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Performance of poplar (*populus deltoides* bartr.) and its effect on wheat yield under agroforestry system in irrigated agro-ecosystem, India

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ABSTRACT

The quantitative performance of wheat crop under 1-5 year old poplar plantations in irrigated agro-ecosystem was studied to ascertain the biological yield of tree and crop. Results revealed that growth and yield of wheat decreased significantly with the increase in poplar age. The per cent reduction in net grain yield was 17% under one year old poplar plantation, which increased to 52.15% under five year old plantation. The values of micro-meteorological parameters (light intensity and air temperature) were also low under plantations than in open condition and decreased with increase in plantation age. The current and mean annual increments in biomass and carbon storage curves exhibited a sharp increase of up to three years which thereafter increased with decreasing order. The carbon storage in the poplar biomass was estimated to be 34.075t/ha at the age of five years, which can be fixed as the maximum volume production rotation of this species under the prevailing conditions.

Keywords: *Poplar, wheat, agroforestry, productivity, carbon storage.*

INTRODUCTION

The state of Punjab, India with only 1.5% geographical area of the country contributes 55% of the share of wheat and 33% of rice to the central pool. However, intensive cultivation of extensively followed traditional paddy-wheat rotation is creating many complications in the agro-ecosystem of the state as it has resulted in lowering the ground water table, development of compact sub-soil layer and nutrient imbalance, and is thus no longer ecologically sustainable although economically profitable (Aulakh, 2005). The situation is at an alarming stage, which calls for a need to diversify rotation through appropriate and sustainable land use system while maintaining the status quo as well as increasing the production of agricultural crops in the state.

In India, fast growing exotic tree species have been introduced on-farm in order to obtain maximum monetary gains from a given land unit in a short period of time. Poplar (*Populus deltoides* Bartr.), a winter deciduous tree, has proved itself to be the most promising tree in irrigated agro-ecosystems of Punjab and of adjoining states of the country and is being raised either as block plantation or along field boundaries/windbreaks. *Populus deltoides* based agroforestry system is one of the viable alternate land use systems to prevent further degradation, obtain biological production on sustainable basis and ameliorate the environment. The past three decades have witnessed the rapid increase in poplar based agroforestry as an alternate land use practice through out the irrigated agro-ecosystem in Punjab and adjoining states. It is a general practice to combine agricultural crops with poplar plantations. Poplar being deciduous in nature, a winter crop, predominantly wheat, is intercropped throughout rotations but needs the quantification at different ages of poplar plantations. It is probably the first study to report poplar-wheat interaction under different age plantations during the same year at the same site. Earlier studies have been conducted on a plantation for over the years (5-6 years) with variable climatic and management practices (Ralhan *et al*., 1992; Gill *et al.,* 2009), giving variable results.

Growing fast growing trees in association with arable crops will not only improve the sustainability of farming systems, but also diversify farmer's income, provide new products to the wood based industry, meet increasing energy requirements, generate employment and create novel landscapes of high value for the generations in posterity.

In addition, trees on the farm store carbon in different tree components and in the soil underneath. Introduction of trees in agricultural landscape may be a useful tool to lockup the carbon and increase soil carbon status. The carbon storage in the agroforestry system in above/below ground biomass and soil has been expected to be greater than that in a conventional agricultural operation (Paul *et al*., 2002; Sauer *et al*., 2007). Short rotation woody crops can also offset carbon emissions to the atmosphere through fossil fuel displacement (Tolbert *et al*., 2000; Tuskan & Walsh, 2001) Very limited data on enhanced carbon storage in poplar based silvo-arable systems rather than in agricultural systems is available. The present study was an attempt to quantify system productivity along with carbon storage in woody components. However, concerted efforts are required to quantify carbon sequestration potential of short rotation tree species along with agricultural crop in variable combinations and time scale.

MATERIALS and METHODS

Study area:

The study was conducted in the central zone of Punjab (India) at Rajowal, district Ludhiana (30°-54'N latitude and 75°-48'E longitude, 247 m above sea level). The climate in this region is subtropical to tropical with a long dry season from September to early June and a wet season from late June to early September. May and June are the hottest months (maximum temperature rises to 45-46°C), whereas, December and January are the coldest months (lowest January temperature as low as 4.27°C). The experimental site on an average receives 768mm rainfall and a major proportion (about 80%) is received from June to September (rainy season). The textural class of upper layers of the soil (0-15 cm) was characterized as loam, whereas a 15-30 cm layer was 'sandy loam' and beyond that loamy sand. The soil of the experimental site was slightly alkaline, low in organic carbon, low in alkaline $KMnO_4$-extractable N, medium in 0.5N $NaHCO_3$-extractable P and medium in NH_4OAc-extractable K.

