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# Biomass production and carbon stock of poplar agroforestry systems in Yamunanagar and Saharanpur districts of northwestern India

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**Poplar (*Populus deltoides*) has gained considerable importance in agroforestry plantations of western Uttar Pradesh, Uttarakhand, Haryana, Punjab, and Jammu and Kashmir due to its deciduous nature, fast growth, short rotation and high industrial requirement. Poplar-based agroforestry systems are prevalent among farmers of Saharanpur (UP) and Yamunanagar (Haryana) districts of northwestern India. These systems are not only remunerative to the farmers, but also play an important role in the assimilation of atmospheric carbon dioxide in the form of biomass carbon stocks. An assessment of carbon storage vis-à-vis $CO_2$ assimilation by poplar plantations in agroforestry has been made for these two districts. Contribution of poplar plantations to carbon storage was found to be 27–32 t ha$^{-1}$ in boundary system, whereas it was 66–83 t ha$^{-1}$ in agrisilviculture system at a rotation period of 7 years in the two districts. Thus, poplar plantations make important contributions towards atmospheric $CO_2$ assimilation and hence play a significant role in the mitigation of atmospheric accumulation of greenhouse gases.**

**Keywords:** Agroforestry, biomass, carbon stock, carbon dioxide assimilation, poplar.

SEVERAL forms of agroforestry are common throughout the country that contribute to local communities and produce raw material for the industry. Pathak *et al.*[1] have given an account of the prominent agroforestry systems in different agro-climatic regions of India. Agrisilviculture and agrihorticulture systems in western and eastern Himalayan regions; agrihorti-silviculture systems in the upper and trans-Gangetic plains, and agrisilviculture and silvipastoral systems in the southern plateau and hilly regions are some of them.

*Populus deltoides* (poplar) has been successfully incorporated in agroforestry and has been extensively planted in farmlands in Uttar Pradesh (UP), Haryana and Punjab after 1980. Poplars are fast-growing trees; they recycle nutrients fast due to their shedding of a large quantity of leaves which decompose early[2]. Poplar trees are grown in agrisilviculture systems, where an agriculture crop is grown within rows of trees and on the field boundary. The

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prominent agroforestry systems practised by farmers in Saharanpur District, western UP, are agrisilviculture, agrihorticulture and agrihorti-silviculture. Dominant woody perennials that prevail in this district are eucalyptus hybrid, *Eucalyptus tereticornis*, *P. deltoides* (poplar), inter-sparse plantations of *Sizygium cumini* (jamun) and *Dalbergia sissoo* (shisham). *Mangifera indica* (mango) is the dominant fruit tree in agrihorticulture. Wheat, mustard, sugarcane and paddy are the dominant crops grown by the farmers[3].

Kumar *et al.*[4] studied various agroforestry models adopted by farmers of Yamunanagar and Haridwar districts, and found them to be economically viable. The benefit–cost ratio for these models varied from 2.35 to 3.73, indicating them to be highly lucrative. Karnatak[5] reported that in Yamunanagar District, farmers grow sugarcane for the first three years and then take wheat and jowar/potato crops from the fourth year up to sixth year under poplar agroforestry systems. Farmers get good economic returns from this system for a rotation period of 6 years. Farmers of Saharanpur and Yamunanagar districts plant poplar at a spacing of 5 m × 4 m or 4.5 m × 4.5 m in agrisilviculture system and at 2 m spacing in boundary system. In Saharanpur District, a majority of the farmers prefer to plant both eucalyptus and poplar trees on the field boundary.

Most, if not all, agroforestry systems have the potential to sequester carbon for a short period, say 6–8 yrs. With adequate management of trees under agroforestry systems, a significant fraction of the atmospheric C could be captured and stored in plant biomass and in the soils. The impact of agroforestry systems on soil fertility in terms of higher organic matter content, total nitrogen, available phosphorus and potash in the top soil, and improved microbial activities in the system has been reported. On an average, dry litter production of *P. deltoides* was 5 kg $tree^{-1}$ $yr^{-1}$ and soil organic carbon (SOC) was enhanced by 33–83% and available nitrogen by 38.1–68.9% in 0–15 cm soil layer.

