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Poplars in India

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at

Forest Research Institute, Dehradun (India)

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FOREST RESEARCH INSTITUTE
(INDIAN COUNCIL OF FORESTRY RESEARCH AND EDUCATION)
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ENVIS Forestry Bulletin

Poplars in India

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Message

The genus *Populus*, consisting of more than 30 species, occurs throughout the forests of temperate and cold regions of northern hemisphere between the southern limit of around 30^0 N and northern limit of latitude 45^0N. Out of them, *Populus ciliata, P. alba, P. euphratica, P. gamblii, P. jacquemontii* var. *glauca and P. rotundifolia* are considered indigenous to India. Due to increased demand of timber for wood based industries, in 1950s, a large number of exotic clones like G3, G48, etc. of poplars were introduced in the country, mainly for increasing the wood availability for match, composite board, plywood and sport goods industries. *Populus deltoides* Marsh is an important commercial timber species, used for match stick, veneer and pulpwood. Forest Research Institute, Dehradun (FRI) has been one of the key institutions for introduction of poplar clonal material from USA and Australia. Poplar cultivation in India received a boost with the introduction of fast-growing *P. deltoides* clones from abroad. Later more introductions were made by FRI, State Forest Department of Uttar Pradesh, particularly Haldwani centre, which is now in Uttarakhand, WIMCO and Dr. Y.S. Parmar University of Horticulture and Forestry, Solan, Himachal Pradesh.

Poplars are most preferred tree species for the purpose of agroforestry by the farmers. Many clones of exotic poplars are cultivated in Punjab, Haryana, Uttarakhand, Uttar Pradesh as well as lower parts of Himachal Pradesh, and Jammu and Kashmir. Indian Council of Forestry Research and Education (ICFRE) has been working on popularization of poplar cultivation in plains of Uttar Pradesh and Bihar. In Vaishali District of Bihar (latitude 25^0 41’ N and longitude $85^0$13’E), which is well beyond the normal distribution range of poplars, planting of 6.1 million poplar seedlings on the farmland of more than a thousand villages is planned under Bihar Project, sponsored by the Planning Commission, Govt. of India, through its Forest Research and Extension Centre (FREC), Patna.

Poplar plays an important role in rural development by generating employment to many categories of skilled, semi skilled and unskilled workers and, thus, helps in achieving the Millennium Goal of poverty alleviation laid down by the Food and Agriculture Organization (FAO). Poplar cultivation has become an important source of livelihood and prosperity, encouraging more and more farmers to grow poplars in agroforestry model. Research institutes under ICFRE have been extending helping hand to the growers.

Poplars generate remunerative and much higher consolidated returns than the normal agricultural crop rotations, thereby, assuring security against crop failures due to extreme climatic conditions. It is a viable option for the rural economy of India.

(V.K. Bahuguna)

CONSIGLIO PER LA RICERCA
E LA SPERIMENTAZIONE
IN AGRICOLTURA

Message

I am deeply honored by this opportunity to commemorate the achievements of poplar research and cultivation in India with the launching of the new publication 'Poplars in India' on the occasion of the 24th Session of the International Poplar Commission in Dehradun. As Chairman of the International Poplar Commission (IPC) I would like to congratulate the Indian Council of Forestry Research and Education (ICFRE) and the Forest Research Institute (FRI) on this memorable work coupled with the wish that this important publication will have a wide distribution among the members of the international poplar community.

In India, poplars are the most popular tree species in agroforestry production systems where they are intercropped with agricultural crops like wheat, sugarcane, paddy and shade-tolerant fodder crops due to their fast growth, outstanding properties and quick and high financial returns. Smallholders and farmers own an increasing area of poplar plantations and depend on them for the improvement of their livelihoods. A large number of people, among them many women, gain employment and income from poplar cultivation, particularly in remote areas where forestry and agroforestry are the only economically viable land use options. Timber from poplars often forms the backbone for the development of vibrant plywood, composite board, match, paper and sports goods industries, which further contribute to the improvement of rural livelihoods, especially when a significant portion of the wealth of such value-added activity remains in the local economy and among the forest-dependent workforce.

India is a long-term member of the IPC which was founded in 1947 with a view to supporting the reconstruction of rural and industrial economies. It has become a statutory body of FAO in 1959 and has since increased its membership to the current number of 37 countries. For the past 65 years, the IPC, through National Poplar Commissions, Working Parties and the Sub-Committee on Nomenclature and Registration has provided a bridge linking research of poplar and willow cultivation, conservation and utilization with development policies, planning and implementation practices. IPC through its member countries has also promoted the organization of international conferences and meetings combined with field-study tours on poplar and willow culture.

In this context the Indian Council of Forestry Research and Education (ICFRE) and the Forest Research Institute (FRI) in Dehradun have embraced to host the 24th Session of IPC in 2012, for which I wish to express my sincere gratitude. I am convinced that this event will mark a significant milestone in the history of the International Poplar Commission.

Stefano Bisoffi
Chairman of the International Poplar Commission (IPC)
Rome, October 2012

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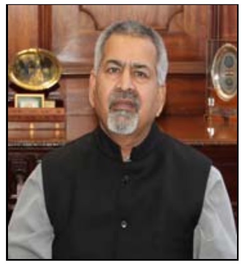

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Dated: 19.10. 2012

Message

Introduction of poplar (*Populus* spp.) as an agroforestry species in the states of Punjab, Haryana and western Uttar Pradesh has undergone three distinct phases: Initially, during 1970s and mid 1980s, the farmers were skeptical in adopting the cultivation of poplars on their farmlands. However, the government plantations demonstrated that poplar having shorter rotation (5-8 years) could be grown successfully in combination with many agricultural and cash crops without substantially reducing their yield. This demonstration motivated large progressive and absentee farmers for growing poplars on their farmlands. The development of poplar based industries such as plywood, pencil making, packaging boxes and the depression in market prices of *Eucalyptus* in the 1980s resulted in switching over from *Eucalyptus* to poplar plantations by majority of farmers in these states. In the recent past, the practice of cultivation of poplars in private farms under agroforestry has become a passion even with small and marginal farmers who saw it as a potential source of additional income. Consequently, one comes across a mosaic of large blocks of poplar plantations from 2,000 to 10,000 trees and smaller plantations raised as boundary rows of about 50-100 trees scattered over an otherwise agricultural dominant landscape. It is well known that poplar now contributes significantly to people and livelihood through the provision of wood, wood products, non-wood products, environmental and social services in India.

The Forest Research Institute at Dehradun, through its research professionals, has strived to develop agroforestry models of poplar. Subsequently, the institute has also worked on other aspects, such as botany, silviculture, pathology and entomology, economics and policy issues involved in the cultivation of poplar by Indian farmers and the state forest departments. Similarly, the work done by the professionals at the institute on clonal development with respect to this species has been commendable. The ENVIS Centre on Forestry at the National Forest Library and Information Centre has put together important issues related to poplar culture in India in the commemorate issue of *ENVIS Forestry Bulletin* to be released on the occasion of 24^{th} Session of the International Poplar Commission. This occasion will bring all the stake-holders together to deliberate on the issues concerning poplar raising and utilization in 21^{st} century.

This publication is a comprehensive account of development of poplar and its spread in the northern states of the Republic of India. Consequently, the chapters will familiarize the readers with various aspects of nursery raising, plantation, upkeep, harvesting and utilization, etc. of poplar in India. The publication also touches upon the role of poplar as mitigation alternative in the light of phenomenon of climate change.

I congratulate the editors of the bulletin who have taken responsibility to develop the manuscript and bring out this important document.

(P.P. Bhojvaid)

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Contents

Editorial

Poplar culture in India is mainly dependent on indigenously developed and introduced clones of *Populus deltoides.* However, other common species cultivated in the country are *P. alba, P. ciliata, P. gamblei* and *P. nigra. P. ciliata* is generally planted in cold arid region of Jammu and Kashmir and Himachal Pradesh states, whereas *P. gamblei* is found in isolated pockets of a few eastern states. These species have been largely planted on forest and agricultural lands for diverse purposes. *P. alba* and *P. nigra* have been planted for centuries in the inner Himalayas for meeting the domestic tree based needs of fuel, fodder and small timber for local inhabitants in the vegetation deficit cold arid region.