The wheat var. PBW-343 was sown during the first week of November keeping a row to row distance of 22.5 cm with a seed rate of 50 kg/acre. One half of the nitrogen (N)and whole of phosphorous (P_2O_5) treatment (62.5 kg N ha^{-1} and 62.5 kg P_2O_5 ha^{-1}) was applied at the time of sowing and remaining N (62.5 kg N ha^{-1}) was applied to wheat crop under all the poplar plantations and open condition after the first irrigation. Wheat crop was estimated in terms of growth and yield parameters (plant height, grains per ear and grain weight and grain/straw yield) by quadrate method at the time of harvest in the month of April. Five quadrates of $1m^2$ were selected per replication running diagonally (east to west) between two rows of poplar. The yield of the produce (grain and straw) was calculated after bringing them to uniform moisture level. The relative decrease in values under poplar plantation compared to that in open condition was calculated for all the parameters.

Poplar plantations of clone G-48 (1-5 years) planted at 4.5m x 4.5m spacing (493 trees per hectare) with north-south row orientation were more than a hectare for all ages. *Populus deltoides* trees were measured for their diameter at breast height (dbh), top height, clear bole height and crown spread by selecting ten trees per replication during the month of January. Tree height and clear bole length was measured with the help of a multimeter. The diameter at breast height (1.37 m above the ground level) was measured with the help of digital calipers. Crown spread was measured through cross-sectional crown diameter with the help of a measuring tape. The component wise biomass was derived by fitting the tree height and dbh values in regression equations developed by Sharma *et al*. (2007). Most of the researchers estimated carbon by assuming carbon content of dry biomass to be a constant 50% by weight (Dury *et al.,* 2002 & Losi *et al*., 2003) but the carbon storage in the present study was computed by multiplying the actual carbon value with the respective dry biomass and number of trees per hectare. The actual carbon content of different tree components was estimated by CHNS analyzer (Vario ELIII, Germany). The light intensity and air temperature were measured regularly with the help of a tube solarimeter and digital thermometer, respectively at the height of 1.25 m from ground level at the experimental sites under each plantation and in the open area. The experimental data recorded on various aspects/ parameters were statistically analyzed using analysis of variance and the results were compared at 95% level of significance on the basis of least square difference (LSD 0.05) values as described by Gomez and Gomez (1984).

RESULTS and DISCUSSION

Crop yield contributing parameters

The yield and yield contributing parameters exhibited significant differences under different age plantations. The performance of crop with respect to growth and yield in open condition was better than that under poplar plantation and the values of all the parameters decreased with increase in age of poplar plantation. Difference in wheat grain and straw yield under poplar plantations to the yield in open condition (control) was statistically significant (Table 1). The maximum grain yield was recorded in controls (52.25q/ha). The yield reduced significantly with the increasing age of poplar plantations. The order of yield reduction with increasing age from 1 to 5 years of poplar plantations was 17, 30.9, 40.72, 47.6 and 52.15%, respectively. The loss of yield, however, was not only due to the growth of trees but also due to the loss of land area to trees. It was only possible to raise crop on 90% of the original area.

There are other numerous reasons for reduction in yield under canopy. The plant number under canopy itself reduced on unit area basis. A reduction of 5 to 28% was noticed in first year to fifth year plantations. Half of the decrease in yield and yield contributing parameters is due to raising plantations (approx. 10%) and lower plant populations under poplar plantations (6-23% under one to five year old poplars), which is due to the reduced germination and development of germinating seedlings. The leaf shedding immediately after the crop sowing affects germination as well as the seedling development initially, which is compounded at the later stage with ultimate reduced yield. Leaf fall acts as a barrier to germination and affects the availability of light and nutrition to developing seedlings, thus their survival as well as tillering is affected. Whereas, the other half of yield reduction is due to the competition between the tree and crop for light, moisture, nutrients, etc. and the modification of micro-environmental conditions (Srinidhi *et al.*, 2007).