The IPCC Third Assessment Report on Climate Change[6] contains an endorsement of the potential for agroforestry to contribute to increase in carbon stocks in agricultural lands: ‘Agroforestry can both sequester carbon and produce a range of economic, environmental, and socioeconomic benefits. For example, trees in agroforestry farms improve soil fertility through control of erosion, maintenance of soil organic matter and physical properties, increase N, extraction of nutrients from deep soil horizons, and promotion of more closed nutrient cycling’. Agroforestry is an ideal option to increase productivity of wastelands, increase tree cover outside the forest and reduce human pressure on forests under different agro-ecological regions, and is then a viable option to prevent and mitigate climate-change effects[7].

In the present communication, an attempt has been made to estimate the carbon stocks in tree biomass of poplar-based agroforestry systems in Yamunanagar and Saharanpur districts of northwestern India. Contribution of these systems in tapping atmospheric $CO_2$ vis-à-vis reducing greenhouse gases (GHG) has also been assessed.

Yamunanagar District lies to the north of Haryana, located at 30°07′N lat. and 77°17′E long., and has a geographical area of 1756 sq. km. The district has subtropical continental monsoon climate and experiences extreme conditions. May and June are the hottest months, and December and January are the coldest. The average annual rainfall of the district is 970.3 mm. The soils in the district are mainly silty loam, loam and light loam. The district encompasses the Shivalik hills and foothill rolling plain in the north and northeast, and flood plain along the Yamuna river in the east and southeast. Tropical dry deciduous forests and subtropical forests are found here. The total cultivated area of the district is about 1264 sq. km, and the cropping pattern is mainly sugarcane–wheat and paddy–wheat. The area under sugarcane, paddy and wheat is 32%, 31% and 37% respectively. Rizvi *et al.*[8] estimated the area under agroforestry systems in Yamunanagar using GIS and remote sensing technologies to be 18.76% in this district.

Saharanpur District is surrounded by Shivalik hills in the north and northeast and Yamuna river forms the boundary in the west, which separates it from Karnal and Yamunanagar districts of Haryana. The district is rectangular in shape and lies between 29°34′45″–30°21′30″N lat. and 77°9′–78°14′45″E long. The geographical area of the district is 3860 sq. km. Saharanpur has a tropical climate because of the proximity of the Himalayan region across this northern district. It is a sub-humid region, especially in the upper Ganga plain area. Saharanpur records an average temperature of about 23.3°C during the course of the year. June is the hottest month, and January is the coldest. Humidity is more in the western area compared to the eastern region of Saharanpur. Agriculture plays an important role in the economy of the district. Roughly 70% of the land is under agricultural use. The important food crops of the region are wheat, rice, jowar, maize and bajra. Sugarcane, oilseeds, cotton and jute are the main commercial crops.

Field survey was conducted in six blocks of Yamunanagar and eleven blocks of Saharanpur districts during 2008–2009. Agroforestry plantations of poplar of different ages were selected from farmers’ fields, and 10–20 trees were randomly selected from each plantation. Data were recorded on spacing, tree height, diameter at breast height (dbh), basal diameter, crown diameter, etc. Tree height was measured using Ravi Altimeter. In the case of poplar, timber biomass and volume per tree were estimated using the equations developed by Rizvi and Khare[9]. Timber production per hectare in age sequence was also estimated by considering the tree densities of 200 trees/ha for boundary plantation and 500 trees/ha for agrisilviculture system.

