Status of Intercropping in Poplar Based Agroforestry in India

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Introduction

India has made heavy investment and growth in agricultural sector. There has been tremendous increase in production area and productivity of food grains, which however, has not come without negative impact on ecology, thus, affecting the generations to come. The mankind is facing a huge challenge of meeting its basic needs of food, shelter, etc. on the one hand and conservation of natural resource on the other hand. The use of agrochemicals in agriculture crop production promised food security, but at the cost of polluting air, soil and water resources. The loss of forest land, for human habitation, developmental activities and intensive agriculture resulted in ecological imbalance. Further, the crucial support systems like soil health, air and water quality, groundwater recharge, natural control of pests, etc. are diminishing. Therefore, need has been realized to conserve the natural resources and protect the deteriorating environment so that the much needed growth in agriculture is maintained sustainably.

Agroforestry is a land use system, which contributes pragmatically in all these spheres to materialize the desired goals. The unmatched advantages and implications of this land use system have precipitated the recent concerned interest in agroforestry all around including India. Agroforestry offers not only a sustained productivity, but also its sustainability over the longer period. It buffers against the vagaries of climate through its unique way of amelioration of microclimate and reshapes the agro-ecosystem with enhanced stability and resilience. Global warming and associated problems of climate change have pressed the need for land use system that are more dependable in production and more sustainable in terms of resource conservation to ensure food security (Nair, 1991; Sanchez, 1995; Singh, 1999; Lal, 2004; Srinidhi et al., 2007). The theme of agroforestry centered around sustainability in terms of economics (productivity and profitability), ecology (environmental and resource conservation) and social issues (food security, health and safety) that make it an unparallel land use system (Pandey, 2007). The current interest in agroforestry in India has transformed the land-use system in terms of economic sustainability. Introduction of trees on farm land has not only benefited farmers but generated employment in different sectors; i.e., on-farm (nursery to harvesting of trees), wood based industries, transportation, trading, etc. and provided the wood products at affordable prices.
Farmers have been integrating variety of components; i.e., perennial trees (fruit/timber/fodder/fuel), livestock, apiculture, pisciculture, etc. depending upon their requirements, available resources/ agro-ecological conditions (Hymavathi et al., 2010) and achieving a favourable benefit-cost ratio from multiple components in agroforestry system. Continuing with the traditions, the need of the day is to plan and make intelligent investments in farming and diversify the traditional crop rotations; i.e., adopting management practices that increases biomass production and/or reduce natural resources depletion with increase in soil organic carbon.

Lesser availability of land, low returns from traditional crops and the ever-increasing demand for fuel, fodder, timber, etc. are the reasons that compel farmers to integrate multipurpose tree species on their farmland. Also inter-cropping provides certain environmental benefits and enrich the soil through nutrient pumping from deep profile, return of litter and reduce soil erosion. It is well recognized that agroforestry is one among the few options that can successfully address food security, poverty reduction and environmental protection. It is a key path to prosperity of the farmers and a mean to address the changing climate issue. Current et al. (1995) reviewed 56 agroforestry practices in eight countries and found that a majority was profitable and in 40 per cent of cases, financial returns were at least 25 per cent higher than alternative farming systems.

The adoption of any new system depends upon the user’s awareness, attitude, perception, capacity to take risk and capacity to overcome the constraints. The choice of trees for agroforestry system depends upon the purpose of the farmer whether to grow them for personal or industrial use. Farmers concern is the ultimate profitability from the system and he will adopt an alternative to traditional crop rotations only if it assures higher returns. Sharma and Kumar (2000a); Nouman et al. (2008); Chauhan et al. (2009a) have reported that in spite of good economic realization from poplar based agroforestry systems, farmers fail to adopt the intervention due to low awareness, unfavourable attitude and lack of capacity to overcome constraints; (i.e., land holding, technical know how, financial support, legal, social, etc.).

**Poplar Based Agroforestry**

Agroforestry is emerging as one of the diversification options for farmers in irrigated agro-ecosystem in north-western states in India. It is a refined concept in this region where land units are deliberately so managed under trees and crops, with or without animals, that the system is scientifically sound, practically feasible, economically viable, socially acceptable and ecologically desirable/sustainable. Agroforestry is a resource-conserving, not depleting system compared with the existing land management systems involving few crops like rice, wheat, sugarcane, cotton, etc. which are extremely resource-exhaustive, be it in terms of natural, financial or human resources. The most common crop rotation (rice-wheat) in the irrigated agro-ecosystem in Punjab, Haryana and adjoining states is over exploiting the water resources as a result the water table has been receding at an average rate of over 42 cm per year (Aulakh, 2005).

In the coming years, the tree-based direct needs will exclusively be met from farm forestry or agroforestry, and poplar (*Populus deltoides*) based agroforestry systems, adopted extensively by the farmers on a commercial scale, will play a significant role to meet the economic, social and environmental concerns of the people. Poplar has become the most preferred cash crop in north-western states (Chandra, 1986). Almost any crop (cereals, pulses, vegetables, forage, fruit/vegetable crops, etc.) can be grown with it (Sharma, 1996; Chauhan and Mangat, 2006). It is one of the world’s fastest-growing industrial soft woods, which can be harvested within a reasonably short period of 5-8 yrs. Poplar intercropping is a highly profitable venture as much as poplar growing is a highly lucrative business since market for its products are readily available because of established processing industries in the region (approximately 1,200 units of all category in Punjab, Haryana, Delhi, Uttarakhand, Uttar Pradesh, etc.). The deciduous nature of the tree with slender crown and straight clean stem, permits culture of a variety of seasonal and annual agricultural crops, depending on their age, geometry of planting, season, etc. Poplars being sensitive to waterlogged conditions can check the vicious cycle of wheat-paddy rotation, which is responsible for the lowering of water table and becoming unsustainable for crop production in this region.

For intercropping, the spacing for poplar plantation is generally kept at 5 m x 4 m, which allows mechanical ploughing and other operations without any difficulty. It is planted either on field bunds/along irrigation channels in single rows (boundary planting) or in the field as pure block planting. Kharif crops do not remain profitable during older age (3rd year onwards) of plantations, nevertheless, rabi crops can be grown till the harvesting, as they get sufficient sun light due to complete leaflessness of poplar. Further with the meager area under forests that too of degraded condition coupled with the restriction on felling puts poplar in price driving position. Being a major raw material available to plywood industry of the region, it has sustained demand and market. With intensive management of poplar based
agroforestry models, presently, the farmers are getting better financial returns than from other cropping rotations. It has not only benefited farmers but also helped the wood based industry and employment of various kinds.

