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Research article

SOIL ORGANIC CARBON (SOC) CHANGES UNDER BIODIESEL PLANTATIONS (*PONGAMIA PINNATA*)

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ABSTRACT: Soil organic carbon (SOC) represents an important C sink in the lifecycle C balances of biofuels and strongly influences soil quality. One potentially significant impact of growing *Pongamia pinnata* in drylands will be the Sequestration or release of carbon (C) in soil and large amount of organic matter added through litter fall and improve the soil health. We assembled and analysed on carbon sequestration and soil properties estimates of SOC change from 2003 to 2013 following conversion of natural land to Pongamia plantations. We estimated net change in SOC relative to a control (open plot) since establishment year (2003). Soil samples were collected from all treatments of Pongamia plantations at two different depths: 0-20 cm and 20-40 cm Under Tree Canopy (UTC), Under Litter Trap (ULT) and Uncultivated Area (Open Plot). Soil samples were air dried ground and sieved to 1mm and analysed for total carbon content by combustion method using the LECO CR-412 carbon analyser. The average contribution of SOC by different treatments at 0-20cm depth was UTC (13.37 ton/ha), ULT (5.18 ton/ha), Open area (4.75 ton /ha).and whereas at 20-40cm the values of SOC by UTC, ULT and open area were 7.76 tons/ha, 3.76 tons/ha and 3.69 tons/ha, respectively. Excavation of total root system was done manually and carried out within one week of the above ground sampling under dry soil conditions and subsequently washed with water to remove the adhering soil. The below ground dry biomass was 18.63 tons/ha. The litter traps made of 1 x 1m nylon fishing net fitted to stakes at 1 m above the ground was used to trap the litter, were placed under the canopy of each tree per treatment (various spacing). The results showed that the total quantity of litter dry biomass produced in a year was 8.35 ton/ha, 7.49 ton/ha, 7.2 ton/ha and 6.79 ton/ha under tree spacings of 5mx5m, 6mx4m, 6mx6m and 8mx6m respectively. However, the dry carbon biomass under tree spacings of 5mx5m, 6mx4m, 6mx6m and 8mx6m was 3.93t/ha,3.52t/ha,3.39t/ha, and 3.19 t/ha, respectively.

Key words: Pongamia, biofuel, Biomass, Litter fall, Soil Organic Carbon

INTRODUCTION:

India occupies second place in population and 7th place in area in the World. Due to large population and the need of transportation made India top 5th country in the World in consumption of petroleum products [1]. Yearly consumption of diesel in India is approximately 40 million tonnes, which constitutes about 40% of the total petro-products consumption [2]. As these carbon sources are limited and the consumption of petro-products is increasing day by day there is a need of alternative and renewable resources, which includes solar energy, thermal energy, hydro energy and bio-energy [3]. Among these alternative resources bio-energy is the most important and easily useful source for energy production. Production of diesel using plant sources is good alternative resource through which we can meet the demand for petroleum products. Biodiesel is an alternative to diesel which is made from renewable resources such as vegetable oils (or) animal fats [4, 5]. Biodiesel can be produced from edible oil-seed crops like Soya bean, Ground nut, and Sun flower and from non edible oil-seeds such as Pongamia and Jatropha. However, developing, Countries like India needing huge quantity of edible oils for consumption, cannot afford to use edible oils for biodiesel production and hence non edible oil seeds such as Pongamia and Jatropha are explored. *Pongamia pinnata* (L.) Pierre, an arboreal legume, is a member of the subfamily Papilionoideae, more specifically the Millettieae tribe. This medium-size tree is indigenous to the Indian subcontinent and south-east Asia, and has been successfully introduced to humid tropical regions of the world as well as parts of Australia, New Zealand, China and the USA.

