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QUANTIFICATION OF ECOSERVICES IN TRADITIONAL AGROFORESTRY SYSTEMS IN SEMI ARID TROPICS

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Abstract

Neem (*Azadirachta indica* A. Juss.) being an important tropical tree, traditional neem-based agroforestry (bund/boundary/scattered tree planting with field crops) systems were evaluated for their carbon sequestration (CS) potential, soil quality, pest dynamics and provisioning services in comparison with prevailing grain based system in the tropical India. Results revealed higher economic gain from soil quality services followed by CS in all the agroforestry systems among the non-marketable services, whereas higher provisioning services were obtained with crops alone. In all, total economic value was higher in boundary planting ($ 1053.94/ha/yr) followed by bund planting ($ 961.95/ha/yr) and was lower with scattered planting ($ 939.76/ha/yr). However, the provisioning services ($ 841 - 889/ha/yr) rendered by agroforestry systems were lower than those of agriculture alone ($ 904/ha/yr) but were still significant from ecological and sustainable angles.

Although intensive agriculture increased the productivity to some extent and thereby provided the much needed provisioning services (food and fiber) to the society it was at the cost of other critical services offered by the natural ecosystem (Alam *et al*. 2014). Hence, more sustainable forms of land use system needs to be identified where one can get higher productivity with enhanced environmental quality (Chittapur and Doddabasawa 2018). To find out more sustainable forms of land use system one needs to understand the ecological processes which determine critical ecosystem services (Kremen 2005).

Comprehensive quantification of ecosystem services of traditional agroforestry systems have not been adequate (Scroth *et al*. 2004). This might be due to difficulty in quantification and valuation of the ecological benefits. Keeping these points in view the present study was undertaken for quantification and valuation of ecological benefits in different neem-based agroforestry systems in comparison with conventional agriculture in semi arid tropics under rain fed condition.

The present study was carried out during 2016 - 2017 on farmers' fields on participatory mode in Yadgir district of North eastern dry zone (Zone II) of Karnataka, India. The region belongs to dry semi arid with cool winters and dry hot summers. The average rainfalls is around 750 mm and mean annual temperatures ranges from 18.6 to 32.5^{0}C and mean elevation ranges from 350 - 680 m. The soils are deep (90 cm), very deep (> 90 cm) or medium deep black (60 - 90 cm) soils in major areas while sandy loam and light textured soils are also present in some pockets. The agroforestry system comprising pigeonpea, the major field crop grown under rainfed ecosystem in association with around 25 years old neem on bunds, boundary or scattered in the whole field was selected for assessing ecosystem services. The data on yield and biomass were collected by selecting 4 farmers in each system with a plot size of one hectare and as the plots were located in

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different locations average of 4 farmers without trees (agriculture system) representing the locations were taken as control for comparison. Ecosystem services rendered by agroforestry systems which are quantifiable and easily measurable *viz.*, carbon sequestration, soil fertility improvement, pest control and provisioning ecosystem services were considered for comparing with agriculture system.

The productivity of tree biomass was calculated by non-harvesting method by taking the measurements of girth (cm) and height (m) of the 20 randomly selected trees in each system and the volume was calculated by using equation 1. (Chaturvedi and Khanna 1981).

$$V = \frac{g^2}{4\pi} \times h \qquad (1)$$

Further, the above ground biomass was converted into dry biomass by multiplying with wood density (dry biomass = Volume × Specific wood density) (Brown and Lugo 1982). The specific wood density used for the study was 0.690 (FAO 1997). Later, mean dry biomass was converted into C equivalents by multiplying the mean dry biomass with a value of 0.45 (Yadav *et al*. 2017). Further, the C was converted in terms of carbon dioxide equivalents (CO_2 = 3.67 times of carbon). Similarly the productivity of pigeonpea was assessed in terms of yield and biomass; the yield and biomass of pigeonpea was recorded with a net plot size 6 m × 5 m. Grain and haulm were separated, dried and weighed and were computed and extrapolated to per hectare basis.

To assess the improvement in soil quality, the composite soil samples were taken from depth of 0 - 15 cm after harvesting of the crop and were analyzed for chemical properties by following standard procedures (Walkley and Black 1934, Subbiah and Asija 1956, Jackson 1973).

