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Carbon sequestration in *Populus deltoides* based agroforestry system in Northern India

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Abstract
Globally carbon storage and sequestration in agroforestry systems are playing a pivotal role in combating climate change and a proven low cost technology for reducing greenhouse gas emission. Trans Indo-Gangetic plain with deep fertile alluvium witnessed green revolution but now the productivity becomes stagnant. Introduction of agroforestry systems improved the soil fertility and micro-environment however; limited information is available on sequestration potential of Poplar based agroforestry systems in Northern India. The objective of this review is to improve and update our present state of knowledge on Poplar based agroforestry system in Northern India for better adoption in other regions of India. *Populus deltoides* based agroforestry systems in Trans-Gangetic Plains of India showed promising carbon sequestration rate ranging from 0.85 to 5.05 Mg C ha^{-1} y^{-1} at 0-15 cm soil depth under different plantation age (4-11 years). It can be concluded that Poplar based agroforestry systems are sustainable land use system for increasing biological productivity (biomass), soil carbon and fertility as well as other ecosystem services. From the results, it is evident that integrating Poplar with the crops (rice/wheat/sugarcane/maize/turmeric/sorghum/fruits) substantially increased carbon sequestration that ultimately helps in combating climate change and sustain livelihood in Northern India.

Keywords: Carbon stock, trans-gangetic plains, poplar, climate change, adoption

Introduction
From the rapid industrialization and urbanization in western countries was causing speedy loss of resources and combustion of fossil fuels for energy which causes detrimental effects on the environment which rising concerns for pollution and global warming. The average global temperatures are higher than they have ever been during the past millennium, and the levels of CO_2 in the atmosphere have crossed all previous records. A scrutiny of the past records of 100 years indicates that India figures in the first 10 in the world in terms of fatalities and economic losses in a variety of climatic disasters (IPCC 2007) [18]. In developing countries, drastic population growth, industrial growth, rapid deforestation and increased transportation activities are increasing the concentration of air pollutants like greenhouse gases, especially CO_2 enormously (Mishra *et al*. 2014a; Gulshan *et al.* 2019) [24]. These are leading to increased atmospheric temperature through the trapping of certain wavelengths of heat radiation in the atmosphere. The increasing carbon emission is of major concerns; it has been well addressed in the Kyoto protocol (Ravindranath *et al.* 1997) [30]. Trees act as a sink for CO_2 by fixing carbon during photosynthesis and storing excess carbon as biomass. The net long term CO_2 source/sink dynamics of forests change through time as trees grow, die and decay. The most promising management practices for CO_2 mitigation are reforestation, agroforestry and natural reforestation (Winjum *et al.* 1992; Chaudhari *et al.* 2014; Kumar *et al.* 2018) [36, 7, 23]. As more photosynthesis occurs, more CO_2 is converted into biomass, reducing carbon in the atmosphere and sequestering it in plant tissue above and below ground (Gorte, 2009; IPCC, 2003; Kumar *et al.* 2015) [14, 6, 22] resulting in growth of different parts. Above ground biomass, below ground biomass, dead litter, soil organic matter are the major carbon pools in any ecosystem. Biological carbon sequestration is the process through which agricultural and forestry practices remove CO_2 from the atmosphere and store it in the terrestrial ecosystem for a very long period of time (Mishra *et al.* 2013) [25]. Carbon storage and sequestration schemes seek to consider the contribution of forests to global warming, either by a reduction in forest degradation and deforestation or by reforestation, or by some combination of the two (Mishra *et al.* 2014a and b) [24, 26].

The trees act as major CO_2 sink which captures carbon from the atmosphere and acts as a sink, stores the same in the form of fixed biomass during the growth process. Therefore, growing trees in urban areas can be a potential contributor in reducing the concentration of CO_2 in the atmosphere by its accumulation in the form of biomass (Chavan and Rasal, 2010; Arya *et al.* 2018) [8, 3]. Mainly two terms are generally used for tree planting: reforestation, for planting trees or other activities to establish tree stands (such as assisting natural tree regeneration or preparing sites and sowing tree seeds) on areas recently cleared of forest through timber harvesting or natural disaster; and afforestation, for planting trees on sites that have long been cleared of forests, such as crop, pasture, and brush lands.