**Table 1.** Growth and yield of poplar tree in agrisilviculture system (AS) and boundary plantation (BP) in Saharanpur District

| Growth/yield parameters | | Age (years) 3 | 4 | 5 | 6 | 7 |
|---|---|---|---|---|---|---|
| Height (m) | AS | 12.35–15.28 (14.23) | 15.40–18.38 (17.66) | 16.81–19.93 (18.59) | 18.21–21.65 (20.05) | 20.13–24.30 (22.17) |
| | BP | 10.21–12.75 (11.31) | 12.98–15.45 (14.04) | 15.45–19.31 (17.42) | 17.20–21.35 (19.65) | 18.74–23.90 (21.30) |
| Diameter at breast height (cm) | AS | 12.80–17.71 (15.91) | 14.42–19.84 (17.98) | 17.61–22.37 (19.60) | 19.94–24.46 (22.31) | 21.70–27.45 (24.39) |
| | BP | 8.98–12.90 (11.42) | 11.46–17.75 (14.92) | 15.58–20.48 (17.70) | 18.12–24.21 (21.94) | 19.03–26.97 (23.36) |
| Timber weight (kg/tree) | AS | 99.77–147.13 (126.05) | 109.79–188.55 (163.30) | 159.88–225.37 (185.59) | 191.82–256.85 (226.12) | 225.39–325.04 (267.34) |
| | BP | 62.61–95.62 (80.59) | 86.98–148.66 (117.53) | 128.65–199.19 (159.17) | 161.64–278.76 (219.60) | 186.12–315.68 (249.01) |
| Timber volume ($m^3$/tree) | AS | 0.060–0.118 (0.091) | 0.071–0.173 (0.140) | 0.135–0.224 (0.170) | 0.178–0.266 (0.224) | 0.224–0.353 (0.279) |
| | BP | 0.022–0.055 (0.039) | 0.046–0.120 (0.081) | 0.094–0.188 (0.134) | 0.137–0.295 (0.215) | 0.170–0.341 (0.254) |

Mean in parentheses.

Dry stemwood biomass was estimated using the equation: $W = 25.21 - 6.50D + 0.7D^2 - 0.006D^3$, where $D$ is the diameter at breast height (dbh; cm) and $W$ the dry stemwood biomass (kg); developed by Puri[10] for poplar clones grown in agricultural fields. Total dry biomass was computed from stemwood biomass by assuming it to be 51% of the total biomass, because studies suggested that stemwood biomass accounted for 49.7–51.7% of the total biomass. Thereafter, aboveground and belowground biomass have beeen estimated by considering their contribution to the total biomass in the order of 79% and 21% respectively[11,12].

A literature search revealed that carbon concentration in stemwood of poplar was in the range 45–46% (refs 13, 14). Therefore, carbon storage in stemwood of poplar has been computed by fraction of biomass, i.e. $C = 0.455 \times B$, where $C$ is the carbon content and $B$ the dry biomass. The estimated carbon stocks were converted into $CO_2$ equivalents (quantity of $C \times 44/12$) for calculating $CO_2$ assimilation by biomass of poplar trees in agroforestry systems.

Growth data of poplar tree in agrisilviculture system in Saharanpur (Table 1) revealed that mean height and dbh were 14.23 m and 15.91 cm respectively, at the age of 3 years and reached up to 22.17 m and 24.39 cm respectively, at the age of 7 years. Estimated timber biomass and volume of poplar tree at the age of 3 years were 126.05 kg/tree and 0.091 $m^3$/tree respectively, which became 267.34 kg and 0.279 $m^3$ respectively at the age of 7 years. Timber biomass and volume increased by more than two times and three times from age 3 to age 7 years. In the case of boundary system, growth of poplar tree was not as good as that in agrisilviculture system at the initial stage. Mean height and dbh at the age of 3 years were 11.31 m and 11.42 cm respectively, which increased up to 21.30 m and 23.36 cm respectively, at the age of 7 years. Timber biomass and volume were estimated to be 80.59 kg/tree and 0.039 $m^3$/tree respectively, at the age of 3 years, which reached up to 249.01 kg/tree and 0.254 $m^3$/tree respectively, at the age of 7 years. Timber production of poplar tree in boundary system was found to be lower than that in agrisilviculture system.