Around two dozen clones of *P. deltoides* are being grown in many locations in the poplar growing region that constitutes parts of Punjab, Haryana, Uttarakhnd, Uttar Pradesh and some adjoining states. The tree has recently been introduced by the Indian Council of Forestry Research and Education in Vaishali District of Bihar with the support of Planning Commission, Govt. of India. The tree has also been tried in almost all other states in the country but being a temperate species, its performance has not been found satisfactory in many of central and southern states.

Because of its wide adaptability, *P. deltoides* has been extensively planted from the cold arid to the north-western states of the country. It is mainly planted as a cash crop on agricultural fields in association with crops like sugarcane, wheat, fodder crops, medicinal plants, etc., generating remunerative returns of over Rs. 250,000 per hectare per year, which is an important factor for motivating growers to remain engaged with its culture. With over 300,000 hectares as present area under poplar culture, its role in rural development in terms of economic transformation, employment generation, industrial development and environment amelioration is huge.

Research institutions, private sector and farming community together played an important role in making poplar cultivation a success story. Restrictions on green felling resulted in increased demand of alternative wood like ply woods and composite boards, which created great demand of indigenous raw material for these industries. As a result, cultivation of poplars became popular among farmers. Therefore, there was a boost in the poplar based agroforesry from Jammu and Kashmir to Uttar Pradesh.

The idea of special issue of the *ENVIS Forestry Bulletin* was conceived to provide an exposure of the work done on poplars in India to the delegates of the 24th Session of International Poplar Commission being organized for the first time in the country at the Forest Research Institute, Dehradun. The issue includes inputs from the leading researchers about scientific advancements made on its anatomical studies, improvement, production, protection, usage, etc., poplar stake-holders, viz., private sector and farmers having a lot of practical experience on its culture.

The issue first introduces the indigenous species of poplars with their taxonomical details and distribution. The story of diversity of poplars in India is completed with a word on the introduction of exotics. No introduction is successful unless production technology is perfected in the backdrop of ground realities. The article on breeding primarily confines on the efforts of Dr. Y.S. Parmar University of Horticulture and Forestry, Nauni, but provides a glimpse of overall approach for improvement that is further elaborated in the article on clonal forestry. Poplars in India are more popular as agroforestry crop, this aspect is dealt with in length in the article on intercropping in poplar based agroforestry. It is closely followed by the economics of the poplar culture and its carbon sequestration potential. These twin issues are core to the global market economy in the present context. The production target can never be achieved without a healthy crop and its byproducts, the article on diseases and insect pests address the health management of this commercially important tree. Some other relevant and emerging aspects of poplar culture in India, like wood quality and anatomical studies also find place in the issue. To capture the varied efforts involved in poplar culture, mapping of research on poplars also attempted, besides offering select bibliography of research on poplars in India during last one and half decade (1997-2011).

It is hoped that the delegates and others will find this information useful to understand different dimensions of poplar culture in India.

- ***Editors***

Indian Poplars with Special Reference to Indigenous Species

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There are four indigenous species of *Populus* namely *P. ciliata*, *P. gamblei*, *P. jacquemontii* var. *glauca* and *P. rotundifolia* found in the Himalaya. These species are important for cultivation in Himalayan zone and deserve attention for improvement

Introduction

Populus and its 'sister' lineage, the genus *Salix* (willows), have been considered the only two genera in the Salicaceae family, although some taxonomists have included other genera, mostly from eastern Asia (Eckenwalder, 1996). More recently, however, the Flacourtiaceae family, the closest relative of Salicaceae, was re-classified, and a number of genera formerly included in Flacourtiaceae are now assigned to Salicaceae *sensu lato*, with in the Malpighiales order of the 'Eurosid I' clade (Chase *et al*., 2002; APG, 2003).

Populus is the classical name of the poplar, others consider that this plant was used in ancient times to decorate public places in Rome where it is called '*arbor populi*' 'people's tree'; i.e., *Populus alba* (Naithani *et al*., 2001). These plants are usually dioecious, rarely monoecious, viz., *Populus lasiocarpa* Oliv., native of western China (FAO, 1979). Exceptionally bisexual in *P. jacquemontiana* var. *glauca,* a species endemic to eastern Himalaya (Grierson and Long, 1983; Haines, 1906). Genus *Populus* Linn. includes 44 species in five sections. These are white poplars (*Leuce*), black poplars (*Aigeiros*), balsam poplars (*Tecamahaca*), *Leucoides* and *Turanga*. These are widely distributed in the temperate and sub-tropical regions of the Northern Hemisphere. In the plateaus of near-east and in the borderlands of Mediterranean Sea, since antiquity, people have being planting poplars near their homes, around their fields or along ditches and roads; these trees not only furnished fuel and timber for domestic use as well as forage to cattle but also provided shade, shelter and greenery in countries that would be otherwise.

Realizing the importance of poplars, a National Poplar Commission was created in France in 1942 and, subsequently, an International Poplar Commission was set up under the aegis of the FAO during 1947. India became a member of this Commission in 1965 and constituted a National Poplar Commission with the objective of cultivation of poplars to meet the requirements of timber, fuel wood, etc. However, before the establishment of National Poplar Commission the cultivation of Poplar was traditional in Kashmir for a very long time and in recent years extended to Punjab, Haryana, Himachal Pradesh, Uttar Pradesh and on a very small scale, in West Bengal. Poplars, because of their fast rate of growth, high financial return and multiple utility, have become a very important species for cultivation both in the forest and farms. Poplar wood is widely used in plywood and match splints. Market has been developed for poplar in Punjab, Haryana and Uttar Pradesh.

With regard to the occurrence of poplar in India, Bor (1958) mentioned eight species, viz., *P. alba* Linn., *P. euphratica* Oliv., *P. microcarpa* Hook.f. and Th., *P. nigra* Linn., *P. laurifolia* Led. (*P. balsamifera* Linn.), *P. ciliata* Wall. ex Royle, *P. gamblei* Dode and *P. jacquemontiana* var. *glauca* Haines. There is controversy about the indigenous poplars in India. Many authors, viz., Tewari (1993), Singh and Kumar (1998) considered *P. laurifolia*, *P. euphratica* and *P. alba* as indigenous. In fact, many of them are exotic, viz., Sind poplar, bahan, bhan, padar (*P. euphractica*) has a remarkable geographical distribution. It occurs in Ladakh, plains of the Punjab and Sindh (Pakistan), Tibet; westwards it is indigenous on riverine areas in Afghanistan, Turkey, Iran, Iraq and Palestine, which exhibits a wide range of leaf polymorphism. *P. alba* and its cultivars known from southern Europe, western Siberia and Central Asia, were introduced and naturalized in Kashmir and Ladakh, known by the local name 'Safeda' and 'Mal'. Black poplar (*P. nigra*) and its cultivars are native of temperate Europe, introduced in Kashmir, Himachal Pradesh and in some parts of Garhwal Himalaya. Balsam poplar (*P. laurifolia* Ledeb.) (*P. balsamifera* Linn.) a species of Central Asia, was planted in Leh (Ladakh), Lahaul and Spiti (Himachal Pradesh) and Tawang district of Arunachal Pradesh, where it is generally planted by the Buddhists near monasteries. Eastern cottonwood (*P. deltoides*) from North America is very commonly planted by the farmers in agroforestry plantations in Punjab, Haryana, Uttarakhand and Uttar Pradesh. A part of these *P. x euramericana* and *P. x berolinensis* were introduced in India in 1950. Clones of *P. canescens, P. maximowiczii, P. trichocarpa, P. smonii, P. szechuanica, P. yunnanensis*, etc. were introduced in the subsequent years. *P. deltoides* performed better than all other exotic poplars in the plains of North India, and relegated most other exotic poplars to the status of anonymity in India. In the hills, *P. yunnanensis* and *P. x. euramericana* 'Robusta' proved better than other species (Seth, 1969). These exotic poplars do not regenerate readily due to the absence of seeds caused by the lopping.