The practitioners (farmers) lack options of the mono-cropping system (rice-wheat) before the 1980s in Northern India but Wimco Company along with NABARD develop a strategy of buy back system for Poplar growers and created market in Yamunanagar, Haryana. In India, agroforestry occupies 8.2% (~25.32 Mha) of the total geographical area (Dhyani *et al.* 2013) [9] and its area is expected to increase after the implementation and adoption of National Agroforestry Policy 2014. These systems emerge as an option for crop diversification in north-west India by enhancing productivity, net profitability and mitigating climate change (Chaudhari *et al.* 2014) [7]. However, farmers of other regions of Indo-Gangetic Plains of India lacking awareness and training related to viable species, agronomy practices, market availability and economics. This present review is an attempt to improve our understanding related to carbon sequestration in Poplar based agroforestry systems and strategies to proliferate in other regions of the country.

The significance of agroforestry systems

Agroforestry is the intentional mixing of trees and shrubs into crop and/or animal production systems to create environmental, economic and social benefits. Agroforestry is a useful strategy for soil carbon sequestration for mitigating the impact of climate change under Clean Development Mechanism of the Kyoto Protocol (IPCC 2000, Nair 2007) [16, 17, 27]. The service function of agroforestry are in control of soil erosion, wind breaker, maintenance and improvement of soil fertility, control of weeds and fencing, and carbon sequestration in soil (Gupta *et al.* 2009; Nair *et al.* 2009) [12, 28] and biodiversity conservation (Pandey, 2007) [29]. A range of products including fuel wood, fodder, timber and medicinal products serve to diversify the outputs from agroforestry systems. The third assessment report of the Intergovernmental Panel on Climate Change stressed the importance of agroforestry (particularly on unproductive grasslands and croplands) for carbon sequestration and mitigating climate change (IPCC 2001) [19].

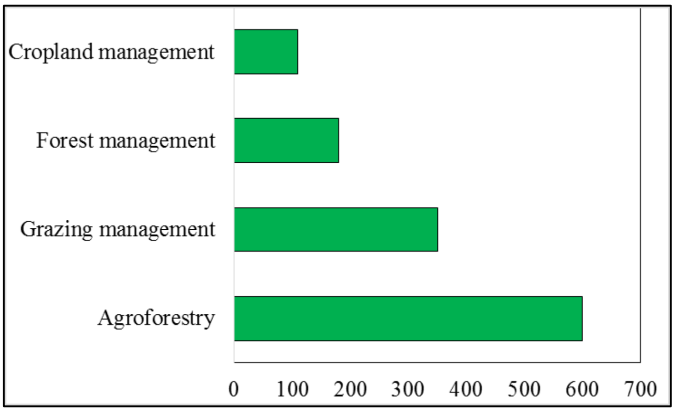

Fig 1: Projections of carbon sequestration in different landuse (IPCC, 2000) [16, 17].

According to projections predicted by IPCC (2000) [16, 17], agroforestry systems showed maximum potential to sequester carbon by 2040, followed by grazing management (Figure 1). Within agroforestry, carbon sequestration potential varies depending on several factors such as climate, soil type, plant species, plantation age, agronomic management and compatibility with crops.

The contribution of Poplar based agroforestry systems in carbon sequestration in India

Agroforestry systems grow substantially in last few decades with its multifaceted benefits. In Northern India, Poplar has been successfully and extensively planted in farmlands in Uttar Pradesh, Haryana and Punjab after 1980. Poplars are fast-growing trees; they salvage nutrients fast due to their shedding of a large number of leaves which decompose easily (Rizvi *et al.* 2011) [31]. Poplar can be grown in rows and on the boundary in the agricultural field.