Growth and biomass of poplar tree in agrisilviculture and boundary systems in Yamunanagar are presented in Table 2. Mean height and dbh of poplar tree were found to be 15.34 m and 15.77 cm respectively, at the age of 3 years, which reached up to 21.96 m and 21.38 cm respectively, at the age of 7 years. Timber biomass and volume were estimated to be 130.22 kg/tree and 0.104 $m^3$/tree respectively, at the age of 3 years. These two values became 226.55 kg/tree and 0.237 $m^3$/tree respectively at the age of 7 years, was found to be less than those for Saharanpur at the same age.

Tree growth of poplar in boundary system in Yamunanagar (Table 2) revealed that tree height ranged from 11.45 to 13.60 m at the age of 3 years and from 20.50 to 24.60 m at the age of 7 years. Dbh ranged from 8.96 to 16.31 cm at the age of 3 years and from 19.49 to 23.31 cm at the age of 7 years. Estimated timber biomass varied from 64.41 to 125.16 kg/tree at 3 years and from 194.64 to 263.96 kg/tree at 7 years. Range of timber volume was 0.024–0.090 $m^3$/tree at 3 years and 0.182–0.275 $m^3$/tree at 7 years.

**Table 2.** Growth and yield of poplar tree in agrisilviculture (AS) system and boundary plantation (BP) in Yamunanagar District

| | | Age (years) | | | | |
|---|---|---|---|---|---|---|
| Growth/yield parameters | | 3 | 4 | 5 | 6 | 7 |
| Height (m) | AS | 14.15–16.90 (15.34) | 15.50–18.75 (17.82) | 16.65–20.15 (18.45) | 18.25–22.30 (19.81) | 19.50–24.65 (21.96) |
| | BP | 11.45–13.60 (12.57) | 14.20–16.52 (15.33) | 17.35–19.10 (18.28) | 20.10–23.25 (21.71) | 20.50–24.60 (22.83) |
| Diameter at breast height (cm) | AS | 13.28–18.79 (15.77) | 14.20–19.49 (17.48) | 16.56–22.86 (18.19) | 16.27–24.14 (19.86) | 19.49–24.96 (21.38) |
| | BP | 8.96–16.31 (13.67) | 11.21–18.66 (15.91) | 16.56–21.11 (19.04) | 18.98–22.04 (20.11) | 19.49–23.31 (21.43) |
| Timber weight (kg/tree) | AS | 108.84–164.51 (130.22) | 117.13–198.24 (159.07) | 149.13–215.13 (168.99) | 153.64–251.15 (195.34) | 192.64–263.96 (226.55) |
| | BP | 64.41–125.16 (101.33) | 89.35–163.24 (131.92) | 149.32–205.15 (177.48) | 174.56–238.46 (216.43) | 194.64–263.96 (229.53) |
| Timber volume ($m^3$/tree) | AS | 0.076–0.150 (0.104) | 0.087–0.197 (0.143) | 0.129–0.221 (0.156) | 0.135–0.271 (0.193) | 0.190–0.288 (0.237) |
| | BP | 0.024–0.090 (0.062) | 0.048–0.139 (0.099) | 0.121–0.196 (0.159) | 0.161–0.241 (0.205) | 0.182–0.275 (0.229) |

Mean in parentheses.