The number of agricultural crops (wheat, mustard, turmeric, ginger, colocasia, cabbage, potato, spinach, garlic, etc.) including fruit crops (citrus, guava, mango, etc.) can be profitably raised with poplar (Sharma, 1996). While few crops like sugarcane, sorghum, soybean, mentha, etc., can be grown only during initial two years. The scanty information available, reflects the positive response in some crops and inverse trend with others when raised under varied tree canopies (Gandhi and Joshi, 2002; Chauhan et al., 2005, 2007; Chauhan and Mangat, 2006). Poplar based agroforestry models whether block or boundary are popular in the irrigated agro-ecosystem throughout the north-western states in India, with some region-wise variations in the inter-crops (Dogra et al., 2007; Chandra, 2011).

Trees for industrial use are catching the attention of farmers to grow economically and poplar based agroforestry systems have proven worth in north-western states of India (Newman, 1997; Chauhan and Mangat, 2006; Chandra, 2011). Dhiman (2012) identified intercrops grown in poplar based agroforestry and reported that around 98 per cent of the poplar block plantations grow intercrops and only a few absentee land owners or casual growers avoid intercrops. Success stories of poplar plantations have not only been reported in India but world over (Ranasinghe and Mayhead, 1990; Burgess et al., 2000; Chaudhry et al., 2003; Ball et al., 2005; Gautam and Thapa, 2007; Nouman et al., 2008; Rivest et al., 2009; Christersson, 2010; Henderson and Jose, 2010; Pearson et al., 2010). Around one million people in Siyang county in China are benefiting from poplar plantations. China is presently world’s biggest poplar growing country (8 million ha) followed by France, thus engaging farmers in income generating activities, development of wood based industries, job creation, etc. for economic development of rural as well as urban residents (www.fao.org/news/story/en/item/44518). Silvo-arable Forestry in Europe Project (www.montpellier.inra.fr/safe) has emphasized the importance of the species in different European countries for timber production, renewable energy and scope for economically viable intercropping.

Some of the potential benefits and services provided by poplar based agroforestry technologies that virtually contribute towards achievement of sustainable development and ensure food security in Northwestern states of India without depleting the natural resource base have briefly been reviewed in this paper. Cautiously, the studies reported in the country report (India) of National Poplar Commission, (2008-2012) have been avoided (NPC, 2012). Lot of work on varied aspects of tree-crop interaction (need based and site specific): i.e., productivity, geometry of planting, pruning, nutritional; requirements, socio-economic aspects, above and below- ground interaction, carbon sequestration, etc. have been reported on poplar based systems and it was little difficult to comprehend vast literature and include in this paper, therefore, authors restricted to their own data with supportive latest references.

**Poplar and Wheat Crop Intercropping**

There has been much emphasis to diversify the traditional crop rotation of rice-wheat and more specifically rice, to capture better financial returns and sustainable management of natural resources. On system basis, the trees and crops can generate higher returns on unit area. The silvo-arable agroforestry for Europe has shown that one hectare planted with alternate strips of poplars and wheat, produced the same output as 0.9 ha of wheat and 0.4 ha of poplar (Brelivet, 2006). Though, intercropping is complex but winter crops in poplar based system have been found successful due to the leafless nature of the poplar trees during winters. Tree based mixed systems are reported more productive than monocultures, especially when trees obtain resources that would, otherwise, be unavailable to the crops. However, some adverse effects due to allelopathy have also been reported by various scientists (Kaur and Rao, 1988; Kohli et al., 1997; Singh et al., 1998, 2001; Sharma et al., 2000; Kaushal et al., 2003; Nandal and Dhillon, 2007). Poplar being deciduous in nature is more favourable for winter crops when shading is not a problem and sunlight is available to the under storey crops. By the time poplar develops their foliage, the under storey wheat crops have virtually completed vegetative growth and enter into reproductive phase. Wheat-poplar intercropping has been extensively studied and it started very early (Tiwari, 1968) but focused emphasis was given in eighties and it is continuing till date with variation on different need based aspects of investigation; i.e., geometry, crop varieties/tree clones, fertility, tending, crop quality, productivity, carbon sequestration, economics, etc. Wheat is one of the main crop of poplar growing region and therefore farmers are usually reluctant to leave it. Further, adoption of poplar-wheat model is common because of extensive research on model, food requirements and minimum support price attached with the crop for ensured marketing.

Though, Tiwari (1968) reported drastic reduction in wheat crop yield but Sheikh et al. (1983) and Sharma et al.
(2001) did not observe significant influence of poplar tree competition for resources on wheat crop. Instead, Dhadwal and Narain (1984) observed increase in crop yield with poplar trees on the boundary instead of block plantation. Shading has significant influence on crop productivity. Pendleton and Weibel (1965) reported 37, 70 and 99 per cent decrease in crop yield at 30, 60 and 90 per cent shading, respectively from early spring to harvesting. Increase in distance between the tree rows minimizes the competition for growth resources (Chauhan and Dhiman, 2002). Spacing of 5x5 m is appropriate for crop yield and tree productivity but 5x4m is preferred to accommodate more number of trees for better overall economics with insignificant loss to crop and trees (Gandhi and Dhiman, 2010). There is direct relation of crop and tree productivity with increase in row spacing (Chauhan and Dhiman, 2002), which governs the light for the under storey crops. Pruning of lower branches second year onwards not only benefits the trees but intercultivated crops as well through increased value of large clear bole and penetration of more relative illumination, respectively. There is strong relationship between stem volume/basal area and crown surface area (Mishra and Gupta, 1993). Topping to discourage height growth in favour of diameter growth itself is not successful in poplar because it leads to forking due to apical dominance with no additional benefit in diameter.

Age of poplar (P. deltoides) trees is recorded as the most important factor influencing grain yield of intercropped wheat (Chauhan et al., 2009a). On an average, reduction in grain yield (var. PBW 343) was 20.10 per cent under 1-yr old poplar plantation, which increased to 54 per cent under 4-yr old plantation. While comparing the crop yield under block and boundary planting models, wheat and paddy yield (grain and straw) substantial reduction was recorded in poplar based system than the tree-less plots (Fig. 1). The grain yield of wheat crop was maximum under control plots; i.e., 4.55 t per ha, which was higher than the crop grown under boundary plantation (3.28 t per ha) and lowest at block plantation (2.03 t per ha). During summer season, rice is grown in control and boundary plantation, whereas, no crop is grown in block plantation (poplar does not tolerate stagnating water). The higher grain yield of rice was attained in treeless area (7.42 t per ha) than in the boundary plantation (4.74 t per ha). Similarly, trend was recorded for straw yield in wheat and rice (Chauhan et al., 2012a). The reduction in boundary plantations, however, was variable on different row directions due to more shading effect on south-western rows than north-east rows.