Classification

Louis-Albert Dode (1875-1945), a noted French dendrologist worked on *Poplus* and *Salix*. He had a private plantation having approximately 1,500 poplars and willows. In addition to studying his own living collections he made extentive use of his own herbarium collections.

Dode's classification of poplar is interesting, he was the first to recognize sub-genera (as well as sections) in the genus. He raised section *Turang*a of Bunge (including only *P. euphractica* and *P. pruinosa*) to subgenus. Wesmael (1868) previously classified these species with the aspens in section *Leuce*. Browicz (1966) used subgenus *Balmiflua* (Griff.) Browicz, for the turanga poplars as a whole, and recognized a Kenyan species, viz., *Populus ilicifolia* in a section *Tsava* (Jarn.) Browicz (Table 1).

Table 1. Classification of Populus

Section (synonym)	Species	Distribution
Abaso Eckenwalder	*Populus Mexicana* Wesmael	Mexico
Turanga Bunge	*P.euhratica* Oliver	NE Africa, Asia
	P. ilicifolia (Engler) Rouleau	E Africa
	P. pruinosa Schrenk	Asia
Leucoides Spach	*P. jacquemontiana* var. *glauca* Haines *sl*[a]	China ? USA
	P. heterophylla L.	China
	P.lasiocarpa Olivier	
Aigeiros Duby	*P. deltoides* Marshall sl[a]	N America
	P. fremontii S. Watson	USA
	P. nigra L.	
Tacamahaca Spach		Eurasia, N America
	P. angustifolia James	N America
	P. balsamifera L.	N America
	P.ciliata Royle	Himalaya
	P. laurifolia ledebour	Eurasia
	P. simonii Carriere	E Asia
	P. suaveolens Fischer *sl*[a]	NE China, Japan
	P. szechuanica Schneider	E Eurasia
	P. trichocarpa Torrey and Gray	N America
	P. yunnanensis Dode	Eurasia
Populus (*Leuce* Duby)	*P. adenopoda* Maximowicz	China
	P. alba L.	Europe, N Africa, Central Asia
	P. gamblei Haines?	E Eurasia?
	P. grandidentata Michaux	N America
	P. guzmanantlensis Vazques and Cuevas	Mexico
	P. monticola Brandegee	Mexico
	P. sieboldii Miquel	Japan
	P. simaroa Rzedowski	Mexico
	P. tremula L.	Europe, N Africa, NE Asia
	P. tremuloides Michaux	N America

Source: Eckenwalder (1996).

Key to the Sub Genus

1. Leaves entire, coriaceous, glaucous, never tomentose below, both surfaces identical; foliar glands not far projecting; buds small, bowl-shaped, often showing only scale; perianth caducous; stigma 3, large carmine; stamens ± 12; capsule elongated---Subgenus *Turanga*

\+ Leaves sometimes lobed, light green above, sometimes tomentose below; foliar glands projecting, bowl-shaped; bud average, with several obvious scales; perianth persistent; stigma, 2 palepink to carmine; stamens 5-20; capsule elongated---Subgenus *Leuce*

Catkins always rather compact

Leaves green above, lighter of sometimes pubescent below, teeth very deep, never lobed; petiole ± compressed or with quadrangular or rectangular section; buds rather large, viscid with many very obvious scales; perianth persistent; stigma 2-4, greenish, warted; stamens 8-8; capsule elliptic-globular--------------------------------------Subgenus *Eupopulus*

Key to the Group

1 Pubescence less developed on young wood than on old; perianth with divisions scarcely exceeding half the height --*Euphratica*

\+ Pubescence more developed in young wood than an old; perianth with divisions almost reaching it base more reduit--*Pruinosa*

Key to the Sections under Subgenus Leuce

1 Mature turion leaves less woolly below; ± lobed; floral bracts little or somewhat divided; multiplication by cuttings possible--------------------------------------*albidae*

\+ Turion leaves glabrescent, silky-hairy or with rough hairs, ± irregularly serrate-toothed floral bracts deeply divided; ordinary methods of vegetative propagation by cuttings are unsuccessful-------------------------------------*Trepidae*

Key to the Group under Subgenus Eupopulus

1 Leaves ± glaucous below; foliar glands ridge-shaped; Petioles ± compressed laterally, those of the turion leaves ceably so and all proportions remaining equal to extent of those of brachyplast leaves;----------------------*aigiri*

\+ Leaves glaucous, whitish or white below; foliar glands rather bowl-shaped; petiole quadrangular in cross section; usually laterally compressed, those of the turion leaves constant in shape, usually shorter than those of the brachyblast leaves-----------------------*Tacamahacae*

Group under Subgenus Leucoideae

Leaves white woodly below when young, thus only glacous; foliar gland rather bowl-shaped; petiole round-sub quadrangular in cross-section; and all the portions remaining equal in extent to those of the brachyblast leaves---*Leucoideae*

Key to Common Introduced Species

1. Leaves lobed (or sometimes narrowly oblong), entire on young plants and suckers; buds not sticky---------------2

\+ Leaves not lobed; buds sticky--------------------------------3

2. Leaves glabrous, polymorphous, entire in young plants and suckers -----------------------------------*P. euphractica*

\+ Leaves white tomentose beneath-------*P. alba (P. caspica)*

3. Leaves with clearly defined translucent border-----------4

\+ Leaves without translucent border---*P. laurifolia (P. pamirica)*

4. Leaves rhomboidal, cuneate at base; glands at the base of the blade absent ------------------------------------*P. nigra*

\+ Leaves deltoid at base; glands present at the base of blade---*P. deltoides*

Indigenous Species

There are four indigenous species of *Populus* namely *P. ciliata*, *P. gamblei*, *P. jacquemontii* var. *glauca* and *P. rotundifolia* found in the Himalaya. These species are important for cultivation in Himalayan zone and deserve attention for improvement. These need recognition, systematic survey, collection and evaluation of desirable geographical races and development of suitable clones.

Key of Indigenous Species

1. Leaves ovate, acuminate--------------------------------------2

\+ Leaves broadly ovate or orbicular, shortly acute or apiculate---*P. rotundifolia*

2. Plants dioecious; leaf margin crenate or dentate-serrate;--3

\+ Flowers bisexual; leaf margin sharply serrate---*P. jacquemontii* var. *glauca*

3. Leaves truncate at base; capsule 2-valved--*P. gamblei*

\+ Leaves cordate at base; capsule 3-valved---------*P. ciliata*

Populus ciliata Wall. ex Royle

Vern.: *Himalayan poplar, safeda, piplas, pahari pipal, chelaun, chalni, banpipal, bagnu, syan, pak butra*

This is the most widespread species of native poplars. Distributed from Kashmir to Arunachal Pradesh at an altitude between 1,000-3,000m. It is most widely distributed species in India and grows well on alluvial deposits along the water channels, road cuttings, land slides, occasionally forming small gregarious patches on banks of the large water courses. During a qualitative survey during 1995 to 1997 in Uttarakhand in western Himalayas, it was found growing in ban-oak (*Quercus leucotrichophora*), pangar (*Aesculus indica),* toon (*Toona serrata*), deodar (*Cedrus deodara*), kail (*Pinus wallichiana*), fir (*Abies pindrow*), spruce (*Picea* *smithiana*), *Rhus chinensis, Rhus punjabensis, Rhododendron arboreum, Cornus macrophylla, Coriaria nepalensis, Lyonia ovalifolia, Machilus odoratissima, M. duthiei* and hill bamboo *Sinarundinara falcata*. Ground flora consists of *Desmodium elegans, Oplismenus compositus, Arisaema tortuosum, Impatiens scrabida, Daphnae papyracea, Rumex hastatus, Prinsepia utilis, Indigofera heterantha, Rosa moschata, Lonicera quinquelocularis*, etc. In eastern Himalaya, it is sparsely distributed in Sikkim, Bhutan and Arunachal Pradesh often grown with *Pinus bhutanica, Pinus wallichiana, Salix bhutanica, Salix wallichiana, Alnus nepalensis, Ilex griffithii, Castanopsis hystrix, Trevesia palmata* and hill bamboo *Sinarundinaria hookeriana*. Outside India, it is known from north Myanmar and Yunnan Province of China. It has been observed that *Populus ciliata* grown near Bomdi La, West Kameng District and Tawang District in Arunachal Pradesh has different shape and size of leaf as compared to western Himalaya. This species affected by rust diseases in winter but without any significant damage. However, in many places, it is affected by parasite *Loranthes* which causes damage.

