded that the differences in soil carbon occurred in the top 40 cm soil depth. Drinkwater et al [24] suggested that, the use of low carbon-to-nitrogen organic residues to maintain soil fertility, combined with diversity in cropping sequences, significantly increases the retention of soil carbon. Post and Kwon [25] reported that, SOC tended to increase when cultivable soil is planted with permanent grasses, which definitely correlate with the results of the present study. Wright and Hons, [26] reported that, high cropping intensity results in the greatest SOC sequestration potential. Residues from the cultivated crops returned to soil were assimilated into macro aggregate fractions as evidenced by higher SOC content and lower C/N ratios. Organic matter turnover, mineralizable C, and soil microbial biomass were higher for intensive cropping sequences which suggest that higher residue inputs from intensive cropping sequences are offset by enhanced organic matter degradation thereby increasing carbon sequestration potential [27]. Ghulamhabib et al. [28] suggested that legume fodder crops improve soil organic C with an added advantage of crop canopy protecting top soil from monsoon rains which has reduced erosion and water runoff from the field and enhancing fodder supply to existing underfed livestock, which was one of the objective of providing feed and fodder for the existing farm animals at the selected villages and providing seeds and seedlings to the fellow farmers to encourage them for cultivation for reducing carbon emissions to adapt for the changing climate and to generate their agricultural income. The differences in soil C between land use treatments divided by duration of land use conversion can serve as an indicator of C sequestration rate [29]. Agricultural lands can potentially sequester C and mitigate greenhouse gas emissions through adoption of reduced and no-till management, use of high C input rotations that include hay, legumes, pasture, cover crops, irrigation or organic amendments, setting aside lands from cropland production, and through cropping intensification.

The set of practices identified in this study assume that the objective of farmers is to increase both carbon sequestration and income. However, farmers' practices can be flexible in order to minimize risk by showing opportunistic responses to the changing environmental conditions [30]. Soil carbon sinks resulting from sequestration activities are not permanent and will continue as long as appropriate management practices are maintained. If a land management or land use is reversed, the carbon accumulated will be lost, usually more rapidly than it was accumulated. Additional studies considering the role of carbon payments in the capacity of farmers to cope with risk are needed.

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