In the changing climatic conditions, varietal evaluation has been taken up for their suitability under tree canopy. Singh et al. (1993) recorded yield reduction in the order of PBW34 (57.71 per cent)> PBW-222 (19.14 per cent)> HD 2329 (15.3 per cent). Pannu and Dhillon (1999) recorded maximum yield of PBW-226 variety of wheat under poplar, while CPAN 3004 performed very poor under the tree canopy. Among the six newly developed wheat varieties, PBW 502 out performed in terms of yield and nutrient uptake. Date of sowing itself influence the crop yield, which is governed by the leaf shedding period (Zomer et al., 2007). First week of November was found more suitable for the sowing of crops because by this time leaf shedding is complete, otherwise, the leaf shedding affect the germination of crop if sown before November (Gill et al., 2009) and germination/growth itself is affected if sown late due to lower temperature during December-January. Singh et al. (1999) and Kumar et al. (2001) observed that fallen leaves are one of the factors that adversely affect the growth of wheat crop. Similarly clonal differences for influence on wheat crop have also been recorded (Puri and Sharma, 2002; Mishra et al., 2006).

Poplar planted in rows in any direction has no significant effect on yields of crops upto 4th year of planting (Calstellono and Prevoster, 1961), but Chauhan et al. (2007) recorded significant directional effect on wheat/paddy crops and north-south row orientation is recommended for more insulation to the under storey crops. Crop yield, declines as the poplar tree age increases (Ralthan et al., 1992). Wheat yield reduction from 10 to 50-60 per cent has been reported by Puri and Bangarwa (1992) and Chauhan et al. (2009a, 2012a). The increase in age of poplar trees is associated with root and canopy development, which causes intense competition for light/nutrients/water, etc. thus reduces crop yield with increase in age than open condition. However, yield reduction is not only due to the competition between inter-cultivated components but also due to allocation of approx. 10 cent land to poplar trees.

Studies have inferred competition between poplar tree and crop roots for soil resources due to
shallow tree roots, thus, leading to yield depression (Puri et al., 1994). A study was conducted to standardize the appropriate planting technology for better plant growth with minimum root competition with inter-cultivated crops. The poplar plants were uprooted after one year of planting to study the rooting behaviour. It was observed (Table 1) that the planting of poplar ETPs in 1m³ pit had better above as well as below ground growth in comparison to traditional auger hole planting (1m deep, 15cm diameter). On physical observation, it was noticed that the polythene sheet did not allow the roots to extend beyond the polythene lining and the root fibrosis was more in comparison to the pits without polythene lining, where roots extended horizontally on the top layer (Fig. 2). But during second year, it was observed that the roots have extended beyond the polythene lining, which indicates that we need to apply polythene lining with different thickness around the plants or create some other barrier to avoid the tree-crop competition. Digging trench around the trees would not be a viable alternative since it would lead to wastage of productive land and hinder crop cultivation as well.

The conservation of natural resources is an area of concern for sustainable productivity and micro-environmental conditions are also modified under the canopy (Fig. 3). It has been observed that air as well as soil temperature is low while the humidity remains higher under tree canopy, which itself has generated the interest for future research for adaptation to changing climate (Rani, 2009; Dhillon et al., 2010, 2011; Rani et al., 2011; Chauhan et al., 2012b). Gupta et al. (2005) recorded no significant depletion of ground water level in poplar growing areas in Uttar Pradesh State. The deciduous phenology of poplar minimizes the evapo-transpiration, which contributes considerably to its low water impact on water use rather improves water productivity with a dormancy period that corresponds with the peak growth of winter crops (Zomer et al., 2007). Earlier Burgess et al. (1996) also reported little competition for moisture between poplar and wheat crop. Rani (2009) recored better crop productivity on raised beds than normal sowing, thus saving significant amount of water.

Poplar litter serves as a potential source of organic inputs where the biogeochemical nutrient cycling is dominated by litter production and decomposition. Singh and Sharma (2007); Gupta and Pandey (2008); Gupta et al. (2009); Chauhan et al. (2010a, b) observed significant increase in organic carbon in older plantations than young

### Table 1. Planting technology for reduced root competition with the intercrops (ICAR, 2010)

<table>
<thead>
<tr>
<th>Pit size</th>
<th>Plant height (m)</th>
<th>Collar girth (cm)</th>
<th>Root spread (m²)</th>
<th>Total root fresh weight (kg)</th>
<th>Lateral root fresh weight (kg)</th>
<th>Root number</th>
<th>Total stem dry weight (kg)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Auger hole 1m (15cm diameter)</td>
<td>5.5</td>
<td>16.7</td>
<td>4.4</td>
<td>1.4</td>
<td>0.70</td>
<td>35.7</td>
<td>1.4</td>
</tr>
<tr>
<td>45cm pit + auger hole 55cm</td>
<td>5.9</td>
<td>18.0</td>
<td>4.5</td>
<td>1.7</td>
<td>0.81</td>
<td>24.8</td>
<td>2.1</td>
</tr>
<tr>
<td>1m³ pit</td>
<td>6.0</td>
<td>24.0</td>
<td>6.7</td>
<td>2.8</td>
<td>1.42</td>
<td>32.3</td>
<td>4.9</td>
</tr>
<tr>
<td>45cm pit with polythene lining +55 cm auger hole</td>
<td>5.0</td>
<td>19.7</td>
<td>5.4</td>
<td>2.5</td>
<td>1.07</td>
<td>38.7</td>
<td>2.5</td>
</tr>
<tr>
<td>1m³ pit with polythene lining</td>
<td>5.8</td>
<td>21.0</td>
<td>6.1</td>
<td>2.2</td>
<td>0.94</td>
<td>31.5</td>
<td>2.6</td>
</tr>
</tbody>
</table>

CD 5% NS NS 1.5 NS NS NS 1.73

Fig. 2. Rooting behavior of poplar roots.
during June-August increases the decomposition rate and their availability to the under storey crops. Das and Chaturvedi (2005) recorded a range of 37.3-146.2 kg N, 5.6-17.9 kg P and 25.0-66.3 kg K per hectare in 3 and 9-yr old plantations, respectively. However, there is also removal of nutrients from the system on harvesting of poplar trees. Tandon et al. (1991) calculated 533, 15, 627, 545 and 229 kg/ha removal of N, P, K, Ca and Mg, respectively. Durai et al. (2009) also recorded removal of substantial amount of nutrients from the system through pruning (46.32 kg N, 6.92 kg P and 19.93 kg K per hectare) and timber harvest (652.8 kg N, 75.84 kg P and 719.84 kg K per hectare). Since, the nutrient removal exceeds annual return, therefore, additional doses of fertilizers are recommended to maintain the soil fertility and sustainability in land productivity.