Keeping in view their fast growing nature various exotic species of poplar have been planted in many parts of northern India. However, not much emphasis has been provided to indigenous species. Thus to encourage the indigenous species of poplar a project entitled ‘Conservation of Indigenous Poplar in India’ was undertaken in Garhwal and Kumaun hills for selection of provenance and plus trees was taken up. In Uttarakhand about 500 trees were observed and marked with numbers for the selection. In the survey best trees were located at Govind Pashu Vihar in Taluka Range (Tons Forest Division) and in Gangotri Range, Uttarkashi Forest Division, where a tree of maximum 4.5 m girth (Fig. 1) was observed. Earlier probably record girth was measured 4.62 m from Kullu Forest Division, Himachal Pradesh (Singh, 1982) and 3.5-4 m from Hazara (Troup, 1921). Joshi (1981) stated that in Uttar Pradesh, the total area of *P. ciliata* (in mixture with other coniferous and broad leaved species) would be around 40,000 ha, but this species generally constitutes a small component (less than 5 per cent) of the whole crop. Its pure patches are also located at Hanuman Chatti, Badrinath Forest Division below Bhayundar, on way to the Valley of Flowers and Dharali area of Uttarkashi. These pure patches for conservation point of view should be declared as ‘National Poplar Reserve’.

According to Rajawat *et al*. (1987) suitability of *P. ciliata* had been studied for making various grades of plywood and blockboards like *P. deltoides* tested earlier. *P. ciliata* has also been found to give good veneers on peeling. Plywood prepared from the veneers using U-F and P.F. glues has been found to be suitable for making general purpose plywood, marine plywood for concrete shuttering work, preservative treated plywood and fire retardant plywood. The species could thus be included in the relevant Indian Standards specifications for their manufacture. It is also suitable for hardboards (Shukla *et al*., 1985). It is suitable for making packing cases and crates (Shukla, 1981), It also supports doors. Its wood is of excellent quality for the manufacture of matches (FAO, 1979). It is also used in manufacture of artificial limbs. These includes knee skin assemblies and knee mechanism of all types, hip disarticulation joint, wooden foot and wooden block. The laminated wooden blocks manufactured cover block thigh, block foot, block knee, block ankle, etc. (Misra, 1981). In Kashmir, it is used for building purposes and also as fuel. The bark is used as tonic, stimulant and blood purifier. The leaves are used as a fodder for goats (Khan and Kachroo, 1981). Guha and Mathur (1959) staed that *P. ciliata* is suitable for writing and printing paper. It is useful for afforesting unstable hill slopes.

Haines (1906) and Parker (1918) mentioned that the male trees are rare in *P. ciliata*. However, Khurana and Khosla (1978) analysed natural stands of *P. ciliata* and also plantations for sex ratio around Manali, Harlu, lower Kulu and Parvati ranges in Himachal Pradesh. Based on survey of 3,531 trees, it was observed that male trees dominate and have 67.71 per cent frequently as compared to 38.9 per cent female. This gives an approximately 3:2 male to female ratio. Singh (1982) stated that pooling the data of 586 trees examined in various localities of Himachal Pradesh gave the ratio of male and female trees as 2:1. However, during survey in 1995-1998 in Garhwal Himalaya, Uttarakhand, it was found that the population of female trees was maximum (Fig. 2) and that male trees were very less. Joshi (1981) also stated that in the Uttar Pradesh region most of trees were female, male trees were scarce. Gupta (1969) while mentioning its occurrence in Jaunsar and Tehri Garhwal, Uttarakhand also stated that the male trees were very scarce. This indicates that the ratio of male and female trees varies with the locality.

P. ciliata can easily be propagated by cuttings. Troup (1921) stated that its regeneration through seeds is negligible. However, the commonest form of its natural reproduction is by root-suckers. The seeds of *P. ciliata* are light, about 14,000 to 15,000 seeds weigh one gram (Singh, 1981; Beniwal and Singh, 1989). In laboratory condition, 75-95 per cent germination of seed was noted by Singh and Gupta (1981). Mathur *et al*. (1982) mentioned that under laboratory condition its germination is

86.25 per cent, while on land slip under natural condition, only 0.30 per cent was noticed. Under natural conditions, however, seed germination is considerably poor. Some seedlings, manage to grow in crevices of rocks or newly exposed ground such as landslips and road cuttings and on alluvial boulder deposits along streams. The seedlings establishment is uncommon because of the following reasons (Singh, 1982):

- Most of the seeds are caught on the grass, weed and moss covering the soil fail to come in contact with mineral soil.
- Unfavourable moisture conditions at the time of seed dispersal. Sufficiently moist soil is needed at the time of germination and for a fairly long time after germination.
- Susceptibility of seedlings to fungal attacks particularly damping off.
- Washing away of seeds and tiny seedlings by run-off water on slopes and their desposition in depressions where they get covered by soil and fail to germinate.

Nautiyal *et al*. (1995) reported its profuse natural regeneration in Tons Forest Division, Uttarakhand. They also stated that the area of around 40 m radius was full of the seedlings. The site was sunny and slopey.

A study of the performance of forest clones of poplars and the farm forestry condition trial was laid down at Khaltoo (Himachal Pradesh) in 1976 with six species namely *P. ciliata*, *P. casale; P. yunnanensis*, *P. trichocarpa*, *P. oxford* and *P.deltoides* planted at 60 x 30 cm spacing. It was found that maximum survival was recorded in *P. ciliata* followed by *P. deltoides* while height and diameter was maximum in *P. yunnanensis* followed by *P. ciliata* (Khurana and Khosla, 1978). During the period of 1986 to 1990, seeds were produced in Gaja Nursery, Uttarakhand. The best clones were tried in the field in January 2008.

Populus gamblei Dode

Vern.: *Pipalpate, pilpile*

It is the southern-most poplar in the Northern Hemisphere and is distributed in Yazuli and Yachuli area of Lower Subansiri District of Arunachal Pradesh. In Darjeeling hills, West Bengal, it is naturally found in Damson forests, where it is sometimes observed colonizing the slip areas. Also occurs along the roads from Kalimpong to Teesta. In the recent past, it has been naturally found common 4 km before Sechu (Sechii) on Kohima-Dimapur Road, Nagaland. About 40 small to medium sized tree were located in the area. A large tree about 15 m high having a girth of 3.2 m (Fig. 3) is also measured. Beside Sechu some tree of this species are also located Niepfei area near Kohima. In Nagaland, it is used in shifting cultivated fields for temporary hut construction (Naithani *et al*., 2005). In a very recent (May 2012) quantitative survey conducted by one of the author in Yazuli, Lower Subansiri District, Arunachal Pradesh, *P. gamblei* was found associated with common trees which *Schima wallichii, Dalbergia sericea, Erythrina indica, Callicarpa arborea, Rhus chinensis, Celtis australis, Engelhardtia spicata, Sterospermum chilinoides*. Ground cover was with *Artemisia nilagirica, Eupatorium adenophorum, Pteridium revolutum, Oxalis corniculata, Lepidagathis incurva, Sida rhombifolia, Bidens pilosa,* etc. During March-April each year, natural regeneration of *P. gamblei* is found in profusion under the areas affected by land slips, the young seedlings appear to colonize the slip affected areas.

P. gamblei provides an annual output from 16.3 m per ha to 35.9 m per ha depending on age (Lahri, 1979). The wood of *P. gamblei* has been found to the suitable for ply, match and packing case industries. Eighteen trees of *P. gamblei* planted in the year 1975 are growing in the Tashiding I compartment beat in Kalimpong Division, North Bengal. The seeds of *P. gamblei* are very minute, weighing about 1,500 an ounce and attached to fluffy floss, often difficult to collect because of short time gap between flowering, fruiting and quick dispersal (Ghose, 1969; Lahri, 1979) Muhle-Larsen (1970) reported 12 species of *Populus* showing change in sex in standing population. Sharma *et al*. (1999) reported reversion of sex in *P. gamblei* from male to female in a 20-yr old tree cuttings which were brought from Arunachal Pradesh and planted in the Plant Physiology Discipline of Forest Research Institute, Dehradun. The reversion of sex mentioned by Sharma *et al*. (1999) is incorrect. This tree, when first flowered was examined and noted that it was female and not male (Fig. 4).

