



Valuation of carbon sequestration by poplar based agroforestry systems in Yamunanagar, Haryana

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ABSTRACT

Poplar (*Populus deltoides*) based agroforestry systems in Yamunanagar district of Haryana have great potential for carbon sequestration, which is considered as an ecosystem service. This study bridges the knowledge gap regarding payment for ecosystem services through carbon sequestration by poplar farmers. This study was conducted in year 2018 with the objective of estimating the quantity and value of carbon sequestered by poplar based agroforestry systems. Remote sensing analysis for year 2017 revealed that poplar is dominant tree species grown by farmers on their field and occupied about 13.97% of district's geographical area. Timber production of poplar trees was estimated at 45.9 and 113.3 t/ha for seven years of rotation in boundary and agrisilviculture systems, respectively. The CO₂ sequestered by poplar trees in boundary and agrisilviculture systems come out to be 99.2 and 242.0 tCO₂e for seven year-old plantation, and total value of this carbon sequestered was estimated at US\$ 1778 and 4673 @US\$ 5.1/t CO₂e for seven years of rotation, respectively. At district level, estimated value for carbon sequestered by poplar based agroforestry systems was amounted to US\$ 25.43 million @US\$ 5.1/t CO₂e for entire rotation period of seven years in an area of 172506.96 ha. At country level, this ecosystem service of carbon sequestration would yield hefty amount of about US\$ 285 million (₹ 185 billion). Hence, poplar based agroforestry systems in India are sustainable solution for not only climate change mitigation but can also enhance farmers' income through payment of ecosystem service.

Key words: Agroforestry, Carbon sequestration, Climate change, Ecosystem service, Remote sensing

The climate is changing, human influence on the climate system is clear, therefore, we have to limit climate change and build a more prosperous and sustainable future (IPCC 2014). The Clean Development Mechanism (CDM) of the Kyoto Protocol (1997) imposed carbon emissions limits on its signatories. 116 out of 131 countries mention forestry as a sector for adaptation (FAO 2016). In fact, assignment of value to the carbon (C) is one of the innovative mechanisms for solutions to the global climate change. Markets for carbon allow for the purchase of carbon credits by carbon emitters who need to offset their emissions based on cap set for concerned country. Agroforestry is considered as viable strategy to prevent and mitigate climate change effects. Agroforestry was recognized by IPCC as having high potential for sequestering C as part of climate change mitigation strategies. For small holder agroforestry systems in tropics, potential C-sequestration rate ranges

from 1.5–3.5 Mg C/ha/yr (Montagnini and Nair 2004). To achieve the committed targets under Paris Agreement (2015), agroforestry is sustainable solution for climate change mitigation along with enhancing farmer's income.

Poplar (*Populus deltoides*) based agroforestry systems are prevalent in north-western India, which include boundary, block and agrisilviculture systems on farmlands. Many studies reported the carbon storage and sequestration potential of poplar species in agroforestry (Rizvi *et al.* 2011, Gaur and Gupta 2012, Singh and Gill 2014, Chauhan *et al.* 2015, Panwar *et al.* 2017) and in forests (Kaul *et al.* 2010). Dhiman *et al.* (2009) quantified C-sequestration of poplar culture in India to approx. 2.5 million tC per annum, out of which 1.04 million tC is locked in poplar based products for different durations, 1.15 million tC equivalent is locked in other tree parts mainly used as firewood and 0.3 million tC is added to the soil through leaf litter every year. The monetary value associated with this ecosystem service provided by poplar based agroforestry system has not yet been assessed at district or country level. Therefore, present study was carried out for valuation of carbon sequestered by poplar based agroforestry systems in Yamunanagar, Haryana.