Historically, this plant has been used in India and neighbouring regions as a source of traditional medicines, animal fodder, green manure, timber, fish poison and fuel. More importantly, *Pongamia pinnata* has recently been recognized as a viable source of oil for the burgeoning biofuel industry. The sustainable production of plant oils for biodiesel production from a tree crop such as P. pinnata, which can be cultivated on marginal land, has the potential to not only provide a renewable energy resource but in addition will alleviate the competitive situation that exists with food crops as biofuels and associated arable land and water use. Finally, *Pongamia pinnata* has been identified as a resource for agroforestry.

One potential impact of biofuel deployment is the storage or release of soil organic carbon (SOC). SOC sequestration is an important component in the life cycle of biofuel production and may be key in determining the greenhouse gas (GHG) reduction potential of biofuels relative to fossil fuels [6, 7].Additionally, increases in SOC produce a host of other advantages including increased productivity and crop quality, improved water and nutrient retention, decreased runoff of both sediment and pollutants, and increased soil biodiversity [8].Thus, an understanding of changes in SOC under biofuel crops is essential for thorough cost–benefit analyses of biofuels [9 10].Carbon storage in forest ecosystems involves numerous components including biomass carbon and soil carbon. As more photosynthesis occurs, more CO is converted into biomass, reducing carbon in the atmosphere and sequestering it in plant tissue above and below ground [11,12] resulting in growth of different parts [13]. Biomass production in different forms plays important role in carbon sequestration in trees [14]. Above Ground Biomass, Below Ground Biomass, Dead Wood, Litter, and Soil Organic Matter are the major carbon pools in any ecosystem [15, 12, 16]. Assessment of carbon stocks and stock changes in tree biomass are relevant to deal with the united nation Framework Convention on Climate Change (UNFCCC) [17] and Kyoto Protocol report [18].
Pongamia pinnata is a deciduous tree species and one of the widely available trees found in the study area. Studying about this particular species is valuable in various aspects particularly estimating the carbon sequestration potential and extraction of biodiesel from the seed of this tree to be an input for the climate change mitigation activities taking place in India and in the world at large, since climate change is the worldwide issue.

MATERIALS AND METHODS

Description of experimental site

The experiment was conducted during 2003-2013 at the Hayatnagar Research farm of Central Research Institute for Dryland Agriculture (17°27′N latitude and 78°35′E longitude and about 515 m above sea level), Hyderabad in Southern part of India. Annual long-term rainfall for the site is about 746.2 mm received predominantly from June to October. The soils are medium-textured, red soil with shallow depth.(Typic Haplustalf as per USDA soil classification).