Branch cuttings of most of the poplar species root easily without any pretreatment of synthetic growth regulators but cuttings of *P. gamblei* do not root easily (Guhathakurta, 1973). Ghose and Bhatnagar (1977) stated that rooting response of branch cuttings of *P. gamblei* to different growth regulator treatments and seasonal variation in rooting. Growth regulators have considerably increased rooting. Twenty-four hours dip treatment in aqueous solution of 200 ppm concentration of indole acetic acid has given best results in which 70 per cent rooting has been achieved. In view of its good rate of growth it offers potential of developing hybrid clones (Guhathkurta, 1973).

Populus jacquemontiana Dode var. *glauca* (Haines) Kimura (*P. glauca* Haines)

Vern.: *Pipalpate* or dude *malata*

This is the only Indian poplar which has bisexual flowers (Fig. 5). It is distributed in Tonglo in Sikkim and Eastern Nepal

Fig. 1. *Populus ciliata* in Uttarkashi Forest Division, Uttarakhand tree with a girth of 4.5 m.

Fig. 2. *Populus ciliata* female.

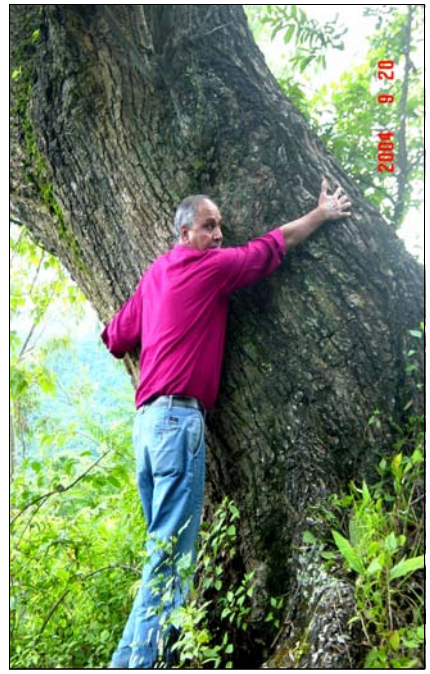

Fig. 3. *Populus gamblei* tree, 15 m high with a girth of 3.2 m in Nagaland.

Fig. 4. *Populus gamblei* female inflorescence.

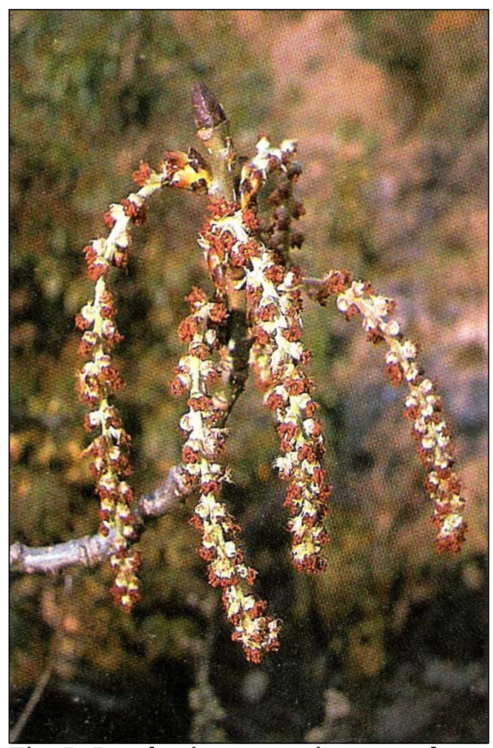

Fig. 5. *Populus jacquemontiana* var glauca inflorescence. (Courtesy: Stainton, 2005).

at an altitude between 2,500-2,900 m. It is generally found in forests clearing; quite common around villages. A beautiful colour photograph of this rare species was given by Stainton (2005). It is also regarded by some experts as a form of *P. ciliata* (FAO, 1979). At present, it is not correct because *P. ciliata* is dioecious.

Populus jacquemontiana var. *glauca* was tested against the cadmium stress which is highly toxic heavy metal, which causes strong oxidative stress, thereby, interaction PSII and the photosynthetic electron transport by Solti *et al.* (2011) and found that an acute acclimatization phase were identified as a consequence of the delay in activation of anti-oxidative defense mechanism, the protective role of which is important in the acclimatization to moderate cadmium stress.

Populus rotundifolia Griff.(*P. microcarpa* Hk.f. and Th.; *P. bonatii* Leve.)

Vern.: *Kashing, kashi*

A shrub or tree, 2-10 m. This species is endemic to Thimpu, Punakha and Bumthang District of Bhutan Himalaya, distributed in *Pinus wallichiana* (blue pine) forest at an altitude between 2,300-3,050 m (Grierson and Long, 1983). This little known species has been included here because phyto-geographically Bhutan is a part of eastern Himalaya. Therefore, in future it can be found in adjacent states like Sikkim and Arunachal Pradesh as the vegetation of these states is similar to Bhutan.

In the plains, introduced clones of *P. deltoides* have given good performance. However, instead of depending solely upon introduced clones of *P. deltoides* for the hills, work should be initiated in indigenous species to generate new clones or hybrids. Suggested lines of work are:

- Patches of wild poplar should be declared and maintained as ‘National Poplar Reserves’.
- Germplasm banks of plus trees of indigenous poplars should be raised at plantation sites in hills to study genotype and site interaction.
- A poplar breeding programme incorporating indigenous and exotic poplars should be taken up on priorities to generate superior clonal material for planting under agroforestry in hill areas and plains.

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Status of Poplar Introduction in India

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Systematic introduction of exotic poplars took place more than seven decades ago, and that more than 600 clones and 266 open-pollinated seed families have been introduced into India from different parts of the world

Introduction

Poplars hold a place of great significance in India as they are among the most preferred tree species in the unique agroforestry systems in northern part of the country. Six indigenous species of poplars, viz., *Populus ciliata, P. alba, P. euphratica, P. gamblii, P. jacquemontii* var. *glauca and P. rotundifolia* are reported in India. Some experts consider *P. alba and P. euphratica* as exotics (Naithani *et al.*, 2001). However, since both these species grow widely in several areas and record of their introduction are not available, these two species are being treated as indigenous in this paper.

Poplars, primarily the exotic species, are being grown on around 312,000 hectare area in various agroforestry models in Punjab, Haryana, Uttar Pradesh, lower hills and outer valleys of Himachal Pradesh, Uttarakhand and Jammu and Kashmir. Exotic poplars are also planted as avenue plantations in Kashmir on a significant scale. Now, with the efforts of Indian Council of Forestry Research and Education (ICFRE), cultivation of poplar in agroforestry has been extended to Vaishali District of Bihar. *Populus deltoides* is the most popular exotic species. The annual returns from its cultivation are estimated to be up to 250,000 rupees per hectare per year. Wood from poplars is the backbone of vibrant plywood, board, match and paper industrial units. Poplars provide huge cash returns to individuals and communities engaged in their cultivation and management, contribute considerably to government exchequer, reduce pressure on forests and entail massive ecological and environmental benefits besides providing a wide range of other wood products and employment opportunities to various subsidiary sectors.

While indigenous poplars have mostly remained confined to forest areas and community lands, exotic poplars, in addition to native species and eucalypts, have been responsible for creating wooded landscape in areas outside the forest in north India. Systematic introduction of exotic poplars took place more than seven decades ago. This paper gives an account of the introduction of exotic species of poplars in the country.