MATERIALS AND METHODS

Remote sensing data for mapping: For mapping of

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present area under poplar in Yamunanagar, Landsat8 OLI images (spatial resolution- 30 m) were downloaded from the USGS website (<http://earthexplorer.usgs.gov/>). The Landsat8 Scenes of Path 147 and Row 39 for three dates of pass (23-Jan, 15-May and 06-Oct, 2017) were downloaded. Layer stacking of blue, green, red and NIR bands and then sub-setting of district area was done by boundary shape file. Various vegetation indices such as normalized difference vegetation index (NDVI), green NDVI (GNDVI), transformed NDVI (TNDVI), soil & atmospherically resistant vegetation index (SARVI) and renormalized difference vegetation index (RDVI) have been computed as:

$$\text{NDVI} = (\text{NIR} - \text{Red}) / (\text{NIR} + \text{Red}) \quad (1)$$

$$\text{GNDVI} = (\text{NIR} - \text{Green}) / (\text{NIR} + \text{Green}) \quad (2)$$

$$\text{RDVI} = (\text{NIR} - \text{Red}) / \text{SQRT}(\text{NIR} + \text{Red}) \quad (3)$$

$$\text{TNDVI} = \text{SQRT}((\text{NIR} - \text{Red}) / (\text{NIR} + \text{Red})) + 0.5 \quad (4)$$

$$\text{SARVI} = (\text{NIR} - \text{RB}) * (1 + \text{L}) / (\text{NIR} + \text{RB} + \text{L}) \quad (5)$$

$$\text{RB} = \text{Red} - \text{Gamma} * (\text{Blue} - \text{Red})$$

These indices were used by Bhavsar *et al.* (2017) for separability analysis of three forest types in Western Himalaya. These vegetation indices were compared for tone and texture of poplar plantations found in Yamunanagar district for the month of May. For poplar species, tone was found in dark grey to light grey shade in all indices, whereas smooth texture was observed in NDVI and SARVI images and not in others (Fig 1). The results of NDVI were found more accurate than other indices as far as poplar is concerned. Therefore, NDVI image of May, 2017 has been used for identification and mapping of poplar species with the help of ground GPS points.

Data collection and analysis: The field survey was conducted in six development blocks of Haryana in the year 2008–09 and again in 2017–18. The primary data on height and diameter at breast height (DBH) for different age of poplar trees was collected from farmers' fields. Data on different physiographical parameters was collected from Statistical Abstract of Haryana (2016) published from Department of Economics and Statistical Analysis, Government of Haryana. The price of carbon sequestered was taken from Ecosystem Marketplace as @US\$5.1/tCO₂e for the year 2016–17.

The carbon storage in total biomass was computed as:

$$C = 0.455 \times B$$

where C, carbon storage; B, dry biomass.

CO₂ equivalent carbon in the biomass of poplar trees was computed as:

$$C \times 3.67$$

where C, total carbon storage as applied by Rizvi *et al.* (2011). It is assumed that 1 and 2- year old trees have small amount of biomass, therefore only three to seven years of data on all parameters were considered for analysis.

RESULTS AND DISCUSSION

Assessment of poplar area in Yamunanagar: Present area under poplar has been assessed using remote sensing data of Landsat 8 for year 2017. Range of NDVI values obtained for poplar was $0.191 < \text{NDVI} \leq 0.310$, for which help of ground verification points was taken. The NDVI image was classified into two classes: i) Poplar spp. (if $0.191 < \text{NDVI} \leq 0.310$), ii) other LULC classes ($\text{NDVI} \leq 0.191$ & $\text{NDVI} > 0.310$). The classified image was verified using 66 ground check points and also with the help of Google Earth. Reasonably good accuracy of more than 80 percent was found in poplar species identification. In this way poplar area was estimated to be 24109.20 ha which is about 13.97% of district geographical area (Table 1 and Fig 2). Best possible approaches were adopted for mapping poplar species, but there are likely chances that eucalyptus species may be mixed with poplar.