Table 1: States wise tree cover under different agroforestry system in Northern India

States	Geographical area (sq. km)	Tree cover (sq. km)	% tree cover to the total geographic area
Haryana	44,212	1,333	3.01
Punjab	50,362	1,635	3.25
Uttar Pradesh	240,928	7,082	2.94
Total	335,502	10,050	9.20

Source: Forest Survey of India (FSI) report, 2013

Tree cover in different regions of Northern India is presented in Table 1. As a percentage to a geographical area, the maximum percentage of tree green cover was observed in Punjab followed by Haryana. Total carbon stock in million tonnes in different regions through tree cover in agroforestry is recorded in figure 2. Maximum carbon stock was observed in Uttar Pradesh with 18.48 million tonnes, followed by Punjab with 4.03 million tonnes (Figure 2). Poplar-based boundary and agrisilviculture systems account for 99–304 t ha^{-1} CO_2 assimilation in biomass (above and below) at the rotation period of 7 years in the Saharanpur and Yamunanagar districts of north western India, which is considerable amount of biomass, that helps the farmers in generating income and sustaining productivity (Rizvi *et al.* 2011) [31].

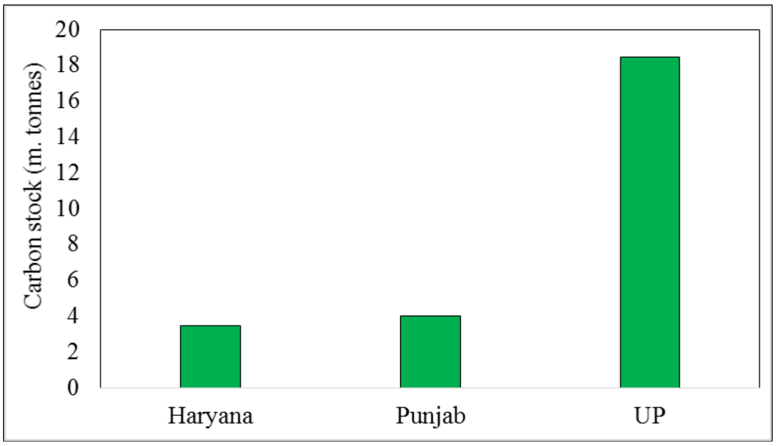

Fig 2: Carbon stock in different states of Northern India (FSI, 2013); Note that data presented for UP consist of overall value not just for the northern region.

Popular based agroforestry system showed promising increment in soil carbon stock up to 0-15 cm soil depth having sandy-loam to loam soil texture at the harvesting age of 6 year Northern India (Table 2). Maximum soil carbon stock exhibited in the popular-wheat intercropping system and also in ≤6 year old plantation. The carbon stock per hectare in soil was calculated by multiplying the values of soil depth (cm), bulk density (g cm^{-3}), and the percentage of SOC content. The carbon stock up to 0-15 cm soil depth in Poplar + wheat + rice/pulse crop is 8.32 Mg ha^{-1} to 17.0 Mg ha^{-1}, whereas, in Poplar, block plantation is 4.19 Mg ha^{-1} to 19.6 Mg ha^{-1} (Table 2). Such variation might be attributed to plantation age, agronomic management and other variables. Soil texture for optimal biomass and carbon stocking in different regions consisting mainly sandy loam soil, whereas, light clay soil in Uttarakhand region not sequestered that much of carbon compared to Haryana and Punjab (Table 2).

Table 2: Soil carbon stock under Poplar based agroforestry systems in Northern India