Species Introduced

The following species of *Populus* have been introduced into India so far:

- *P. deltoides*
- *P. nigra*
- *P. laurifolia*
- *P. yunnanensis*
- *P. trichocarpa*
- *P. violascens*
- *P. maximowiczii*
- *P. simonii*
- *P. szechuanica*
- *P. tacamahaca*
- *P. tremuloides*
- *P. grandidentata*
- *P. robusta*

In addition to the above species, interspecific hybrids of several species of poplars have also been introduced. The most important among them has been *P.* x *euramericana*, a hybrid between *P. deltoides* and *P.* nigra (Kaul and Sharma, 1982). More than 600 clones and 266 open-pollinated seed families have been introduced into India from different parts of the world.

Reliable data on suitability of different species were not available till late 1960s. Hence, till that time focus was on introducing germplasm of all possible species. However, in view of better adaptation and productivity of *P. deltoides* in areas of commercial poplar cultivation in India, later introductions have mostly focused on *P. deltoides* only. Thus, *P. deltoides* has so far been the most important exotic species of this genus in the country. So widespread has been its cultivation in North India that the term 'poplar' has become synonymous with *P. deltoides* in the country.

Forest Research Institute, Dehradun (FRI) has been the major organization which introduced clonal material from abroad. State forest department of Uttarakhand (Haldwani centre) and WIMCO Ltd. have also introduced clones from abroad. There has been good exchange of introduced material among these organizations. Introduced material has also been supplied by them to other government as well as non-government agencies involved in poplar cultivation in India. Germplasm in the form of seed has been introduced by FRI and Dr. Y. S. Parmar University of Horticulture and Forestry, Solan, Himachal Pradesh, Uttar Pradesh Forest Department (now Uttrakhand) and WIMCO Ltd.

Timeline of Introduction of Exotic Germplasm

Early Phase

The fastigiate form of *P. nigra*; i.e., Lombardy poplar or pyramidal poplar (cv. 'Italica' and cv. 'Pyramidalis') is frequently planted in western Himalayas up to 3,700 m altitude, particularly in Kashmir. Besides *P. nigra*, some clones of *P. deltoides* and *P. alba* are planted here and there in Kashmir. How and when these clones were introduced is not known (Khan *et al.*, 1961).

Middle Phase

This phase has been the most important phase of poplar introduction in India and has played a pivotal role in laying the foundation of commercial cultivation of poplar.

The first systematic attempt at introduction of European and Euramerican poplar clones was made by the forest department of Uttar Pradesh (now Uttarakhand) by 1950 when hybrid clones of *P.* x *euramericana* cv. 'Serotina', *P.* x *euramericana* cv. 'Gelrica', *P.* x *euramericana* cv. 'Robusta' and *P.* x *berolinensis* were tested in the Himalayas at 1,500 to 2,400 m elevation and 1,000 to 1,500 mm rainfall. Trials on a larger scale were started by FRI by 1959 when 24 clones of various hybrids were imported through the British Forestry Commission. These clones were planted in Kashmir, Himachal Pradesh, Punjab, Uttar Pradesh (including present-day Uttarakhand), West Bengal and Tamilnadu (Ootacamund) at 1,200 to 1,800 m altitude, besides being planted in demonstration area of FRI. This collection included 17 clones of black poplar (Section Aigeiros), 5 of balsam poplar (Section Tacamahaca) and 2 of Section Leucoides (Khan *et al.*, 1961).

During 1959 to 1976, FRI introduced 199 clones of various exotic species and hybrids, which included 29 clones of *P. deltoides*, among others. Clones G-3, G-48 and D-121 which subsequently became very popular with the growers clones, were also introduced during 1969 (Kaul and Sharma, 1982). WIMCO also introduced exotic clones of poplars directly from abroad.

Another set of 138 clones of *Populus* was received by FRI, Dehradun from 1977 to 1981. This contained 98 clones of *P. deltoides* (Kaul and Sharma, 1982). Introduction of more clones continued and, as a result, about 440 clones of *Populus* spp. had been introduced till 1983 by FRI (Tewari, 1993). Multiplication of clones by vegetative propagation and their distribution to different states also continued. However, systematic feedback on performance of clones in those states was not received.

More clones of *P. deltoides* were sent to India during mid-1980s by Dr. Sam Foster in Louisiana (U.S.A.) who made controlled crosses among select clones of Stoneville (Mississippi, U.S.A) origin. These clones were tested by WIMCO and discarded as not suitable. Another collection of clones from throughout the USA was sent to the Haldwani centre of state forest department by Dr. E.A. Hansen of the United States Forest Service during 1986 (Land, 1996). From of this collection, nursery trials were conducted on 121 clones of *P. deltoides*, 27 clones of *P. trichocarpa* and 20 clones of *P. deltoides* x *P.* trichocarpa at Lalkua (Haldwani).

Field trials in the Tarai region of Uttar Pradesh (including present-day Uttarakhand) on new introductions revealed superior growth of clones G-3, G-48, D-67, D-75, D-82, D-121, D-161, D-171, D-181 of *P. deltoides* in comparison with clones of other species (Chaturvedi, 1982). In view of this, several trials on different clones of *P. deltoides* were carried out in the alluvial plains of north India during 1980s and 1990s. Clones G-3, G-48 and D-121, which had shown good performance in preliminary tests, were included in most of the trials. Dinesh Kumar *et al.* (1999) observed that only 3 to 5 (sometimes around 10) clones of *P. deltoides* were usually tried in the experiments. Clones G-3, G-48 and D-121grew very well in several trials. Apart from these three clones, the other clones were not consistently included in the experiments in other regions conducted by various researchers (Dhanda, 1982; Singh *et al.*, 1987; Sharma, 1991; Gera *et al.*, 1993; GBPUAT, 1994).

Dinesh Kumar *et al.* (1999) analysed the performance of 108 clones of poplars, introduced in India since late 1950s, in two field trials in Haldwani and ranked them on the basis of stem wood volume (Table 1). From the study, it emerged that clones S7C8, 82-35-4 and 113324 of *P. deltoides* give higher yield than G-48, although G-48 has remained one of the most popular clones over the last two decades in agroforestry plantations.

Late Phase

Unlike clonal stock that was imported during the previous two phases, open-pollinated seed has been introduced from abroad in this phase. All the seed has so far belonged to *P. deltoides* only and the USA has been the donor country.

A collection of 59 lots of open-pollinated seed of *P. deltoides* trees growing in the USA was introduced in Haldwani (Jha and Chhimwal, 1992). From this material only 6 clones were planted in the field. Growth data up to 3 years of age are reported (Jha and Gupta, 1992).

In 1990, Dr. Y.S. Parmar University of Horticulture and Forestry, Solan obtained open-pollinated seeds from 103 trees of *P. deltoides* along the Colorado and Brazos rivers in Texas and along the southern part of Mississippi river form Baton Rouge (Louisiana) to Davenport (Tennessee) (Land, 1996). Following three years of nursery measurements, 50 clones were developed out of this collection.

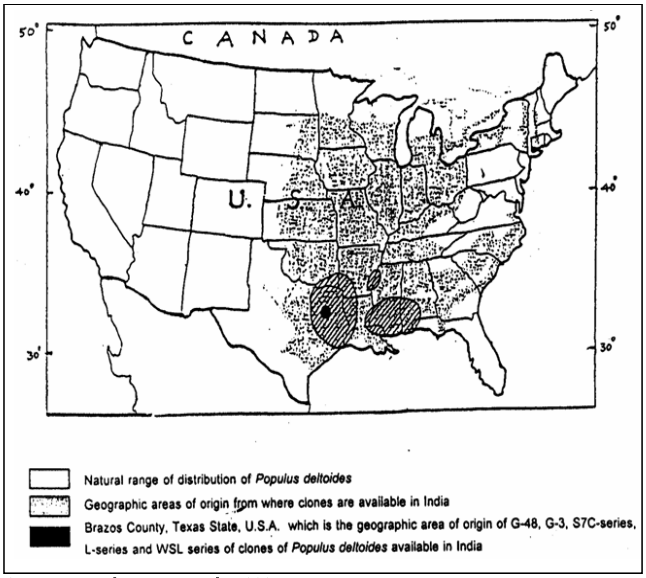
It was later realized that most of the germplasm of *P. deltoides* had been brought from cooler region of natural range of this species in North America. In comparison with the northern range (above 38°N latitude), the climatic conditions in the southern range (below 38°N latitude) of natural distribution match more closely with the conditions prevailing in the *P. deltoides*-growing region of India. Dinesh Kumar *et al.* (1999) examined the origin of 108 clones of *P. deltoides* and found that only 25 per cent part of the