Table 1. Performance of wheat under poplar based silvo-arable system and in open condition*

Plantation age (Years)	No. of wheat plants ($1m^2$)	Plant height (cm)	Ear length (cm)	No. of grain per ear	1000 grain weight (g)	Grain moisture (%)	Grain yield (q**/ha)	Straw yield (q**/ha)
1	126.00 (5.57)	95.59 (6.65)	9.28 (9.90)	46.01 (4.54)	47.50 (4.06)	15.33 (-2.20)	43.35 (17.03)	68.50 (12.46)
2	121.13 (9.22)	87.21 (14.83)	8.98 (12.81)	44.89 (6.87)	43.11 (12.93)	15.60 (-4.00)	36.1 (30.91)	57.23 (26.87)
3	116.80 (12.46)	84.19 (17.78)	8.62 (16.31)	36.46 (24.36)	39.68 (19.85)	16.17 (-7.80)	30.98 (40.72)	49.58 (36.64)
4	109.00 (18.31)	80.65 (21.24)	8.23 (20.09)	31.54 (34.56)	37.09 (25.08)	16.90 (-12.67)	27.38 (47.61)	43.58 (44.31)
5	103.00 (22.81)	76.73 (25.07)	7.93 (23.01)	28.60 (40.66)	37.15 (24.96)	17.90 (-19.33)	25.00 (52.15)	40.13 (48.72)
Control	133.43	102.40	10.30	48.20	49.51	15.00	52.25	78.25
CD5%	5.10	1.24	0.67	2.24	2.02	0.52	1.75	1.75

*Values in parentheses are percent decrease over control; **q = quintal (100kg or 0.1ton)

The straw weight was also significantly depressed under poplar plantations and followed the same pattern as grain yield, however, percent reduction was little less than grain yield. The plots outside the poplar canopy (control) had maximum straw yield (78.25 q/ha). It further reduced from 12.46% under first year plantations to 48.72% under five year old plantations. These results are in line with the findings of Sharma *et al.* (2000) and Puri *et al.* (2001) who reported that straw yield under poplar plantations decreased with increase in age of plantation.

Shading always reduces crop growth rate approximately in direct proportion to the canopy size (Wadud *et al*., 2002). Crop growth and yield reduction in association with trees is not uncommon, however, success of agroforestry systems depend on positive component interactions for resource requirements. The reduction in the gross biological yield was due to the reduction in yield contributing factors (plant height, number of grains per ear and 1000-grain weight), which may have been affected by the micro-environmental changes i.e. solar radiation and air temperature under the canopy (Fig.1). Fischer (1985) and McMaster *et al.*(1987) reported that shading period centered at 10-13 days before anthesis had the biggest effect on grain number per ear in wheat. Grabau *et al.* (1990) observed that shade duration, shade intensity and crop developmental stages when shade is imposed had greater impact on grain yields. Since, leaf sprouting in poplar starts with rise in temperature during February, the shading effect during the period of flowering/anthesis (late February-early March) may have resulted in lower grain number and weight. A significant reduction in light intensity and air temperature has been observed under different age poplar plantations (Fig.1), which is inversely related to the canopy size. Nuberg and Mylins (2002) also reported lower 1000-grain weight in sheltered crop (35.6 g) than in exposed crop (40.1 g) because of reduced photosynthetically active radiations. Kocabas *et al*. (1993) indicated that a 20% reduction in radiation throughout the growing season would result in 15% lower yield. However, there are evidences of plant–plant interactions which go well beyond the above mentioned competitions for shared resources of space, leaf shedding, light, nutrients, moisture, etc. (Schenk *et al*., 1999; Callaway, 2002).

Tree growth parameters

Tree growth is influenced by the genetic constitution of the species, site quality and management. The overall growth pattern of poplar generally followed a rising trend with age. All the growth and biomass parameters of different age plantations differed significantly (Table 2) and increased up to the third year and then started declining. The mean tree height increased from 6.64 m (1st year) to 21.80 m (5th year), whereas dbh ranged from 5.83 to 21.38cm. The tree height and diameter growth followed a linear trend and increase was statistically significant in each year over the previous one except dbh for 4th and 5th year. Crown spread exhibited variation with respect to length of lateral branches. It ranged from 8.01 m^2 (1st year) to 56.58 m^2 (5th year). The competition for light by arable crops in agroforestry systems becomes more severe with greater crown spread as the canopy closure depends on the growth of lateral branches. The clear bole as well as crown spread in poplar under agroforestry is however manipulated through pruning to facilitate insulation for the crop.