Estimation of carbon stock and CO₂ sequestered by poplar: The value for carbon sequestered by poplar trees was assessed at the rate of carbon @US\$ 5.1/t CO₂ e, which comes out to be US\$ 1778 and US\$ 4673 for seven years rotation in boundary and agrisilviculture system, respectively (Columns 3,4,5 of Table 2). In terms of Indian Rupees (₹), the value of carbon sequestered by poplar trees in seven years rotation comes out to be ₹ 115564 and ₹ 303727 for boundary and agrisilviculture system, respectively. If the time value of money on carbon is considered with discount rate of 12%, then above figures will come down to US\$ 1009 and US\$ 2651 in boundary and agrisilviculture system, respectively. However, if we compare the net income from rice-wheat rotation, which is US\$ 3501 per ha for seven years; the value of carbon from poplar for the same period stood at US\$ 2651 per ha in the study area. It indicates that payment of ecosystem service in terms of carbon sequestered by poplar plantations constitutes about 75% of net income from rice-wheat system, a system which needs more water and other natural resources.

Sensitivity analysis for value of carbon sequestered by poplar: As per the latest data of year (2016–17), an average price from all sources of certified emission reductions (CERs) for India was fixed at US\$0.6/ tCO₂ (World Bank 2017). The sensitivity analysis was conducted on the basis of lowest minimum price offered for India, i.e. US\$0.6/

Table 1 Estimated area under poplar species in Yamunanagar, Haryana

Name of block	Geog. area (ha)	Poplar area (ha)	Poplar area (%)
Chhachrauli	47902.32	8972.91	5.20
Mustafabad	18843.12	2660.85	1.54
Jagadhari	37471.95	5831.37	3.38
Sadhura	12781.98	1446.12	0.84
Bilaspur	27602.19	2350.71	1.36
Radaur	27905.40	2847.24	1.65
Total	172506.96	24109.20	13.97

Table 2 Estimated value of carbon stock of poplar based systems and sensitivity analysis based on changes in price of carbon sequestration

Age of poplar (years)	Carbon stock (t ha ⁻¹) [#]	CO ₂ sequestered (tCO ₂ e)	Value of CO ₂ sequestered/ha @ US\$5.1/t CO ₂ e	Value of CO ₂ sequestered/ha (1 US\$ = ₹ 65)	Value of CO ₂ sequestered/ha		Value of CO ₂ sequestered/ha	
					@US\$40/t CO ₂ e	@US\$0.6/t CO ₂ e	In Indian Rupees (1 US\$ = ₹ 65)	
<i>Boundary plantation (200 trees/ha)</i>								
3	9.56	35.09	178.96	11632.40	1403.41	21.05	91221.65	1368.25
4	13.65	50.10	255.51	16608.15	2003.82	30.06	130248.30	1953.90
5	20.42	74.94	382.20	24843.00	2997.66	44.96	194847.90	2922.40
6	24.33	89.29	455.38	29599.70	3571.64	53.57	232156.60	3482.05
7	27.03	99.20	505.92	32884.80	3968.00	59.52	257920.00	3868.80
Total tree cycle	94.99	348.61	1777.91	115564.15	13944.53	209.17	906394.45	13596.05
<i>Agrisilviculture system (500 trees/ha)</i>								
3	33.04	121.26	618.43	40197.95	4850.27	72.75	315268	4728.75
4	42.14	154.65	788.72	51266.80	6186.15	92.79	402100	6031.35
5	51.55	189.19	964.87	62716.55	7567.54	113.51	491890	7378.15
6	56.96	209.04	1066.10	69296.50	8361.73	125.43	543512	8152.95
7	65.96	242.07	1234.56	80246.40	9682.93	145.24	629390	9440.60
Total tree cycle	249.65	916.22	4672.72	303726.80	36648.62	549.73	2382160	35732.45

(Source: Rizvi *et al.* 2011)

tCO₂ and lowest price suggested by the Commission, i.e. US\$40/tCO₂ e (Columns 5,6,7 of Table 2). A farmer can get as much as US\$ 549.73 per ha from poplar based agrisilviculture, if price crash from present price of US\$ 5.1/tCO₂ e to US\$0.6/tCO₂ e. This remuneration may escalate up to US\$ 36648.62 from poplar based agrisilviculture system if international community accepts the carbon price of US\$40/ tCO₂ e for India.