Table 1. Ranks of 108 exotic clones of poplar

Rank	Clone	Rank	Clone	Rank	Clone
1	S7C8	37	2503	73	ST-148
2	82-35-4	38	74/27	74	4
3	113324	39	ST-66 (D-66)	75	ECO-28
4	G-48	40	S-748/111	76	82-18-2
5	3167	41	D-61(ST-61)	77	A-24
6	3324	42	22-4	78	3234
7	111828	43	82-26-5	79	LUISA-AVANZO
8	73/53-2	44	63/51	80	R-89
9	A-13	45	4/64	81	TRIPLO
10	D-74 (ST-75)	46	421-2	82	721502
11	D-75 (ST-75)	47	3678	83	2498
12	S4C21	48	A-343	84	2/56
13	82-33-3	49	19/66	85	BL-COSTA
14	ST-72	50	ST-244	86	3201
15	110702	51	S13C14	87	9/54-9
16	S7C15	52	LUX (69/55)	88	3456
17	S7C20	53	82-14-1	89	110504
18	28/8	54	G-3	90	1358
19	82-42-5	55	2500	91	111232
20	S7C4	56	S13C11	92	17-10
21	ONDA (72/51)	57	A-194	93	4/68
22	D-121 (ST-121)	58	1147	94	11-3
23	D-171 (ST-171)	59	3677	95	73/53-7
24	ST-124	60	61/58	96	64-243-1
25	D-82 (ST-82)	61	I-18/62	97	3298
26	72/58	62	54-2	98	D-19
27	S7C7	63	3287	99	2651
28	D-67 (ST-67)	64	82-29-2	100	1/56
29	S7C1	65	110120	101	1467
30	S7C2	66	D-29 (ST-29)	102	2
31	2502	67	110610	103	2652
32	ST-70	68	82-41-4	104	3650
33	82-36-1	69	D-181 (ST-181)	105	3232
34	S7C3	70	3651	106	JACOMETTI
35	3576	71	ST-92	107	2650
36	28/13	72	2656	108	3203

Source: Dinesh Kumar *et al.*, 1999.

southern native range of the species was represented in the germplasm in India (Fig. 1). Clones originating from areas located to the east of the Mississippi river in the southern range of the species have not been tested in India.



Source: Dinesh Kumar *et al.*, 1999.

Fig. 1. Four populations in natural range of *P. deltoides*, USA from where most of germplasm of this species has been introduced.

The FRI introduced more germplasm from abroad focusing on southern part of the USA. In the year 1997, seeds of 104 open-pollinated families of this species belonging to 44 stands covering 10 states in the south and east parts of USA were brought to the institute. After testing of seedlings in nursery, cloning of superior individuals (named FRI-AM series clones) and preliminary testing of clones in field, a field test was laid out at Hoshiarpur, Punjab. The best 40 clones identified on the basis of this field test were further subjected to trials at four sites in Uttarakhand and western Uttar Pradesh.

Table 2. Best 30 clones of FRI-AM series ranked on the basis of stem volume in Hoshiarpur, Punjab

Rank	Clone	Rank	Clone	Rank	Clone
1	FRI-AM-58	11	FRI-AM-106	21	FRI-AM-109
2	FRI-AM-51	12	FRI-AM-4	22	FRI-AM-7
3	FRI-AM-41	13	FRI-AM-89	23	FRI-AM-13
4	FRI-AM-32	14	FRI-AM-53	24	FRI-AM-45
5	FRI-AM-54	15	FRI-AM-105	25	FRI-AM-30
6	FRI-AM-44	16	FRI-AM-40	26	FRI-AM-93
7	FRI-AM-59	17	FRI-AM-24	27	G-48 (control)
8	FRI-AM-12	18	FRI-AM-33	28	FRI-AM-21
9	FRI-AM-48	19	FRI-AM-87	29	FRI-AM-14
10	FRI-AM-42	20	FRI-AM-20	30	FRI-AM-50

These trials by FRI led to the identification of the most productive clones in the test sites. Significant genotype-environment interaction was observed. However, the best five clones of any site were present among the best 16 clones of all other sites. Overall, clone FRI-AM-59, FRI-AM-58, FRI-AM-44, FRI-AM-41 and FRI-AM-54 were among the best seven performers (Table 2). Incidence of any significant clone-specific disease or insect attack was not recorded on any of these clones. Clone G48 and S7C8, the two check clones, ranked from 12 to 26 (rank one being assigned to the best clone) and from 5 to 17, respectively. The study indicates potential for multiplication and deployment (Dinesh Kumar and Singh, 2001) of the best five clones of FRI-AM series in operational plantations.

Introduction of Poplar Outside Traditional Cultivation Zone

Exotic poplar has traditionally been planted above 28^{o}N latitude in India in parts of Punjab, Haryana, Uttar Pradesh, lower hills and outer valleys of Himachal Pradesh, Uttarakhand and Jammu and Kashmir. Singh *et al.* (1999, 2001a, b and c) strongly advocated the need for extending cultivation of *P. deltoides* to lower latitudes. Dr. N.B. Singh, Chief Technical Advisor (poplar) during 1999-2001 supplied germplasm of promising clones to researchers in areas both inside and outside the traditional planting zone covering Jammu and Kashmir, Himachal Pradesh, Punjab, Haryana, Uttar Pradesh, Bihar, West Bengal, Orissa, Chhattisgarh, Maharashtra, Gujarat and Assam. Among areas outside the traditional zone, performance of the clones in Bihar was encouraging and poplar cultivation was recommended in these sites. Due to lack of feedback about performance in other non-traditional areas, it can be assumed that performance of poplar was not up to the expectations in those areas.

In previous efforts, *P. deltoides* had been planted in Maharashtra where it showed good performance initially but died after 3-4 yrs (Ballal, 2001). Gera *et al.* (1993) planted this species in sporadically irrigated site at Jabalpur in Madhya Pradesh and observed good early growth but the plants began to die back at 3 years. The first author of this paper has observed good growth of *P. deltoides* at six years of age in farmers' field at Chhindwara in Madhya Pradesh, thereby, suggesting that inadequate irrigation during summer season, which usually results when poplar is not intercropped with appropriate agricultural crop, might be the key factor behind failure of this species in introduction trials in some sites. Failure of *P. deltoides* was also noticed in Kerala state in south India, where this plant was planted in unirrigated land.

Encouraged by the initial performance of *P. deltoides* in Bihar, ICFRE has, in a major initiative, introduced large scale cultivation of this species in northern Bihar. About 6.10 million plants of poplar have been multiplied (Fig. 2) and planted (Fig. 3) in district Vaishali during the first phase of the project that started in 2005. Wherever site selection and cultural operations were done well, performance in the plantations there, has been comparable to plantations in the traditional zone.

Introduction of Poplar into Agroforestry

P. deltoides has very high growth rate (mean annual increment of 20 to 25 m^3/ha/year) in India. The high productivity is achieved only when it is intercropped with such agricultural or horticultural crops as require intensive irrigation and other cultural operations. Research on agroforestry of this species was started by FRI Dehradun, Haldwani centre of state forest department and WIMCO in early 1960s. Cultivation of *P. deltoides* in agroforestry system by farmers started in 1970s; during early years it was practised only by very rich and progressive farmers who had surplus land and financial power to bear the risk of plantation failure. The credit of taking this tree to the farmers for widespread plantation goes to WIMCO that started an extension project for massive plantation of poplar in Punjab, Haryana and western Uttar Pradesh 1976 onward and with financial support of National Bank for Agriculture and Rural Development (NABARD) between 1984-1995 and independently thereafter. WIMCO-NABARD poplar scheme has been a noble venture of joint partnership between the industry and the banking sector working together for the benefit of the farming community, industry and unemployed people besides providing environmental services.