Quantification of ecoservice was done in terms of total economic value (TEV). Replacement cost method was used to assess the monetary value of soil fertility services wherein the values of major nutrients in agriculture system (sole pigeonpea) were taken as base and the rate of improvement or otherwise in the agroforestry systems per hectare per year were worked out by dividing it with the age of trees and multiplied with existing price of nutrients (N 290 $/t, P 260 $/t and K 255 $/t). Similarly, keeping organic carbon (OC) in the agriculture system as base the rate of improvement for the systems was calculated per hectare per year. It is assumed that to maintain 0.3% of organic carbon in the soil every year it needs yearly addition of 10 t FYM per hectare. Hence, the rate of reduction in the use of FYM was calculated based on the rate of improvement of soil organic carbon over base rate and multiplied with price of FYM (14 $/t).

Further, instead of level of infestation the cost incurred in seed treatment for single pest was used and replacement cost was worked out. The pigeon pea crop was treated with *Rhizobium* (500 gm/ha) + *Trichoderma* (50 gm/ha) mainly to control the wilt. The improvement in microbial population helped to reduce the cost incurred for these bio-inoculants over agriculture systems. The present market prices used in the study for *Rhizobium* and *Trichoderma* were 4 $ per kg and 2$ per kg. This would be of 2.1$/ha/yr.

To arrive at marketable services, the quantity of grain yield and haulm yield in each system was multiplied with the existing market price ($ 550/t and 10/t for grain and haulm, respectively). Similarly, neem seed yield was multiplied with market price ($ 85/t with average yield of 20 kg/tree). However, in the investigation value of fuel wood, fodder and timber was considered. Finally, economic value of each non-marketable services and marketable services were calculated and added to arrive at the actual monetary benefits of each land use system and were expressed in $/ha/yr.

Total Economic Value (TEV)= ∑ Non-Marketable Services + ∑ Marketable services where, Non- Marketable Services includes: ∑ Carbon Sequestration + ∑ Soil Quality+ ∑ Pest Control

Table 1. Quantification of carbon sequestration and indicator economic value of different agroforestry systems.

Sl. no.	Agroforestry systems	Av. of trees	Mean no. of trees/ha	Mean biomass (kg/tree)	Total above ground biomass of trees t/ha	Total carbon stock CE t/ha	Total carbon stock CO_2 equivalents t/ha	Economic value ($/ha)	Economic value ($/ha/yr)
1	Bund planting of neem + pigeon pea	25	26.75[c]	224.17	6.00[b]	2.70	9.91	426.13	17.05
2	Boundary planting of neem + pigeon pea	25	39.00[b]	262.74	10.25[c]	4.84	17.76	763.68	30.55
3	Scattered planting of neem + pigeon pea	25	18.25[a]	213.51	3.90[a]	1.76	6.46	277.78	11.11
4	Agriculture system (sole pigeon pea)	-	-	-	-		-	-	-
	F test (P)		<0.05	0.351[NS]	<0.05	-	-	-	-

[a-c]Values within the column with same letter do not differ significantly.

Table 2. Analysis and quantification of soil nutrient improvement and indicator economic value of different agroforestry systems.

Sl. no.	Agroforestry systems	Soil chemical properties				Economic benefit accrued due to reduction of nutrient applications ($/ha/yr)				Total economic benefits ($/ha/yr)
		Organic Carbon (%)	Available N (kg/ha)	Available P_2O_5 (kg/ha)	Available K_2O (kg/ha)	FYM	N	P	K	
1	Bund planting of neem + pigeon pea	0.65[ab] (+0.17)	277.00[ab] (+68/25=2.72)*	70.00[b] (+22/25=0.88)	217.00 (+26/25=1.04)	79.38	0.79	0.23	0.27	80.67
2	Boundary planting of neem + pigeon pea	0.74[b] (+0.28)	320.00[c] (+111/25=4.44)	65.00[ab] (+17/25=0.68)	234.00 (+43/25=1.72)	130.62	1.39	0.18	0.45	132.68
3	Scattered planting of neem + pigeon pea	0.66[ab] (+0.18)	288.00[ab] (+79/25=3.16)	62.00[ab] (+14/25=0.56)	235.00 (+44/25=1.76)	84.00	0.92	0.15	0.45	85.52
4	Agriculture system (sole pigeon pea)	0.48[a] (0.00)	209.00[a] (0.00)	48.00[a] (0.00)	191.00 (0.00)	0.00	0.00	0.00	0.00	0.00
		0.109[NS]	0.093[NS]	0.090[NS]	0.364[NS]	-	-	-	-	-

*Values within the parenthesis indicate average change over tree life in the system. Values within the column with same letter do not differ significantly $p < 0.05$.

Table 3. Quantification and indicator monetary value of provising services of different agroforestry systems.