Poplar and Other Agricultural Crops Intercropping
The diversification of crops under poplar canopy itself is essential to harness higher income than poplar-wheat model. It is important to explore the possibilities of low volume high value crops for the economic betterment. Because, low prices of poplar wood during 2002-2005 in India have not only affected the profits of the intercropping system but confidence as well, thus, forcing the farmers to wait for additional years to harvest/go for distress felling, or look for alternative options. Therefore, crops other than wheat have equally been advocated excepting rice to ensure regular/enhanced income and indirect

ones. Micro as well as macro-nutrients also increase under plantations than intensive crop cultivated area, Fig. 4 shows substantial increase in nutrients on the top layer (Sharma et al., 1998; Dhillon et al., 2012). Poplar leaves decompose fully in 20 and 17 months in surface and subsurface layer, respectively (Kaushal et al., 2005). The higher calcium concentration in poplar leaf litter is one reason for slow decomposition rate. The release of nutrients from decomposition of poplar litter during winter months is quite less but increase of ambient temperature and moisture
benefit to the poplar trees for nutrients, water, weeds control, root aeration, etc. As mentioned earlier, usually crops like sugarcane, cereals, pulses, oilseed, vegetable, fodder, fruit crops, etc. are intercropped with poplar. Chaturevdi (1983); Mathur and Sharma (1983a, b); Jones and Lal (1989); Singh et al. (1990) highlighted the cultivation of diverse crops under poplar by the farmers though at that stage much research inputs on different crops were not available and farmers have been raising traditional crops as per their suitability, which became the basis for further refinement. Due to deciduous nature of the tree, winter crops are grown through out the rotation period but third year onwards during summer; only fodder/leafy/rhizomatous crops are grown. Poplar though does not tolerate stagnating water, therefore is an option to replace rice cultivation. Still the farmers are reluctant to leave rice cultivation and rice can be cultivated with refined cultivation (direct seeded rice) and planting technology (bund planting-boundary/block). As diversification option, Chauhan (2000); Raj et al. (2010) reported very successful cultivation of lemon grass under poplar. Chandra (2001) recorded 27.5t per ha and 15t per ha yields of lettuce and beet root, respectively under poplar. Pitcholi and Tagetes also yielded sizable quantities of oil per unit area under young poplar trees. Gandhi and Joshi (2002) earned Rs 0.4 million from the inter-cultivation of strawberry per annum. Gill et al. (2008) observed substantial reduction in Mentha arvensis (64.9 per cent), M. spicata (65 per cent), coriander (26.7 per cent) but reduction in other medicinal and aromatic crops (fennel, Tagetes, lemongrass, dillseed, turmeric and fenugreek) was not substantial. Dhiman and Gandhi (2010) recorded significantly comparable yield of G50 variety of garlic under poplar than open conditions. Similar observations have been presented in Fig. 5 (ICAR, 2010).

The influence on crop have been due to the ecological interaction of both the integrating components, which could be positive or negative. Tree canopy modifies the microclimate and influences the physiological processes of understorey crops. Under tree canopy, the photosynthetic active radiations (PAR) and temperature decreases while humidity increases (Chauhan and Dhiman, 2007; Rani et al., 2011; Chauhan et al., 2012a). PAR under the canopy is crucial in producing grains, however, some rhizomatous crops; i.e., turmeric (Curcuma domestica) and colocasia (Colocasia esculenta) have been found more suitable under tree canopy (Lal, 1991; Jaswal et al., 1993; Dhillon et al., 2009; Pant et al., 2010; Chauhan et al., 2011a, 2012c). These crops have successfully been grown and adopted by the farmers. To minimize resource competition and improve physiological processes of crops, such as turmeric, colocasia, ginger, etc. canopy management is essential to ensure better yield under poplar-based agri-silvicultural system.

In turmeric and colocasia, photosynthesis rate under poplar canopy was observed to be maximum during noon, whereas, the rate of photosynthesis in the open was maximum at 9:00AM. Under the canopy, the photosynthesis rate was proportional to available PAR (Table 2). The same was not observed in open as the minimum stomatal conductance was observed during noon (Dhillon et al., 2009; Chauhan et al., 2011a), which means that photosynthesis occurs more during noon than morning and evening under tree canopy. However, the yield under the canopy, though reduced but was not drastic. Yield was proportionately related to micro-environmental changes in light, temperature, humidity, etc. under canopy (ICAR, 2010).

Fruit trees (mango, citrus, litchi, ber, pear, guava, etc.) based agroforestry models are also becoming popular, as the forest tree component will be harvested by the time fruit trees start commercial bearing. There was not much change in fruit development under canopy than open condition (Fig.6), such behaviour was observed in pear and plum as well (ICAR, 2010). It has caught the attention of the farmers not only in Punjab, but also in other adjoining states of Haryana, lower areas of Himachal and terai area of Uttarakhand. Some progressive farmers have earned handsome income through the adoption of horti-silvicultural interventions. The economics of such systems is better than the traditional crops in agroforestry (cereal/pulses/oilseed based agroforestry models). Flower seed production during winter months have been found quite remunerative (Chauhan et al., 2010c; Rani et al., 2011). Additionally, some complex models including apiculture and pisciculture components have also been advocated and practically adopted as well to enhance the financial gains.
Performance of Poplar and Biomass/Volume Estimation

Intercropping of agricultural crops with poplar generally has no adverse effect on tree growth rather intercropping enhances tree growth. Poplar plantations associated with agricultural crops show better productivity and economics than the pure plantations (Table 3). Dalal and Trigotra (1983); Mathur and Sharma (1983a); Singh et al. (1988); Jha and Gupta (1991); Ranasinghe and Mayhead (1990); Chaturvedi (1992); Chaudhry et al. (2003); Verma (2008) observed that there was high production of wood in poplar when cultivated with

<table>
<thead>
<tr>
<th>Time</th>
<th>PAR (μmol m⁻² s⁻¹)</th>
<th>Photosynthesis rate (μmol m⁻² s⁻¹)</th>
<th>Transpiration rate (mmol m⁻² s⁻¹)</th>
<th>Stomatal conductance (mmol m⁻² s⁻¹)</th>
<th>Temp. air (°C)</th>
<th>Temp. leaf (°C)</th>
<th>Internal CO₂ (ppm)</th>
</tr>
</thead>
<tbody>
<tr>
<td>9AM</td>
<td>240.27</td>
<td>3.30</td>
<td>0.91</td>
<td>112.92</td>
<td>31.10</td>
<td>32.00</td>
<td>373.23</td>
</tr>
<tr>
<td>12 Noon</td>
<td>487.06</td>
<td>5.20</td>
<td>2.71</td>
<td>239.16</td>
<td>33.20</td>
<td>35.17</td>
<td>321.27</td>
</tr>
<tr>
<td>4PM</td>
<td>119.40</td>
<td>2.02</td>
<td>1.54</td>
<td>149.48</td>
<td>32.27</td>
<td>33.00</td>
<td>404.77</td>
</tr>
</tbody>
</table>