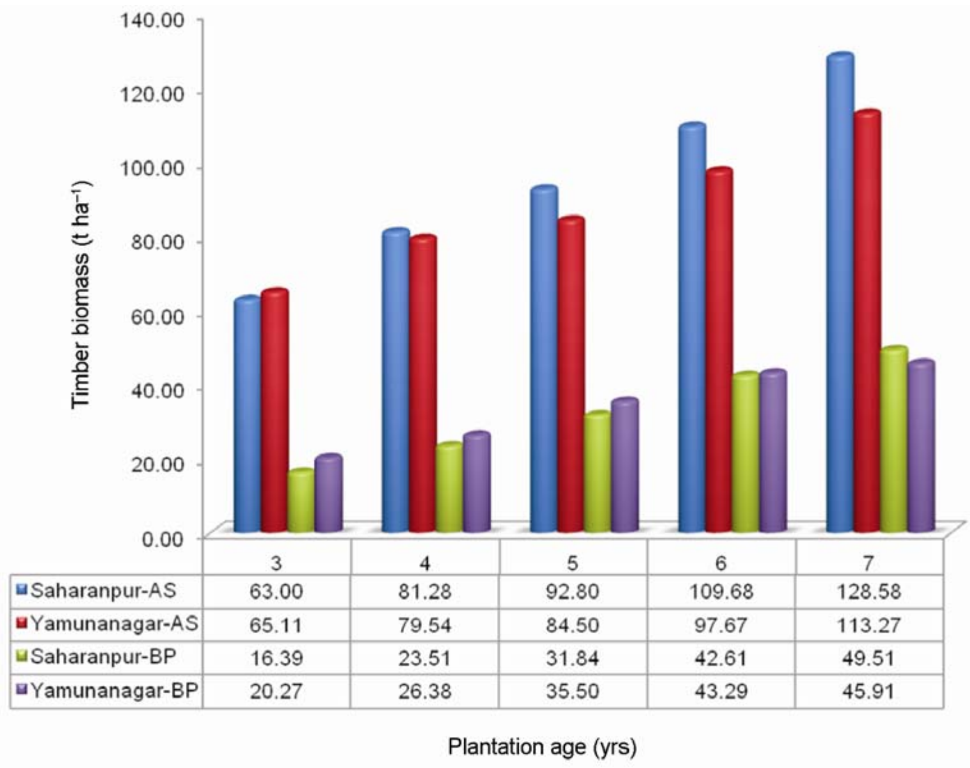


**Figure 1.** Comparison of estimated timber weight in boundary plantation (BP) and agrisilviculture (AS) systems in Saharanpur and Yamunanagar districts.

Timber production per hectare in boundary and agrisilviculture systems in Saharanpur and Yamunanagar districts was also computed and has been compared in Figures 1 and 2. It can be observed that timber production in both agrisilviculture and boundary systems at the rotation period of 7 years were higher in Saharanpur than in Yamunanagar. This is mainly attributed to better growth performance of poplar tree in the former district.