Sl. no.	Agroforestry systems	Mean no. of trees/ha	Crop and tree seed yield			Economic benefit ($/ha/yr)			Total economic benefits ($/ha/yr)
			Grain yield (kg/ha)	Haulm yield (kg/ha)	Neem seeds	Grain	Haulm	Neem seeds	
1	Bund planting of neem + pigeon pea	26.75[c]	1370.00[a] (± 88.41)	6316.00 (± 449.38)	535.00	753.50	63.16	45.47	862.13
2	Boundary planting of neem + pigeon pea	39.00[b]	1378.00[a] (± 23.28)	6331.00 (± 377.98)	780.00	759.00	63.31	66.30	888.46
3	Scattered planting of neem + pigeon pea	18.25[a]	1357.00[a] (± 61.83)	6400.00 (± 293.99)	365.00	746.00	64.00	31.03	841.03
4	Agriculture system (sole pigeon pea)		1520.00[b] (± 80.05)	6840.00 (± 530.63)	0.00	836.00	68.40	0.00	904.40
	F test (p)	< 0.05	< 0.05	0.295[NS]					-

Values in the parentheses indicates the standard deviation. Values within the column with same letter do not differ significantly $p < 0.05$.

Table 4. Economic value of ecosystem services of different agroforestry systems.

Sl. no.	Agroforestry systems/ ecosystem services	Bund planting of neem + pigeon pea	Boundary planting of neem + pigeon pea	Scattered planting of neem + pigeon pea	Agriculture system (sole pigeon pea)
				($/ha/yr)	
A	Non marketable services				
1	Carbon sequestration	17.05	30.55	11.11	0.00
2	Soil fertility improvement	80.67	132.68	85.52	0.00
3	Pest control	2.10	2.10	2.10	0.00
	Total	99.82	165.33	98.73	0.00
B	Marketable services				
1	Grain	753.50	759.00	746.00	836.00
2	Haulm	63.16	63.31	64.00	68.40
3	Neem seeds	45.47	66.30	31.03	-
	Total	862.13	888.61	841.03	904.40
	Grand total (A+B)	961.95	1053.94	939.76	904.40

Boundary system of tree planting in among the agroforestry systems involving pigeon pea had maximum number of trees (39/ha) compared to the other two systems (Table 1).

Soil chemical status revealed overall improvement in organic carbon and available nutrient status in agroforestry systems over agricultural system alone and differences were particularly significant with boundary system of agroforestry particularly with respect to organic carbon (0.74%) and available nitrogen (320 kg/ha) closely followed other agroforestry systems whereas agriculture system recorded 0.48% OC and 209 kg/ha soil available N (Table 2).

Further, presence of trees in the agroforestry systems though resulted in lowering of grain and haulm yields (the provisional services), the differences were statistically not significant (Table 3).

The results of the present investigation revealed that among the non-marketable services higher economic gain was recorded with soil fertility improvement services from tree component followed by C sequestration services in all the agroforestry systems (Table 4). This could be attributed due to higher market price per unit of fertilizers as compared to C sequestered. Marketable services were lower ($ 841 to $ 889 ha/yr) in agroforestry systems compared to agriculture system ($ 904.40 ha/yr). This was mainly due to lower crop yield under agroforestry systems due to inter species competition (Muthuri *et al*. 2005).

The study also brings forth the fact that the competitive effect is more influenced by pattern of planting rather than density of trees alone and management of trees, therefore, assumes significance and if taken due care it is possible to further enhance the monetary gains. Nevertheless, higher total economic value (non-marketable and marketable services) was recorded in boundary planting ($ 1053.94 ha/yr) followed by bund planting ($ 961.95 ha/yr) and scattered planting (($ 939.76 ha/yr) whereas lower total economic value was observed in agriculture system alone ($ 904.40 ha/yr) (Table 4). Thus, boundary, bund planting and scattered planting are more sustainable as compared to agricultural system alone.

In Chittagong Hill tracts of Bangladesh, Rasul (2009) recorded lesser economic benefits in agroforestry and farm forestry systems as compared to annual cash crop, whereas, inclusion of environmental benefits from agroforestry and farm forestry resulted in better performance over annual cash crop.

Although agroforestry systems yield lesser private benefits, they are ecologically more significant than the sole agriculture systems. In the present investigation only a few significant services were considered for system assessment where it was noticed that the ecological and economical benefits also depend on the density of trees and pattern of planting which in turn affect the extent of competitive effect on the crop.

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