**Turmeric without canopy**

<table>
<thead>
<tr>
<th>Time</th>
<th>PAR (μmol m⁻² s⁻¹)</th>
<th>Photosynthesis rate (μmol m⁻² s⁻¹)</th>
<th>Transpiration rate (mmol m⁻² s⁻¹)</th>
<th>Stomatal conductance (mmol m⁻² s⁻¹)</th>
<th>Temp. air (°C)</th>
<th>Temp. leaf (°C)</th>
<th>Internal CO₂ (ppm)</th>
</tr>
</thead>
<tbody>
<tr>
<td>9AM</td>
<td>648.38</td>
<td>11.19</td>
<td>1.19</td>
<td>154.21</td>
<td>36.42</td>
<td>39.76</td>
<td>264.90</td>
</tr>
<tr>
<td>12 Noon</td>
<td>1005.77</td>
<td>3.69</td>
<td>3.69</td>
<td>220.25</td>
<td>34.70</td>
<td>39.40</td>
<td>313.67</td>
</tr>
<tr>
<td>4PM</td>
<td>554.63</td>
<td>1.61</td>
<td>1.69</td>
<td>27.71</td>
<td>38.57</td>
<td>44.60</td>
<td>372.13</td>
</tr>
</tbody>
</table>

**Colocasia under canopy**

<table>
<thead>
<tr>
<th>Time</th>
<th>PAR (μmol m⁻² s⁻¹)</th>
<th>Photosynthesis rate (μmol m⁻² s⁻¹)</th>
<th>Transpiration rate (mmol m⁻² s⁻¹)</th>
<th>Stomatal conductance (mmol m⁻² s⁻¹)</th>
<th>Temp. air (°C)</th>
<th>Temp. leaf (°C)</th>
<th>Internal CO₂ (ppm)</th>
</tr>
</thead>
<tbody>
<tr>
<td>9AM</td>
<td>276.78</td>
<td>0.75</td>
<td>0.53</td>
<td>156.87</td>
<td>31.30</td>
<td>32.18</td>
<td>374.85</td>
</tr>
<tr>
<td>12 Noon</td>
<td>529.34</td>
<td>2.12</td>
<td>2.73</td>
<td>277.14</td>
<td>35.16</td>
<td>36.96</td>
<td>368.03</td>
</tr>
<tr>
<td>4PM</td>
<td>125.83</td>
<td>1.61</td>
<td>1.04</td>
<td>124.03</td>
<td>33.00</td>
<td>35.75</td>
<td>335.70</td>
</tr>
</tbody>
</table>

**Colocasia without canopy**

<table>
<thead>
<tr>
<th>Time</th>
<th>PAR (μmol m⁻² s⁻¹)</th>
<th>Photosynthesis rate (μmol m⁻² s⁻¹)</th>
<th>Transpiration rate (mmol m⁻² s⁻¹)</th>
<th>Stomatal conductance (mmol m⁻² s⁻¹)</th>
<th>Temp. air (°C)</th>
<th>Temp. leaf (°C)</th>
<th>Internal CO₂ (ppm)</th>
</tr>
</thead>
<tbody>
<tr>
<td>9AM</td>
<td>676.20</td>
<td>12.82</td>
<td>3.52</td>
<td>161.27</td>
<td>34.23</td>
<td>38.63</td>
<td>341.97</td>
</tr>
<tr>
<td>12 Noon</td>
<td>1110.80</td>
<td>5.12</td>
<td>4.26</td>
<td>82.27</td>
<td>39.57</td>
<td>43.67</td>
<td>190.33</td>
</tr>
<tr>
<td>4PM</td>
<td>538.13</td>
<td>9.44</td>
<td>2.80</td>
<td>181.88</td>
<td>35.43</td>
<td>38.60</td>
<td>374.07</td>
</tr>
</tbody>
</table>

Table 2. Diurnal variation in eco-physiological parameters of turmeric and colocasia crops (Dhillon et al., 2009; Chauhan et al., 2011a)
seasonal agricultural crops due to the benefit drawn by the poplar plantations from various agricultural inputs like fertilizers, irrigation and proper management of soil. Dickman and Stuart (1983) observed that poplar trees were benefited from the intensive site preparation and fertilization required to grow agricultural crops and, in their turn, provide some protection for seasonal crops. Trees grown under forest conditions could not receive proper tillage and manurial requirements, thereby, resulting in poor performance. Furthermore, trees planted in and around the edges of fields were regularly ploughed and planted with agricultural crops and hence develop vigorous roots, attain more height, diameter and timber. The higher returns in poplar with intercropping are mainly due to higher productivity of poplar than without intercropping (Dhillon et al., 2001, Chauhan and Mahey, 2008). Better tree growth is recorded at wider spacing than 20m² per tree recommended space (Chauhan et al. 2008; Gandhi and Dhiman, 2010) but Khan and Chaudhry (2007); Chauhan et al. (2010a, b, 2011b) reported more biomass on unit area basis at lower spacing than recommended one though per tree biomass was less. However, Burgess et al. (2004) recorded adverse effect on tree growth by the arable treatments due to competition for water/nutrients and damage to the trees during cultivation.

Poplar grows rapidly during initial three to four years and any stress during this period is difficult to cover up. Poplar shows marked effect of irrigation and intercropping. The growth of poplar in different regions presented in Table 4 was found almost the same over the rotation period in all the different regions excepting in semi-arid region (Dogra et al., 2007). The increment in height as well as DBH starts declining third year onwards. Chauhan et al. (2012a) reported increase in biomass MAI up to 4-4.5 yrs and, thereafter, it decreased (Fig. 7), which is the suitable time for its harvesting. Biomass distribution in different tree components at different ages has been presented in Table 5 to workout economics and carbon sequestration potential of the species.