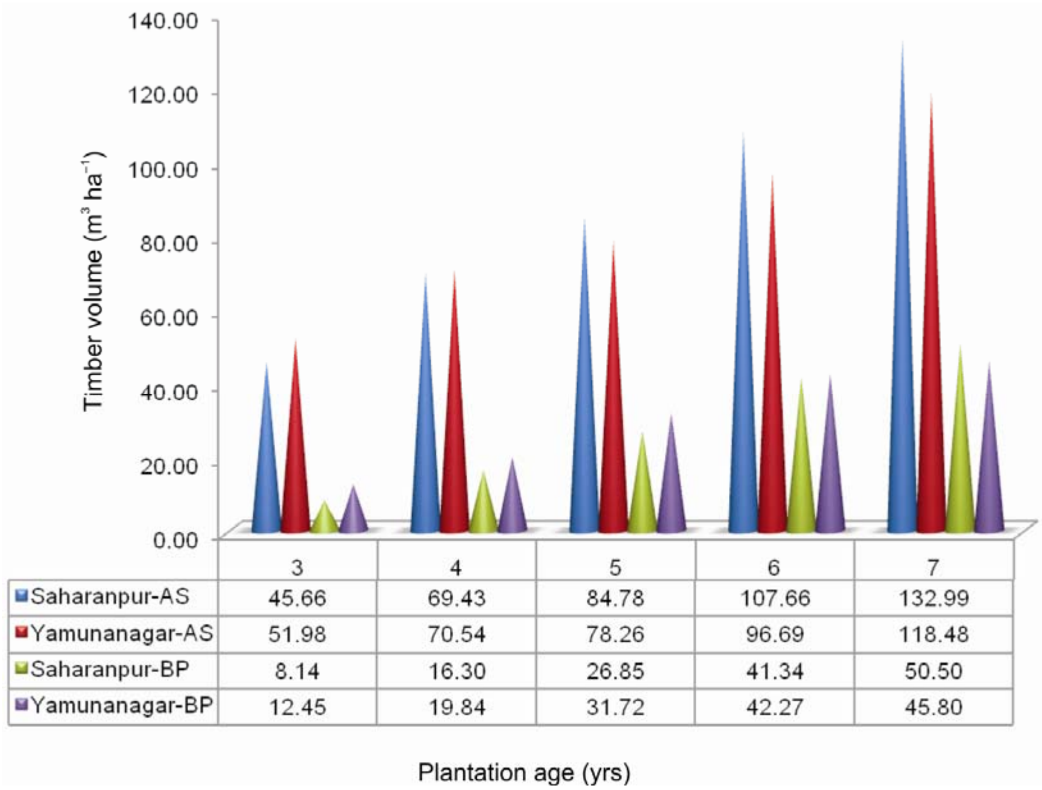


**Figure 2.** Comparison of estimated timber volume in BP and AS systems in Saharanpur and Yamunanagar districts.

Tandon *et al.*[15] estimated bole biomass and aboveground biomass of *P. deltoides* trees planted in agroforestry with a spacing of 5 m × 5 m (400 trees/ha). Bole biomass was 17.42, 37.47 and 47.80 t ha$^{-1}$ at the age of 3, 5 and 7 years respectively. The aboveground biomass was estimated to be 26.91, 52.43 and 65.76 t ha$^{-1}$ for 3, 5 and 7-yr-old plantations respectively. Negi and Tandon[16] studied the biomass production of *P. deltoides* plantations having 917, 500, 489 and 783 trees ha$^{-1}$ for 3, 5, 7 and 9-yr-old tree respectively. The standing bole biomass was in the order of 7.1, 15.3, 44.4 and 83.2 t ha$^{-1}$ respectively. According to Lodhiyal *et al.*[17], total aboveground biomass of *P. deltoides* varied from 67.6 to 149.3 t ha$^{-1}$, of which bole biomass range was 41.3–101.8 t ha$^{-1}$ for 5–9-yr-old plantations having a density of 400 trees/ha. Abovegound and belowground biomass accounted for 79–80.9% and 19.1–21.0% respectively.

Lodhiyal *et al.*[11] studied the dry-matter production in poplar and found that bolewood accounted for 51.7% of total biomass of 8-yr-old plantations. Contribution of aboveground and belowground biomass was estimated to be 79.0% and 21.0% respectively. Swami *et al.*[18] reported that stemwood accounted for 60.4–68.9% to the total biomass, followed by branches 12.3–15% in 6-yr-old poplar clones, viz. G3, G48, D121, S7C1.

Estimated carbon stock as tree biomass in poplar-based agroforestry systems in the two districts is given in Table 3. In Saharanpur District, carbon stock in stemwood, aboveground and belowground biomass was estimated to be 16.30, 25.24 and 6.71 t ha$^{-1}$ respectively at the rotation period of 7 years in the boundary system. Whereas in the case of agrisilviculture system, the estimated carbon stock in stemwood, aboveground and belowground biomass was 42.36, 65.62 and 17.44 t ha$^{-1}$ respectively, for the same rotation period. Total carbon stock as tree biomass in boundary and agrisilviculture systems was estimated to be 31.95 and 83.07 t ha$^{-1}$ respectively, at a rotation period of 7 years.

In Yamunanagar district, carbon stock in stemwood, aboveground and belowground biomass of poplar trees was estimated to be 13.79, 21.35 and 5.68 t ha$^{-1}$ respectively, for a rotation period of 7 years in boundary system. In the case of agrisilviculture system, the values were 33.64, 52.11 and 13.85 t ha$^{-1}$ respectively for the same rotation period. Total carbon stock as tree biomass in boundary and agrisilviculture systems was 27.03 and 65.96 t ha$^{-1}$ respectively, at a rotation age of 7 years. Thus, contribution of poplar trees to carbon storage was 27.03–31.95 t ha$^{-1}$ in boundary system and 65.96–83.07 t ha$^{-1}$ in agrisilviculture system. These values are slightly lower than the recent estimates given by Singh and Lodhiyal[12], and Fang *et al.*[19]. However, this may be due to younger age of the plantation.