Location	Cropping system	Year	Bulk density (g cm^{-3})	SOC (%)	SOC stock (Mg ha^{-1})	References
Yamunanagar, Haryana	Popular-wheat	4	1.38	0.82	17.0	Chaudhary *et al.* (2015) [6].
Kurukshetra, Haryana	Popular plantation	6^b	1.09	0.99	16.2	Arora *et al.* (2014) [1].
Gulabgarh, Kurukshetra, Haryana	Popular-wheat	5	1.35	0.21	4.25	Giri *et al.* (2018) [11].
Hissar, Haryana	Popular-wheat	8	0.86^a	0.74	9.55	Sirohi *et al.* (2017) [33].
Yamunanagar, Haryana	Popular plantation	6	0.86^a	0.5	6.45	Kumar *et al.* (2016) [20].
Rupnagar, Punjab	Popular-wheat-Paddy	6^b	1.64	0.65	15.9	Benbi *et al.* (2011)
Balachaur, Punjab	Popular-wheat-pulse crop	4	1.50^a	0.31	6.98	Chauhan *et al.* (2010) [5].
Lodhowal, Ludhiana	Popular-wheat	6	1.50^a	0.23	5.18	Chauhan *et al.* (2014)
Takarla, Punjab	Popular plantation	6^b	1.38	0.43	8.90	Rajwinder and Bhat (2017) [21].
Mukerian, Punjab	Popular plantation	6^b	1.47	0.89	19.6	Rajwinder and Bhat (2017) [21].
Central Punjab, NW, India	Popular-wheat-greengram	6	1.50^a	0.77	15.8	Gupta *et al.* (2009) [12].
Khera Bet and Nurpur, Ludhiana	Popular-wheat-Rice	6	1.53	0.43	9.86	Sharma *et al.* (2015) [34].
Bathinda, Punjab	Popular-pearlmillet-wheat	6	1.50^a	0.37	8.32	Singh *et al.* (2010) [35].
Bagawal, Uttarakhand	Popular-wheat	9	1.32	2.30	45.5	Yadav (2010) [37].
Tarai, Uttarakhand	Popular plantation	11	1.27	2.20	41.9	Arora *et al.* (2014) [1].

Where a was calculated as a mean value from the region; b was assumed as the harvesting age (6 years)

The soil carbon sequestration rate in Haryana (4-8 years), Punjab (4-6 years) and Uttarakhand (9-11 years) was presented in figure 3 indicating that plantation age significantly influences the soil carbon sequestration rate up to 0-15 cm depth due to continuous flow of diverse organic input in terms of litter fall, root debris, root exudates (Figure 3).

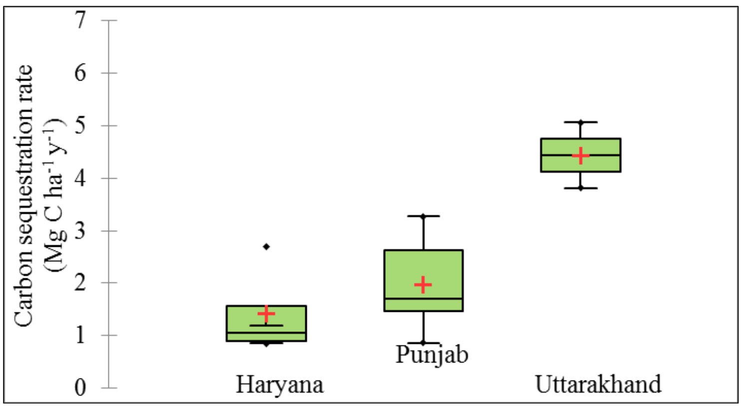

Fig 3: Carbon sequestration rate in different agroforestry systems under different states

Challenges of Poplar based agroforestry system

Its farmer's mind-set and thinking that crop yield reduces due to agroforestry systems. Furthermore, market unavailability induces insecurity coupled with insufficient market price, lack of capital investment are some major identifiable constraints to adoption of agroforestry systems. Above all, the practice of agroforestry is knowledge intensive and requires proper training for optimising the benefits. The harvesting of poplar wood requires 6-8 years of time that also a cause of insecurity among the farmers. Many success stories related to Poplar and Eucalyptus based agroforestry in Northern India might be because of a vast market of timber and wood present in Yamunanagar, Haryana and nearby area. Many educational and awareness campaign should be organized among the farmers to optimise the utilization of this system for their wealth and livelihood in long term with an additional benefit of low cost mitigation strategy for climate change. Thus agroforestry was found to be a sustainable land use system for improving biological productivity and carbon sequestration, these systems can play an important role in climate change mitigation and adaptation.

Conclusion

Poplar based agroforestry system has immense potential in terms of sequestering carbon and other multiple benefits, such systems need to be promoted for achieving sustainable development goals especially in developing countries. Government policies should promote Poplar based agroforestry for ecosystem services and diversifying the farmer's income. Thus, agroforestry was found to be a sustainable land-use system for increasing biological productivity as well as providing environmental services for carbon sequestration. The carbon sequestration in agroforestry increased with age of agroforestry. *Populus deltoides* agro forestry systems help in sequestration of carbon by improving biological productivity and soil productivity.

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