Poplar wood is sold on fresh weight basis and therefore, it is important to know the standing fresh weight of the trees/stands to ascertain their market value. Number of volume/biomass estimating tables have recently been developed (Singh and Upadhyay, 2001; Rizvi and Khare, 2006; Zabek and Prescott, 2006; Gautam and Thapa, 2007; Sharma et al., 2007; Rizvi et al., 2008a, b, 2010; Dhillon et al., 2011; Ajit et al., 2011) but their area of applicability and the range of trees dimensions are limited thus creating problem in assessing periodic economic values as well as carbon sequestration potential. Since, the clonal differences are evident in different growth and quality parameters (Chauhan et al., 2008; Pal et al., 2009; Pande,

---

### Table 3. Growth and biomass of three-year old poplar under agroforestry and sole plantation

<table>
<thead>
<tr>
<th>Environments</th>
<th>Tree height (m)</th>
<th>DBH (cm)</th>
<th>Crown diameter (m)</th>
<th>Crown height (m)</th>
<th>Fresh timber weight (kg/tree)</th>
<th>Total fresh biomass (kg/tree)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Agroforestry plantation</td>
<td>15.7</td>
<td>16.1</td>
<td>4.1</td>
<td>9.1</td>
<td>80.1</td>
<td>178.4</td>
</tr>
<tr>
<td>Sole irrigated poplar plantation</td>
<td>13.5</td>
<td>14.7</td>
<td>3.8</td>
<td>7.7</td>
<td>73.3</td>
<td>163.3</td>
</tr>
</tbody>
</table>

### Table 4. Poplar growth in different regions in Punjab (Dogra et al., 2007)

<table>
<thead>
<tr>
<th>Tree age (yrs)</th>
<th>Ludhiana (flood plain-bet area)</th>
<th>SBS Nagar (Shiwalik foothills-irrigated)</th>
<th>Amritsar (North central)</th>
<th>Bathinda (semi-arid)</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>Height (m)</td>
<td>DBH (cm)</td>
<td>Height (m)</td>
<td>DBH (cm)</td>
</tr>
<tr>
<td>1</td>
<td>6.64</td>
<td>5.83</td>
<td>4.93</td>
<td>5.56</td>
</tr>
<tr>
<td>3</td>
<td>18.04</td>
<td>17.51</td>
<td>15.44</td>
<td>14.37</td>
</tr>
<tr>
<td>4</td>
<td>20.04</td>
<td>21.00</td>
<td>18.12</td>
<td>18.26</td>
</tr>
<tr>
<td>5</td>
<td>21.80</td>
<td>21.37</td>
<td>20.30</td>
<td>19.20</td>
</tr>
<tr>
<td>6</td>
<td>21.98</td>
<td>22.00</td>
<td>22.58</td>
<td>21.75</td>
</tr>
</tbody>
</table>

---

Fig. 7. Current and mean annual increment in dry biomass in poplar trees of different ages (Chauhan et al., 2012a).
intercropping, horti-silvicultural system, etc.), which allow full time tree growth where the wood component represents an important part of the total biomass. However, the cost of carbon sequestered through agroforestry appears to be much lower than other CO$_2$ mitigation options.

The area under the poplar is increasing every year because of huge demand for its wood from industry. Dhiman (2009); Singh and Lodhiyal (2009); Rizvi et al. (2010); Yadav (2010); Zang et al. (2010); Sharma and Sharma (2011); Benbi et al. (2012) also suggested great potential of poplar based intercropping systems in reducing the atmospheric CO$_2$ concentration compared to sole cropping systems. However, data is insufficient, and an understanding of plant/climate relationships is essentially required to guide the future policies. Some studies have been conducted to explore carbon sequestration potential in poplar-wheat based system. Total CO$_2$ assimilation by the biomass in the poplar-wheat based agroforestry system and mono-cropping of poplar and wheat was estimated at 28.6, 17.2 and 17.8 t per ha per yr (Fig. 8). Therefore, even when only the accumulation of biomass carbon is considered, an agri-silvicultural system is very efficient in terms of carbon sequestration (Chauhan and Chauhan, 2009). However, these figures hold true if harvested products are transformed into durable products. Litter (leaves, branches and bark) and roots are added and

Table 5. Growth and biomass partitioning of poplar trees of different ages

<table>
<thead>
<tr>
<th>Tree age (yrs)</th>
<th>Tree height (m)</th>
<th>DBH (cm)</th>
<th>Clear bole (m)</th>
<th>Crown spread (m$^2$)</th>
<th>Timber (kg/tree)</th>
<th>Branch wood (kg/tree)</th>
<th>Small wood (kg/tree)</th>
<th>Lateral roots (kg/tree)</th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td>6.6</td>
<td>5.8</td>
<td>2.9</td>
<td>8.0</td>
<td>3.8</td>
<td>0.6</td>
<td>1.2</td>
<td>0.1</td>
</tr>
<tr>
<td>2</td>
<td>9.9</td>
<td>11.6</td>
<td>2.9</td>
<td>22.8</td>
<td>21.5</td>
<td>3.5</td>
<td>4.5</td>
<td>1.0</td>
</tr>
<tr>
<td>3</td>
<td>18.0</td>
<td>17.5</td>
<td>3.8</td>
<td>38.0</td>
<td>68.2</td>
<td>8.4</td>
<td>6.9</td>
<td>5.8</td>
</tr>
<tr>
<td>4</td>
<td>20.0</td>
<td>21.0</td>
<td>4.4</td>
<td>45.3</td>
<td>107.3</td>
<td>13.1</td>
<td>9.7</td>
<td>16.9</td>
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<tr>
<td>5</td>
<td>21.8</td>
<td>21.4</td>
<td>6.5</td>
<td>56.6</td>
<td>115.3</td>
<td>13.3</td>
<td>9.4</td>
<td>12.5</td>
</tr>
<tr>
<td>CD 5%</td>
<td>0.5</td>
<td>0.6</td>
<td>0.4</td>
<td>3.1</td>
<td>13.4</td>
<td>4.0</td>
<td>1.8</td>
<td>2.2</td>
</tr>
</tbody>
</table>

The practice of agroforestry is not only the way for addressing poverty, hunger, malnutrition, etc. but also the deteriorating environment. Fast growing trees including poplars have an important role for capturing atmospheric carbon dioxide to ameliorate environment. The emerging carbon market may provide a new viable option for land owners provided that carbon prices are high enough to make growing trees a worthwhile investment than existing land uses and the procedures, for trading of carbon sequestered in trees on small farms in fragmented holdings, are simplified for easy documentation and trade.