Singh and Lodhiyal[12] estimated carbon stock in 8-yr-old *P. deltoides* agroforestry plantation to be 47.856 t ha$^{-1}$ in bolewood and 96.23 t ha$^{-1}$ in total biomass of trees.

**Table 3.** Carbon stock (t C ha$^{-1}$) in poplar-based boundary and agrisilviculture systems in Saharanpur and Yamunanagar Districts

| | Boundary system | | | | Agrisilviculture system | | | |
|---|---|---|---|---|---|---|---|---|
| Age (yrs) | SW | AG | BG | TB | SW | AG | BG | TB |
| Saharanpur District | | | | | | | | |
| 3 | 3.20 | 4.96 | 1.32 | 6.28 | 17.06 | 26.43 | 7.03 | 33.46 |
| 4 | 6.01 | 9.30 | 2.47 | 11.78 | 22.73 | 35.21 | 9.36 | 44.57 |
| 5 | 8.83 | 13.67 | 3.63 | 17.30 | 27.85 | 43.13 | 11.47 | 54.60 |
| 6 | 13.59 | 21.06 | 5.59 | 26.65 | 35.00 | 54.22 | 14.41 | 68.63 |
| 7 | 16.29 | 25.24 | 6.71 | 31.95 | 42.36 | 65.62 | 17.44 | 83.07 |
| Yamunanagar District | | | | | | | | |
| 3 | 4.88 | 7.55 | 2.01 | 9.56 | 16.85 | 26.102 | 6.94 | 33.04 |
| 4 | 6.96 | 10.79 | 2.87 | 13.65 | 21.49 | 33.289 | 8.85 | 42.14 |
| 5 | 10.41 | 16.13 | 4.29 | 20.42 | 26.29 | 40.724 | 10.82 | 51.55 |
| 6 | 12.41 | 19.22 | 5.11 | 24.33 | 29.05 | 45.000 | 11.96 | 56.96 |
| 7 | 13.79 | 21.35 | 5.68 | 27.03 | 33.64 | 52.110 | 13.85 | 65.96 |

SW, Stemwood; AG, Aboveground; BG, Belowground; TB, Total biomass.

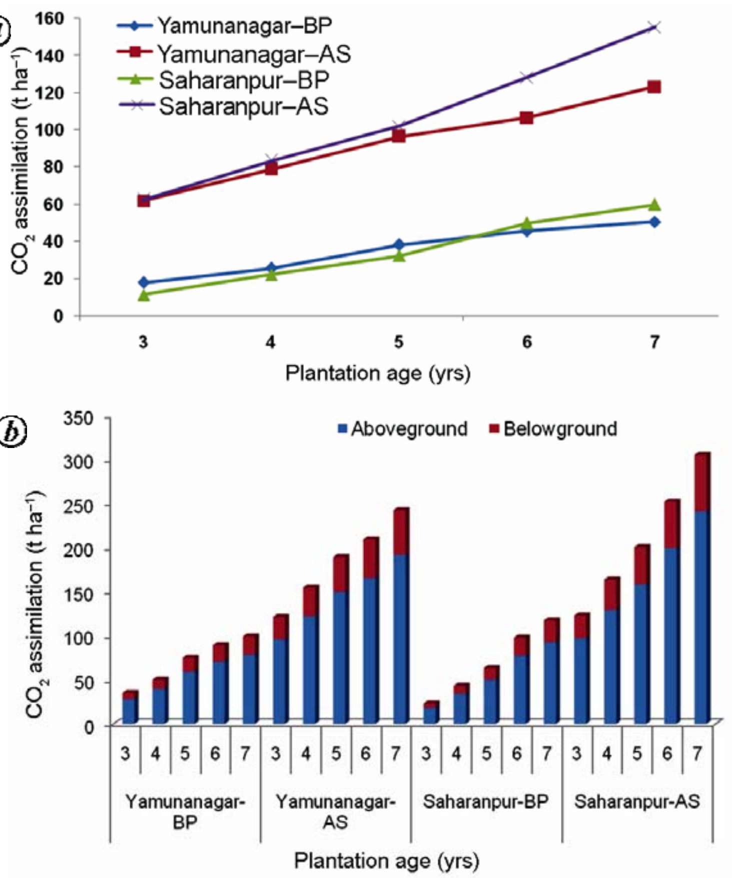


**Figure 3.** Carbon dioxide assimilation by stemwood (***a***), and aboveground and belowground biomass (***b***) of poplar in boundary and agrisilviculture systems in Yamunanagar and Saharanpur districts.