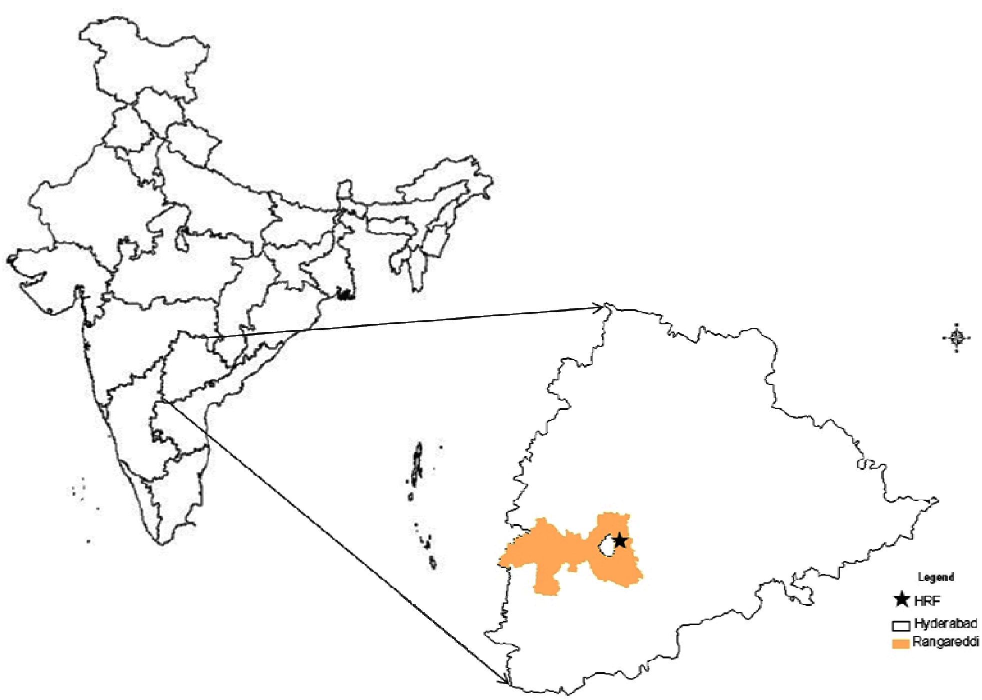

Figure-1: Geo location of study site in Telangana State, India

Experimental design

Tree establishment

In the year 2003, 4 months old nursery raised *Pongamia* seedlings were planted in the pits of 45 cm^3 size during the month of July. The pit mixture contained good dugout soil + 2 kg compost + N, P and K at 42 g, 168 g and 42 g respectively. The date of planting of *Pongamia* was 07.07.2003 with a spacing of 5 x 5m, 6x4m, 6x6m and 8x6m. Resulting in a population of 400, 416, 277 and 208 plants/ha. The total plantation area was 12 ha, which was divided into 4 blocks, each block representing one of the four spacings, within each block/spacing was further divided into 3 blocks of 1ha each representing each replication. There were four spacings with three replications.

Tree growth and biomass production

Data on tree growth such as height, DBH, crown diameter, number of branches and crown depth were measured at 6 monthly interval. The entire field was divided in to plots of equal size and within each plot, 25% of the trees were marked representing the population and the growth parameters of these trees were monitored at regular intervals. Trees were harvested during 9^{th} year in the months of January -March 2012. Entire plantation was divided into four diameter classes viz, 0-5 cm, 5 -10 cm, 10 -15 cm, and 15 -20 cm. As the destructive sampling of the Pongamia trees was very laborious and time consuming only 3 trees representing the respective diameter class were selected randomly for destructive sampling. In total 12 plants were selected for destructive sampling. The growth parameters of the selected 12 plants were given Table 1.

Table-1: *Pongamia pinnata* growth parameters

Parameters	GROWTH PARAMETERS			
	Minimum	Maximum	Mean	Std Deviation
Plant Height (cm)	265.67	652.50	410.13	128.21
C.D (cm)	4.42	18.10	11.28	5.41
No. of Branches	35.00	282.00	137.15	91.08
Crown width (cm)	234.83	696.67	436.74	167.85
Crown depth (cm)	35.33	89.00	64.81	16.95

Destructive sampling

Below ground

Excavation of total root system was done manually and carried out within one week of the above ground sampling under dry soil conditions and subsequently washed with water to remove the adhering soil. During the digging, the horizontal spread of roots was measured and after excavation, the entire root system was rearranged to the extent possible into its original position. All categories of roots cut during excavation were carefully picked up from the soil and rearranged the root system. The total root biomass was estimated separately. Representative samples were taken from fresh roots and dried to at 70^0 C to a constant weight to calculate moisture ratios, as was done in above ground biomass.

Total Carbon Content

Carbon content (%) in composite samples (leaves, stem, branch and root) was determined by TOC Analyzer.

Soil samples collections of Pongamia fields

Soil samples were collected at six monthly intervals, from all treatments of pongamia plantations at two different depths (0cm-20cm and 20cm-40cm) and from three places (Under Tree Canopy (UTC), Under Litter Trap (ULT) and uncultivated area (Open)). Soil samples were air dried ground and sieved to 1mm size and analyzed for total carbon content by combustion method using the LECO CR-412 carbon analyzer.