Value for carbon sequestered by poplar at district level:

Estimated area under agroforestry (Table 1) was further partitioned into area for different ages of poplar plantations. Considering this share of age-wise poplar area as 5, 10, 20, 30 and 35% for 3, 4, 5, 6 and 7 years old plantations, the age-wise total carbon stock, CO₂ sequestered and its monetary value was computed (Table 3). In this way, total carbon stock and CO₂ sequestered under poplar based agroforestry would be about 1.36 million t and 4.99 million tCO₂ e for different ages of plantation. Total value of US\$25.43 million

(₹ 16.52 billion) was substantial for carbon sequestered by poplar based agroforestry system in the district.

As per Country Report by National Poplar Commission of India (FRI 2016), area under poplar in the country is about 317000 ha. This area is spread within Punjab, Haryana, western Uttar Pradesh, Bihar and other plains of Uttarakhand and Himanchal Pradesh. This includes an area of 270000 ha in *Populus deltoides* plantations under agroforestry. Considering this area under poplar based agroforestry, estimated total carbon stock and CO₂ sequestered would be 15.21 million t and 55.84 million tCO₂ e at national level. The total value of carbon has been estimated at US\$ 285 million @US\$5.1/tCO₂ e from poplar based agroforestry systems in the country. Zapfack *et al.* (2016) estimated carbon sequestration of Lobeke National Park of about 81520966.80 tonnes (t) corresponding to over 298 million t of CO₂ sequestered by the park. They valued this ecosystems service at 1434769015.68 USD. Poplar based agroforestry

Table 3 Estimated carbon stock and value of carbon sequestration by poplar based agroforestry in Yamunanagar

Age of tree (year)	Share in area by age of poplar tree (%)	Estimated area by age of poplar tree (ha)	Total carbon stock (t/ ha)	Total carbon stock (million t)	Total CO ₂ sequestered (million t CO ₂ e)	Total value of CO ₂ sequestered @US\$ 5.1/t CO ₂ e (million US\$)	Total value of carbon sequestered (million ₹)
3	5	1205	33.04	0.04	0.15	0.75	48.46
4	10	2411	42.14	0.10	0.37	1.90	123.60
5	20	4822	51.55	0.25	0.91	4.65	302.40
6	30	7233	56.96	0.41	1.51	7.71	501.21
7	35	8438	65.96	0.56	2.04	10.42	677.14
Total	100	24109	249.65	1.36	4.99	25.43	1652.81

systems occupy sizeable area in India as per the Country Report by National Poplar Commission of India (FRI 2016)) and have significant contribution towards carbon sequestration, an ecosystem service.

At national level, estimated value of CO₂ sequestered @US\$ 5.1/tCO₂ e ranged from US\$ 52.10 to US\$ 116.67 million by poplar plantations of 5–7 years age. These poplar plantations will provide a hefty amount of ₹ 185.10 billion as carbon credit to the farmers. Again this country level estimate would be much higher if market value of carbon is fixed around US\$ 40–80/tCO₂ e as suggested by High-level Commission on Carbon Prices. Therefore, by getting price for carbon, farmers will be encouraged to adopt poplar based agroforestry in northern plains and area may also increase.

The present study highlighted the importance of poplar based agroforestry system in terms of carbon sequestration and monetary value associated with this ecosystem service. On comparing the net income from rice-wheat system and value of the carbon sequestration from poplar for the rotation period of 7 years, the payment of ecosystem services was found to be 75% of net income from rice-wheat system. In the present scenario of climate change, farmers should get incentive for their contribution in mitigation of climate change through carbon sequestration. Through suitable policy mechanism at national level, payment for ecosystem service given to poplar farmers will certainly enhance their income. This will lead to encouragement of farmers in adoption of agroforestry in other parts of India.

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