Bolewood contributed maximum to carbon stock, i.e. 49.73%. Fang *et al.*[19] found that total carbon storage in the poplar plantation of 1111 stems ha$^{-1}$ was the highest and about 72.0 t ha$^{-1}$, which was 5.4%, 11.9% and 24.8% higher than that in the plantations of 833, 625 and 500 stems ha$^{-1}$ respectively. The results of the present study are significant as they indicate the standing/total carbon stock of 3.78–11.62 mt C under poplar-based agroforestry in the upper Gangetic region, where 70 million poplar trees are standing with agricultural crops.

$CO_2$ assimilation by different components of poplar tree biomass (stemwood, aboveground, belowground and total) was also computed for different plantation ages (Figure 3). Figure 3 *a* shows that $CO_2$ assimilation by stemwood of poplar tree in boundary plantation for a rotation period of 7 years was 50.55 and 59.75 t $ha^{-1}$ in Yamunanagar and Saharanpur districts respectively. $CO_2$ assimilation by stemwood in agrisilviculture plantation was 123.35 and 155.33 t $ha^{-1}$ in the two districts respectively for the 7 year rotation period.

Figure 3 *b* shows that $CO_2$ assimilation by aboveground biomass of poplar tree in boundary plantation was estimated to be 78.30 and 92.56 t $ha^{-1}$ respectively, at the rotation period of 7 years in Yamunanagar and Saharanpur districts. In the case of agrisilviculture plantation, estimated $CO_2$ assimilation by aboveground biomass was 191.07 and 240.61 t $ha^{-1}$ respectively for the same rotation period in Yamunanagar and Saharanpur districts. Belowground biomass of poplar tree in boundary plantation assimilated $CO_2$ to the tune of 20.81 and 24.60 t $ha^{-1}$ respectively, at the rotation period of 7 years in Yamunanagar and Saharanpur districts. Whereas $CO_2$ assimilation by belowground biomass in case of agrisilviculture plantation was estimated to be 50.79 and 63.96 t $ha^{-1}$ respectively, for the same period in the two districts.

$CO_2$ assimilation by total biomass of poplar tree was in the range 99.11–117.16 t $ha^{-1}$ in boundary plantation and 241.86–304.58 t $ha^{-1}$ in agrisilviculture plantation at the rotation period of 7 years in the two districts (Figure 3 *b*).

Average C storage by agroforestry practices was estimated to be 21–50 t C $ha^{-1}$ in sub-humid and humid regions[20]. At a global scale, agroforestry could store 12–228 t C $ha^{-1}$ under the prevalent climatic and edaphic conditions.

Poplar-based agroforestry plantations in Saharanpur and Yamunanagar districts of northwestern India produce considerable amount of biomass, which helps the farmers in generating income. Poplar-based boundary and agrisilviculture systems account for 99–304 t $ha^{-1}$ $CO_2$ assimilation at the rotation period of 7 years in the two districts. One advantage of these systems is that sequestration does not have to end at wood harvest. C storage can continue well beyond if tree stem or branches are converted into furniture, poles, hardboards, plyboards, etc. Agroforestry trees also improve land cover in agricultural fields, in addition to providing C input (root biomass, litter and pruning) to the soil. Thus, these plantations make important contribution towards carbon stock vis-à-vis atmospheric $CO_2$ assimilation, i.e. tapping of GHGs responsible for global warming. Hence, poplar-based agroforestry systems in these districts play a significant role in mitigation of atmospheric accumulation of GHGs. However, agroforestry alone cannot solve the current climatic problems, but can only be one among a range of strategies.

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