Fig.2 Pongamia plantations at HRF

Fig.3 Litter traps in Pongamia fields

Fig.4 Litter placed in litter trap

Fig.5 Soil samples

Litter fall collection in *Pongamia* fields

Litter collection was done from July, 2011 – June, 2013 at monthly in Pongamia plantation and these samples were utilized for the studies. The litter traps were made up of 1 x 1m nylon fishing net fitted to stakes at 1 m above the ground. Three litter traps were placed under the tree for each treatment of different tree spacings *(*5mx5m, 6mx4m, 6mx6m, 8mx6m).All in all there were 12 litter traps. The collected litter was dried to constant weight by drying it in oven at 60°C for 72 hours to measure the monthly dry matter weight of the litter (Fig-2 to 5).

RESULTS AND DISCUSSION

Soil organic carbon enhancement

The amount Soil organic carbon adding to soil through pongamia biomass and litter fall. The soil carbon content at both the depths of soil sampling (0-20cm & 20-40cm) was high Under Tree Canopy(UTC) fallowed by Under Litter Trap (ULT) and Open area (OA).The average soil organic content at sampling depth of 0-20cm was 13.37t/ha, 5.18t/ha and 5.89t/ha with UTC, ULT and Open area, respectively. While at sampling depth of 20-40cm, the soil organic content values of 7.76t/ha, 3.76t/ha and 3.69t/ha were recorded in combination with UTC, ULT and Open area, respectively. SOC increase in soils is largely due to leaf litter addition to the soil and thereby enhancement of soil carbon storage in drylands. SOC increased by 0.37% to 0.48% (Table 2) in pongamia plantation of the present study. Similar results of increase in Soil organic carbon has been reported in agroforestry plantations ranging in age from 6 years [19] to 20 years [20].In a Poplar based agroforestry system, trees could sequester higher soil organic carbon up to 30cm depth during the first year of plantation (6.07t/ha/yr) than in subsequent years (1.95-2.63 t/ha/yr). Narain [21] reported that planting trees and grasses in degraded lands in arid areas can help increase soil carbon stock from 24.3Pg to 34.9 Pg. This clearly indicates that trees like pongamia add lot of biomass to the soil and is a good source of Organic Carbon, returned to the soil.

Table-2: Soil properties changed before and after planting of *pongamia*

Before plantation of *Pongamia*		After plantation of *Pongamia*	
P^H (soil-water 1:2)	5.30	P^H (soil-water 1:2)	6.13
EC (dsm^{-1})	0.09	EC (dsm^{-1})	0.06
Organic carbon (%)	0.37	Organic carbon (%)	0.48
Total P (mg kg^{-1})	210.00	Total P (mg kg^{-1})	141.95
Available N ($KMnO_4$ method) (mg kg^{-1})	65.00	Available N ($KMnO_4$ method) (mg kg^{-1})	17.10
Available P (0.5 M $NaHCo_3$ extractable) (mg kg^{-1})	5.60	Available P (0.5 M $NaHCo_3$ extractable) (mg kg^{-1})	0.32
Available K (mg kg^{-1})	80.00	Available K (mg kg^{-1})	190.00

Below ground (root) biomass and carbon content

The average below ground dry biomass and carbon content across diameter classes was 18.633 t/ha and 7.653t/ha, respectively (Table 4).

Table-3: Soil Organic Carbon (t/ha) of *Pongamia pinnata* plantation

SOC under *Pongamia* plantation			
Soil depth in cm	Min	Maxi	Average
Under Tree 0-20	5.35	21.39	13.37
Under Litter Trap 0-20	2.07	8.29	5.18
Open Area (Open) 0-20	1.90	7.60	4.75
Under Tree 20-40	3.10	12.41	7.76
Under Litter Trap 20-40	1.51	6.02	3.76
Open area (Open) 20-40	1.47	5.90	3.69

UT= Under Tree, ULT= Under Litter Trap, Open Area (Open)

Table-4: Root dry biomass and carbon in below ground parts of *Pongamia pinnata*

Dia meter Classes	Root dry biomass (t/ha)	C in below ground parts (t/ha)
D1 (0-5 cm)	2.169	0.891
D2 (5-10 cm)	11.405	4.684
D3 (10-15cm)	22.458	9.224
D4 (15-20 cm)	38.499	15.811
Average	**18.633**	**7.653**