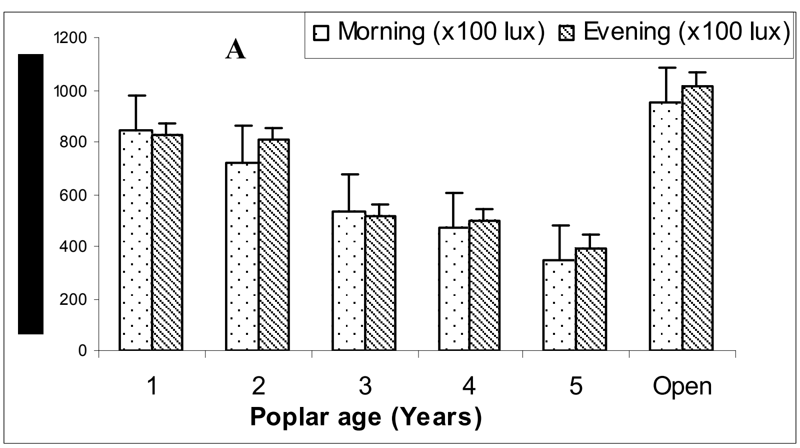


Fig 1. Light intensity (A) and air temperature (B) under poplar and open condition

Table 2. Growth and biomass of poplar trees of different ages

Plantation age (Years)	Tree height (m)	DBH* (cm)	Clear bole (m)	Crown spread (m^2)	Dry biomass (kg/tree)			
					Branch wood	Small wood (lops and tops)	Root	Timber
1	6.64	5.83	2.94	8.01	0.64	1.24	0.08	3.84
2	9.90	11.64	2.94	22.75	3.5	4.51	0.97	21.48
3	18.04	17.51	3.76	37.95	8.37	6.91	5.75	68.21
4	20.04	21.00	4.44	45.33	13.11	9.71	10.92	107.3
5	21.80	21.38	6.52	56.58	13.33	9.38	12.47	115.3
CD5%	0.53	0.58	0.35	3.10	3.96	1.83	2.22	13.36

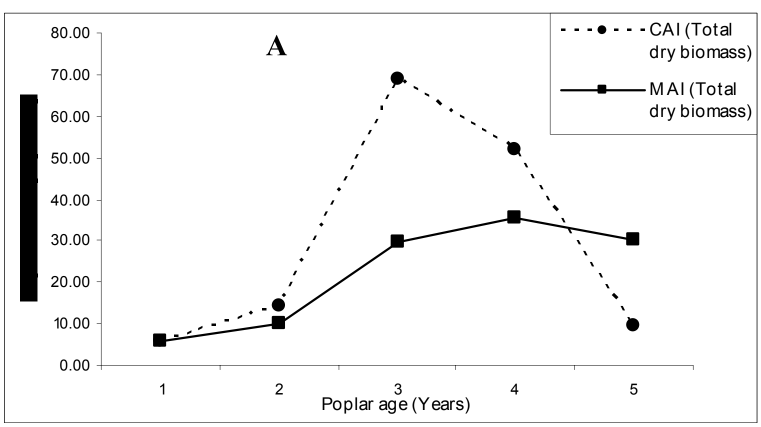
* Diameter at breast height (1.37m above ground level)

Tree carbon storage

The component-wise biomass and carbon content, and the derivatives of tree growth followed the same trend of increase with age (Table 3). The above ground carbon storage was approximately 91% of the total i.e. 34.075t/ha after five years. Incremental carbon potential however depends upon the productivity of the trees. The proportional carbon contribution of all tree components also changed with age. The proportional contribution of branch wood and small wood decreased (11 to 9 and 21 to 6%, respectively), whereas the root and timber share to total tree carbon increased (2 to 9 and 66 to 76%, respectively) from one to five year old plantations. The poplar biomass from the system serves a big pool of carbon in comparison to other forest tree species (Sathaye & Ravindranath, 1998; Jana *et al.*, 2009) if locked for a longer period. The current and mean annual increment of height and diameter depicted the maximum volume production rotation of poplar trees for stem volume/biomass to be four years but the total biomass and carbon content storage in the trees depicted that the silvicultural rotation be extended by an another year (Fig 2). In practice, poplar is harvested at the age of 5-8 years, when it attains a dbh of more than 80-90cm because the market prices are governed by the diameter of the timber (Dhiman 2008).