Several studies have shown that the inclusion of trees in the agricultural landscapes often improves the productivity of systems while providing opportunities to create carbon sinks (Schroeder, 1994; Pandey, 2002; Montagnini and Nair, 2004; Chauhan et al., 2007; Newaj and Dhyani, 2008; Jose, 2009; Schoeneberger, 2009; Nair et al., 2010; Sharma and Sharma, 2011). The amount of carbon sequestered largely depends on the agroforestry put in places, the structure and function, which to a great extent are determined by environmental and socio-economic factors. The carbon sequestration potential for agroforestry practices is more variable, depending on the planting density, production objective, components in system, productivity, etc. Actually, the carbon storage in plant biomass is better feasible in the perennial agroforestry systems (perennial-crop combinations, agroforestry, windbreaks, hedgerow intercropping, horti-silvicultural system, etc.), which allow full time tree growth where the wood component represents an important part of the total biomass. However, the cost of carbon sequestered through agroforestry appears to be much lower than other CO$_2$ mitigation options.

The area under the poplar is increasing every year because of huge demand for its wood from industry. Dhiman (2009); Singh and Lodhiyal (2009); Rizvi et al. (2010); Yadav (2010); Zang et al. (2010); Sharma and Sharma (2011); Benbi et al. (2012) also suggested great potential of poplar based intercropping systems in reducing the atmospheric CO$_2$ concentration compared to sole cropping systems. However, data is insufficient, and an understanding of plant/climate relationships is essentially required to guide the future policies. Some studies have been conducted to explore carbon sequestration potential in poplar-wheat based system. Total CO$_2$ assimilation by the biomass in the poplar-wheat based agroforestry system and mono-cropping of poplar and wheat was estimated at 28.6, 17.2 and 17.8 t per ha per yr, respectively (Fig. 8). Therefore, even when only the accumulation of biomass carbon is considered, an agri-silvicultural system is very efficient in terms of carbon sequestration (Chauhan and Chauhan, 2009). However, these figures hold true if harvested products are transformed into durable products. Litter (leaves, branches and bark) and roots are added and

![Fig. 8. Total CO$_2$ assimilation (t ha$^{-1}$) by poplar-wheat (above- and below-ground biomass) in agroforestry system and sole wheat cultivation (Chauhan and Chauhan, 2009).]
allowed to decompose in the soil to sequester carbon. Gera et al. (2006, 2011) reported 66 and 37 t per ha carbon sequestration potential (2.20 and 1.37t C per ha per yr, respectively) under poplar block and poplar boundary plantations, respectively. Chauhan et al. (2010a) after seven years of poplar growth, estimated timber carbon content of 23.5t per ha, whereas, carbon content of the roots, leaves, and bark was 23.9t per ha and branches 15.01t per ha. Hence, total biomass carbon storage after seven years was equivalent to 62.48t per ha (8.92t per ha per yr). The combined contribution of poplar and wheat was substantially high within the intercropping system. This may be due to the additional carbon pool in the trees and the increased soil carbon pool resulting from litter fall and fine root turnover. The high carbon storage may also be due to the increased growth and assimilation rates of intercropped components as compared to monocropping systems. Moreover, poplar timber locks up carbon in its wood products for longer periods, thereby making it the major carbon assimilator of this type of agroforestry system. Poplar-wheat based agroforestry system, thus fare better than traditional agricultural systems, providing the best land use option for increased carbon sequestration.

Clonal variation in carbon sequestering has been recorded in poplar clones by Pal et al. (2009). The WIMCO-22 clone was the best in terms of sequestering carbon stock, while WIMCO-42 was the poorest one in this respect. The carbon content in different components estimated by Chauhan and Chauhan (2009) were found to range from 44.08 to 47.82 (stem, branches, root, leaves and bark values were 45.67, 46.56, 47.82, 44.08 and 46.93 per cent, respectively). Rizvi et al. (2011) estimated 27-32t/ha and 66-83t/ha carbon storage in boundary and block poplar plantations, respectively at a rotation of seven years. Dhiman (2009) were found to range from 44.08 to 47.82 (stem, branches, root, leaves and bark values were 45.67, 46.56, 47.82, 44.08 and 46.93 per cent, respectively). Rizvi et al. (2011) estimated 27-32t/ha and 66-83t/ha carbon storage in boundary and block poplar plantations, respectively at a rotation of seven years. Dhiman (2009) estimated that only 1.04 mt C out of 2.5 mt C from poplar production system in India is locked in wood based products for different durations and the remaining is released back in the form of fuel and only a marginal fraction of 0.3 mt C is added to soil through leaf litter every year but Benbi et al. (2012) reported that poplar based agroforestry system contains higher concentration and greater stock of soil organic carbon than maize-wheat and rice-wheat system but majority of organic carbon (56-60 per cent) is in an easily oxidizable form, which could be easily lost with change in landuse.

Gupta et al. (2009) found that the average soil organic carbon increased from 0.36 in sole crop to 0.66 per cent in P. deltoides (poplar) based agroforestry soils. The soil organic carbon increased with increase in tree age. The soils under agroforestry had 2.9-4.8 t per ha higher soil organic carbon than in sole crop. The poplar trees could sequester higher soil organic carbon in 0-30 cm profile during the first year of their plantation (6.07 t per ha per yr) than the subsequent years (1.95-2.63 t per ha per yr). The sandy clay soil sequestered higher carbon (2.85 t per ha per yr) than in loamy sand (2.32 t per ha per yr). The carbon proportion in system is also enhanced through exerting check on soil erodibility by tree roots. Top layer, which contains higher proportion of organic matter, is protected (Gupta et al., 2006). The dispersion ratio, erosion ratio and water stable aggregates increased with increase in age of poplar plantations. However, it is important to mention that less than 50 per cent of the total timber is locked for longer period and remaining biomass is used as fuel to meet the energy requirements and replaces fossil fuel. Therefore, an estimate of carbon sequestration for wood used for energy as well, was calculated (Table 6) and it was found that poplar block and boundary plantation sequester substantial amount of carbon in long lived biomass and replace fossil fuel (5.45 and 1.84t per ha per yr in poplar based system with block and boundary plantations, respectively).

Realization of carbon sequestration payments will encourage landholders to adopt less intensive practices. However, the price of carbon must be high enough to encourage farmers to invest in growing trees than continue practicing traditional land use. At present, poplar based

<table>
<thead>
<tr>
<th>Table 6. Carbon sequestration in poplar based agroforestry models</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>Treatments</strong></td>
</tr>
<tr>
<td>----------------</td>
</tr>
<tr>
<td>Block plantation</td>
</tr>
<tr>
<td>Trees + wheat straw</td>
</tr>
<tr>
<td>Trees + rice straw</td>
</tr>
<tr>
<td>wheat straw</td>
</tr>
<tr>
<td>Boundary plantation</td>
</tr>
<tr>
<td>Trees + wheat straw</td>
</tr>
</tbody>
</table>

* calculations made with the presumption that wheat straw is used as fodder, whereas rice straw is used as fuel
** tree and crop (grain + straw) biomass
*** includes soil as well as long lived carbon storage in timber
agroforestry systems are becoming very popular amongst farmers due to substantially higher economic returns from timber than the traditional crop rotation of rice and wheat, the environmental benefits are yet to be realized. Preliminary studies by Gera et al. (2011) observed better IRR with carbon benefits than without carbon benefits in poplar based system (block and boundary plantations) but there are certain reservations on the part of farmers (continuity in adoption of tree-crop interface, transaction costs in developing agroforestry carbon project, technical/marketing/legal guidance, etc.) in CDM projects. Policy initiatives can benefit the farmers to earn from carbon market and mitigate the green house gases to ameliorate the environment.