D = Collar Diameter

Litter fall of *pongamia pinnata* at different spacing Litter fall of *pongamia pinnata* at different spacing

The results showed that the total quantity of litter produced in a year at different spacing was 8.35 ton/ha, 7.49 ton/ha, 7.2 ton/ha and 6.79 ton/ha, for 5mx5m, 6mx4m, 6mx6m and 8mx6m respectively. The highest (8.35 ton/ha) litter fall was recorded in 5mx5m and least (6.79 ton/ha) litter fall with 8mx6m (Figure-6 and 7).

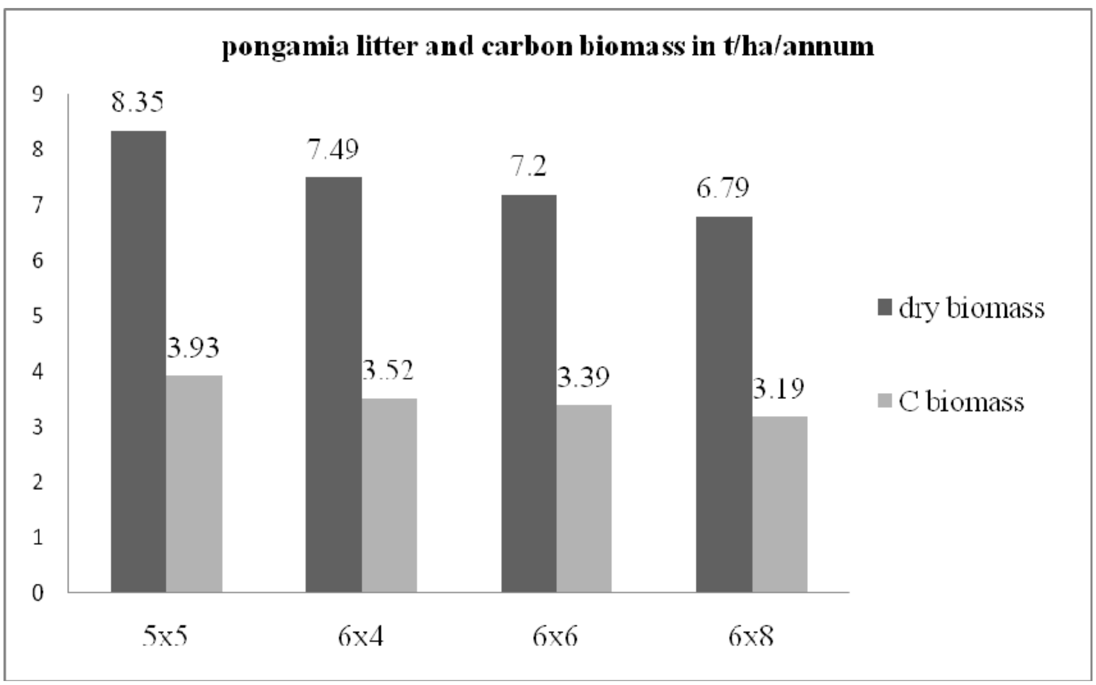

Figure-6: *Pongamia pinnata* litter fall in t/ha and C biomass tons/ha

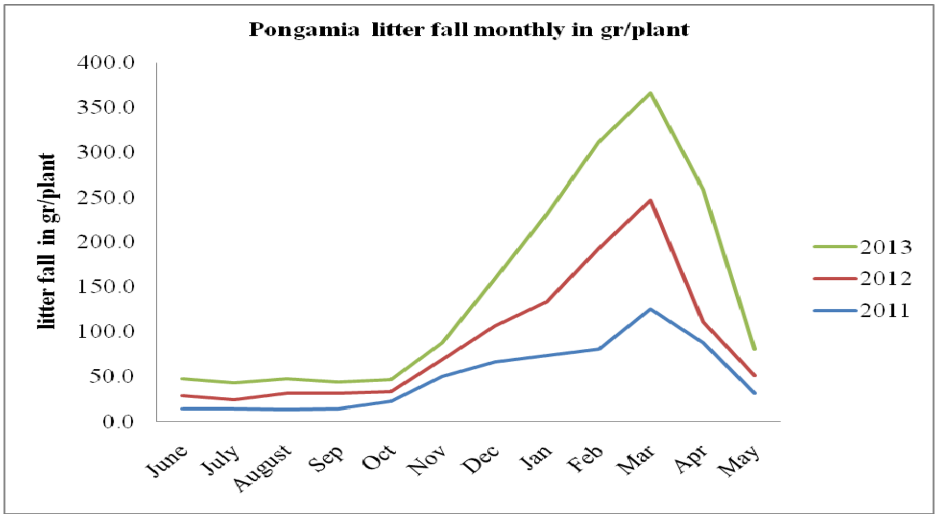

Figure-7: Monthly Pongamia litter fall in gr/plant

The litter fall was collected at monthly interval and in general, litter fall was highest in the month of March across all the years followed by January (Figure 7).

Litter fall and C biomass of *pongamia pinnata*

Pongamia is deciduous tree species, and sheds its leaves during dry season. Soil moisture starts depleting from December onwards and the plant sheds all leaves by January, which are added to the soil. A 9-year older plantation adds large quantities of biomass through addition of the by-product cake left after oil-extraction. As regards C sequestration by *pongamia pinnata* in its above and belowground biomass, earlier study in Plinthic Paleudult soil in Malaysia 22 [19] reported a value of 13,000 kg C ha−1 .Studies in the tropics have identified the best of C sequestering systems in rainfed agriculture by the inclusion of leguminous crops including pigeonpea which under improved management have been reported to increase carbon sequestration maximum up to 330 kg C ha−1 year−1[23] [24].Carbon sequestration in these degraded infertile semi-arid tropical soils serves the dual purpose of reducing the atmospheric CO2 concentration and increasing the soil organic carbon, which plays a crucial role in soil quality improvement and the availability of plant nutrients [25]. Such large C credits if gained on larger tracts, can be traded with other regions or countries and can be a good source of income [26].