Table 3. Component-wise carbon storage in poplar trees of different ages

Plantation age (Years)	Carbon storage (t/ha)				
	Branch wood	Small wood	Timber	Root	Total
1	0.148	0.276	0.863	0.020	1.307
2	0.508	0.670	3.274	0.138	4.590
3	1.923	1.553	15.357	1.356	20.189
4	3.007	2.179	24.152	2.573	31.911
5	3.061	2.105	25.971	2.938	34.075
CD5%	0.216	0.354	2.227	0.438	2.864



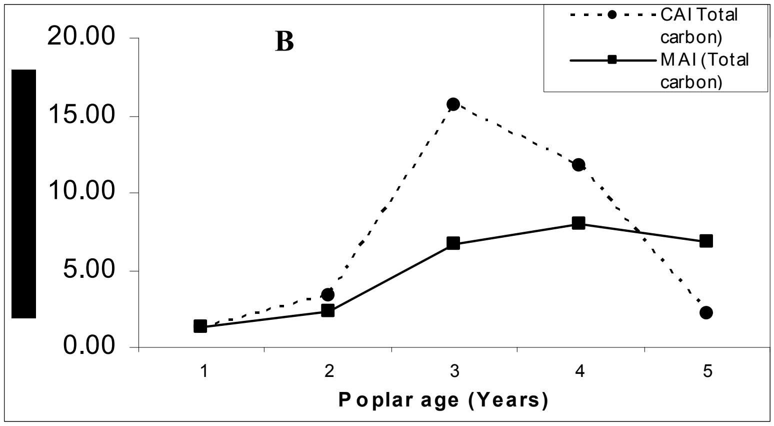


Fig 2. Current and mean annual increment in dry biomass (A) and carbon

The plantations in association with crops are better managed in terms of tending operations, irrigation, fertilization, etc. than sole plantations, therefore they accumulate more biomass and sequester more carbon (Singh and Sharma, 2007). Litter biomass gets mixed in the top layer properly, thus increasing the soil organic carbon buildup, which otherwise is not possible under sole intensive cultivation. Most of the biomass in agriculture is taken away from the system (grain and straw) and only a fractional biomass from stubbles and roots is added.

Results revealed that growth and yield of wheat generally followed a decreasing trend with increasing age of poplar plantation, due to above and below ground competition for light, nutrient, moisture, etc. between trees and crop. The results suggest that though there was reduction in wheat yield, the poplars offer an excellent opportunity for farm diversification. Poplars are leafless during winter months and combine very well with wheat crop. In addition, poplars provide raw materials for small scale industries, generate employment and make a positive contribution to trade balance by reducing import requirements for plywood, paper-pulp and hardwood timber. Such agroforestry practices can give the landowner larger net gains of carbon per unit land area than the traditional sole crop cultivation. The adoption of poplar based agroforestry systems (different crop models) will go a long way in increasing the income levels of the farmers and creating additional employment opportunities in the rural areas. Paddy, another crop commonly grown in rotation with wheat and responsible for methane emission also gets replaced, as poplars cannot tolerate stagnating water. Also as mentioned above, carbon is sequestered in the system but measurement of above ground biomass carbon is best suited for reporting at this stage. Plants fix carbon both in the above and below ground biomass and soils but under the Chicago Climate Exchange program currently allows trading of only above ground biomass contained in live plants (Jindal *et al.,* 2007). Therefore, this intervention in long term can generate additional revenue in terms of carbon credits.

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عملکرد صنوبر (*populus deltoides*) و تأثیر آن بر روی محصول گندم در شرایط آگروفارستری در آگرواکوسیستم آبیاری‌شده، هندوستان

س.ک. چاوهان، م.س. برار، ر. شارما

چکیده

عملکرد کمی محصول گندم زیر کشت 5-1 ساله صنوبر در شرایط اکوسیستم- کشاورزی آبیاری شده به منظور تعیین بازده بیولوژیکی درخت و محصول مورد مطالعه قرار گرفت. نتایج نشان می‌دهد که رشد و محصول گندم بطور معنی داری با افزایش سن در درخت صنوبر، کاهش یافته است. درصد کاهش در محصول دانه خالص زیر کشت یکساله صنوبر 17 ٪ بود که به 52/15 ٪ زیر کشت 5 ساله افزایش یافت. مقادیر پارامترهای هواشناسی مانند (شدت نور و درجه حرارت هوا) در مزارع کمتر از شرایط باز بود و با افزایش سن کاشت، کاهش یافت. افزایش فعلی و میانگین افزایش سالانه بیوماس و منحنی ذخیره کربن کاهش شدیدی را تا سه سال نشان می دهد که پس از این روند کاهشی، افزایش می یابد. تخمین زده شده است که ذخیره کربن در بیوماس صنوبر 5 ساله 34/07 تن در هکتار باشد که می تواند بعنوان حداکثر حجم چرخه تولید این گونه تحت شرایط متداول ثابت باقی بماند.