**Economics Studies in Poplar Based Agroforestry Models**

The success of agroforestry system/model depends upon its adoption by the farmers who are concerned about its ultimate economic viability. New interventions are only adopted if they are economically remunerative than the old ones. Farmers are planting poplar on their land (bunds or block depending on their resources) for additional income from trees. However, to raise trees on agricultural land, the interspaces between these rows are not compromised and crops are raised to meet their livelihood requirements and also for maintenance of trees. Inter-cultivation also supports the poplar trees for their better growth due to the various inputs to agricultural crops like fertilizers, irrigation and other management practices. The higher returns in poplar based intercropping are mainly due to higher productivity of poplar than without intercropping (Dhillon et al., 2001; Chauhan and Mahey, 2008; Bangarwa and Wuehlisch, 2009). Substantial lower poplar growth in uncultivated land than with crop cultivation have been recorded by Verma (2008) and Gill et al. (2008).

Poplar based agroforestry can supply inexhaustible raw material. On an average 20m$^3$ per ha per yr wood is produced and with suitable crop combinations, the profitability has gone very high, thus, encouraging farmers for its adoption. Poplar has played a significant role in enhancing the income of the farmers and average economic returns per hectare of poplar based agroforestry is two to five times more than traditional crop rotation (Joshi, 1996; Dwivedi et al., 2007). Rani et al. (2011) recorded cost-benefit ratio as high as 5.51 with annual flower (Petunia hybrida) seed production under poplar. Jain and Singh (2000); Kumar et al. (2004) estimated the economic profitability of poplar based agroforestry interventions higher than many other major crop rotations and stressed that better economics in agroforestry is due to the higher timber market value, which will always remain high due to huge gap of demand and supply for industrial wood. However, the slump in market during 2003-2005 was a setback to the poplar growers and now they remain vigilant for any such uncertainty (Saxena, 2004). Gupta et al. (2005) has analyzed the poplar market price trend, which was lowest during 2003 and recovered back during 2005 and recently touched the maximum of Rs. 12,000/- per ton, which has again attracted the attention of farmers. It is important to mention that the profitability of poplar based agroforestry is only account able after the harvesting of poplar trees (5-8 yrs). Otherwise, the reduced yield of the crops under the tree canopy, lowers down the profitability margin than sole crop cultivation but the overall profitability on system basis after tree harvesting is substantially high than traditional crop cultivation (Gupta et al., 2005; Singh and Dhaliwal, 2005; Thind, 2005; Chauhan et al., 2010d; Chandra, 2011), thus, encourages the framers to invest in this sector and consider it a best performing low risk asset in near future (Sharma and Kumar, 2000b). Profitability analysis has been presented in different perspectives (farmers’ approach on the basis of available resources) by Chauhan et al. (2010b) and different practical models have been explained for their adoption by the respective farmers.

The minimum support price for poplar timber declared by Haryana Forest Development Corporation (HFDC) is an encouraging incentive for the farmers and other adjoining states should also follow the same. Though the farmers are getting better prices in the open market but such policy initiatives in addition to permission for free harvesting, free interstate movement of timber, etc. boost the farmers for adoption of such remunerative venture. In near future, the carbon market can add to the profitability.

**Conclusion**

Poplar has become life line not only for the growers in the northwestern states but also the dependent industry. Poplar has very specifically been recommended as an option to diversify from the rice cultivation in northwestern states, which is resulting in lowering of water table in this region. In spite of best performing on-farm asset, not all the farmers could understand the long term profits well to invest in it. Today, certainly it is a low risk investment and farmers will continue growing till the prices are better than other agricultural options. Over the years, the interest of the farmers have increased the pressure on the research institutions to develop/import new clones, test new crop combination in...
different geometry/land holdings/year of cultivation, replicate the success stories of the poplar growing pockets in other areas, etc. Resultantly, new clones have been recommended to replace the old ones (G3, D121, L34, G48, etc.), different crop combinations are under investigation and poplar has extended to new areas of Bihar state with a hope to transform economy of the farmers and the industry in that part of the country (Dhiman, 2010). However, it could not be extended southwards because it did not enter into dormancy during mild winters, thus, affected intercropping. Leaf shedding in poplar during winter is an added advantage for its integration with crops with minimum shade effect during vegetative growth phase of winter crops.

Innovation and imaginations are certainly helpful in designing new systems. For achieving the full potential of poplar based agroforestry, still, there is need for fundamental understanding of how and why farmers are interested to make long term land use decisions. To make the agriculture in general and poplar based agroforestry systems in particular a profitable venture, it needs to align with the market/industry requirements. Standardization of the cultivation of clones most sought after by the industry is the key for keeping these systems alive, profitable and viable in future. Thus, by projecting the future scenario from the present perspective with respect to shade loving species, the intercropping of high value crops; i.e., flowers, vegetables, aromatic and medicinal plants, etc. with poplars are inevitable. There is immense possibility of extending poplar cultivation in the North-western states of the country to uplift the socio-economic status of the farmers besides meeting the industrial requirements. The system as such establishes synergy in sharing the vital resources; i.e., light, water and nutrients besides fixing significant carbon quantities both in wood and soil. Adequate care and proper management of plantations are essential to harness appropriate productivity of the poplar trees. The complete package of practices in terms of poplar cultivation have been developed for optimum income from the trees at the end of rotation period (Chandra, 1986; Jones and Lal, 1989; Lal, 1991), additionally other public-private organizations involved in research and extension are supporting the farmers with similar gesture. Still, there is ample gap as regards biophysical and socioeconomic processes in the system and needs extensive focused research. The agroforestry research, extension, human resource and infrastructure need to be strengthened, so that the benefits of resource conservation and environmental amelioration besides timber requirements are realized. The financial resources to strengthen the intensive research in the system through national and international collaboration will certainly meet the growing aspirations of the farmers in meeting the objectives of diversification in traditional unsustainable crop rotations through agroforestry interventions.

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