Maximum litter fall was in the dry season, where rainfall was low. This greatly reduced soil moisture extraction thereby reducing competition with crops for water and nutrients during the period. In the present study the highest litter fall recorded in March is similar to that reported by [27] and [28] in which litter fall was associated with natural senescence of leaves induced by temperature and/or moisture stress in the region. The high litter production during this dry period will ensure soil cover and protection from excessive heat of the dry season as well as maintain nutrient cycling as highlighted by [29]. The pattern of litter fall could be taken advantage to synchronize the nutrient release with crop production in an alley cropping system. The total quantity of litter and carbon produced by Pongamia in a year in the present study, at different spacing were 8.35 tons/ha, 7.49tons/ha, 7.2 tons/ha, and 6.79 tons/ha for 5mx5m, 6mx4m, 6mx6m, and 6mx8m respectively. The corresponding values for carbon biomass was 3.93/ha,3.52t/ha,3.3.9t/ha, and 3.19 t/ha, respectively. This quantity of litter fall was generally low may be because of rainfed crop, poor soils, semiarid environment, similar pattern of results in annual litter fall rates of 2.9 – 3.3 tons/ha for Cordia alliodora, 6.9 tons/ha for Inga jinicuil and 5.3 ton/ha for Inga leptoloba was reported in earlier studies[30]. The low C accumulation in present study indicated need to increase it through tapping germplasm and other best cultivation practices.

CONCLUSION

Pongamia plantations adds large amount of organic matter through fallen leaves and biomass, its helps to improve the microbial biological activity. Microbial activity is used as an indicator of soil health. The role of increased organic matter in enhancing soil quality as a result of more C sequestration well known. The results of our study show that Pongamia grown on dry lands has potential to add large quantities of C to the soil, in addition to that accumulated by the standing crop.

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