Fig. 2. Pre-treatment of cuttings of *P. deltoides* for raising farmer's nursery at Vaishali, Bihar.

Fig. 3. Boundary plantation of *P. deltoides* by a farmer with small landholding at Vaishali, Bihar.

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Status of Poplar Culture in India

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A major share of poplar is grown in parts of Punjab, Haryana, Uttarakhand, Uttar Pradesh and some adjoining states and these locations have been collectively designated as the region of intensive poplar culture (RIPC)

Introduction

Poplar culture in India is mainly taking place on the farmland in parts of the northern India, though a very small percentage is also planted on the forest land by the state forest departments in and around the Himalayan ranges. Introduction trials of poplar species and clones were tried 1950 onwards in the state of Uttar Pradesh and some other states (Chaturvedi, 1982 a and b). The tree is, however, being regularly promoted on farmers' fields by WIMCO – a safety match company since 1976 (NAEB, 1993; Jain and Singh, 1999; Dhiman, 2008a). A number of private nursery growers and a couple of state forest departments also contribute in supplying a sizeable number of saplings to the growers for making fresh plantations. Increased wood availability from WIMCO's promoted programme encouraged establishment of other wood based industrial units in and around its growing region. Due to the increased demand of poplar wood, its trade expanded in the unorganized sector and accordingly its culture. Poplar culture and usage are now fully merged into the social, ecological, agricultural, silvicultural, economical and industrial applications, which are immensely helping in the economical transformation of growers and the region. Poplar is generating goods that include timber, firewood, fodder, leaf manure, etc. The use of poplar wood is now diversified to around three dozen products of which panel products, firewood, paper pulp, match splints, sports goods, artificial limbs are the major ones (Dhiman, 2008b). Its farming helps in sequestration of harmful gases into wood biomass and soil, locking greenhouse gases in products made from its wood; substituting sustainably grown firewood for fossil fuels in domestic and industrial use; bioremediation of soil, air and water by absorbing pollutants; conserving soil and water along the ecologically sensitive river basins of Ganga, Yamuna, Satluj, Beas, Sharda and their tributaries; and reducing industrial effluent load in paper industry by using poplar pulpwood that requires less chemicals in processing in comparison with the traditional pulp woods. Poplar culture also improves water use economy by shifting growing of high water demanding paddy crop to low water demanding agriculture crops grown inside poplar plantations. It has improved living conditions of rural people by generating an employment potential of approximately 100 million man days in poplar related activities mostly in rural locations (Dhiman, 2008b) and further sustaining the agricultural production system by shifting from the monotonous paddy-wheat rotation to ecologically more sustainable and integrated multiple cropping land use with sylvan landscape. Poplar culture in India is assessed to yield approximately 7.5 Mt timber, 1 Mt pulp wood, approximately 5 Mt firewood (also includes wood wastage from industry) and sequestration of approximately 2.50 MtC per annum (Dhiman, 2009) based on planting and harvesting of 20 M trees per annum on 10 yrs average basis. The planting number of its saplings is now increased to over 30 million and, therefore, the benefits of goods and services from its culture have also increased (Table 5 and 6). This paper summarizes the present status of poplar culture especially on volume of its nursery production and fresh plantations made during 2011-12.

Trends in Poplar Nursery and Plantation Culture

Poplars are one of the first tree species which were grown in the hills for getting firewood, fodder and small timber for local consumption. Occurrence of approximately 600-yrs old *P. balsamifera* tree in Leh town (Fotidar, 1983) and that of other trees of this and other species in Jammu and Kashmir (J. and K.), Himachal Pradesh (H.P.) and Arunachal Pradesh (Naithani and Sumer Chandra, 1999; Chauhan and Lakhanpal, 2000) confirms poplar being grown in hills for centuries. Some poplar trees recorded in and around Budhist temples (Gompas) also indicates their sacred value in India (Dhiman, 2010a). A major share of poplar is grown in parts of Punjab, Haryana, Uttarakhand, Uttar Pradesh and some adjoining states and these locations have been collectively designated as the region of intensive poplar culture (RIPC) (Dhiman, 2012). RIPC stretches from western limits in Punjab to eastern limits inside north western Bihar and from north near foot hills of Himalayas down towards north central Haryana and Uttar Pradesh. Poplar culture in this region is based on indigenously developed and introduced cultivars of *P. deltoides*. Some other introduced and indigenous species planted on a limited scale in the central and inner Himalayas especially in the cold arid region of Jammu and Kashmir and Himachal Pradesh states are *P. nigra, P. alba* and *P. balsabifera*. Many productive clones of *P. deltoides* have now been introduced in the cold arid region during the last three decades, and this species is now preferred over other poplar species because of its fast growth almost everywhere. *P. ciliata* and *P. gamblei* are the poplars indigenous to Himalayas and some of their plantations have been made on forest land for diverse forestry purposes.

A major share of poplar is grown as a cash crop similar to many agricultural crops. Spread in its nurseries and plantations depends on market wood prices and the trends, till date, indicate increase in its culture with increase in valuation of its wood. Both the market wood prices and its fresh plantations have been increasing since 2005. Within the RIPC and elsewhere, the intensity of poplar culture is concentrated in certain locations. Poplar culture within each district, location, state and RIPC is not uniformly distributed and there are imbalances in its spread. Poplar growing locations in each state have been categorized into excellent, large, medium, low, and rare/casual levels based on the volume of planted poplar in those locations (Table 1).

There are three distinct and concentrated zones of poplar culture within the RIPC around which maximum poplar is grown in the country. The two zones located on the western side of poplar culture lie around the river basins whereas the third lies in the Tarai region of Uttarakhand and

Table 1. Intensity of poplar culture in different districts of India

S. no.	Scale	Jammu and Kashmir	Himachal Pradesh	Punjab	Haryana	Uttarakhand	Uttar Pradesh	Bihar	Rajasthan
1.	Extensive			Hoshiarpur, SBS Nagar, Roop Nagar, along the river banks of Beas and Sutlej	Yamunanagar	Udham Singh Nagar and Haridwar	Saharanpur, Muzaffarnagar, Bijnor, Meerut, Rampur, Bareilly, Pilibhit, Moradabad, Jyotiba Phule Nagar		
2.	Large	Central Kashmir		Amritsar, Gurdaspur, Jalandhar, Kapurthala, Ludhiana	Karnal, Panchkula, Ambala, Kurukshetra		Baghpat, Amroha, Badaun, Shahajahanpur, Kheri		
3.	Medium	North Kashmir, South Kashmir	Una, Kangra	Pathankot, Moga, Mohali	Panipat, Kaithal	Dehardun and Nainital	Bulandshahr,, Bahraich, Sitapur, Hardoi, Gautam Budh Nagar	Vaishali	
4.	Low	Kathua and Poonch of Jammu region; Ladakh and Kargil of Ladakh region	Sirmour, Solan, Mandi, Lahaul and Spiti	Tarantaran, Firozpur, Patiala, Mukatsar, Fazilka	Sonipat, Rohtak, Faridabad	Pauri Garhwal and Champawat (Tanakpur area)	Maharajganj, Kushinagar, Gorakhpur, Etah, Aligarh, Sidharath Nagar, Sravasti, Balrampur, Deoria, Balia	Muzzafarpur	Ganga Nagar
5.	Rare	Other districts	Other districts	Bathinda, Barnala, Sangrur, Mansa, Fatehgarh	Hissar, Sirsa, Fateihabad, Gurgaon, Jind	Other districts	Kanpur, Agra, Lucknow, Faizabad, Sulatanpur, Azamgarh, and others	Champavat	Hanumangarh Bharatpur

Uttar Pradesh states. Adequate water availability within these zones and deficit around their boundaries appear to make this distinction in poplar culture. The first zone of concentrated poplar culture lies towards the western limits along the basins of rivers Satluj and Beas in Punjab with some overlapping in plain locations of Himachal Pradesh. The land around and between these two rivers is ideally suited for poplar farming because of easy water availability and sandy loam soil conditions. This zone lies towards higher latitudinal limits within the RIPC and is better suited for poplar culture in comparison with two other zones. It starts around Hoshiarpur in Punjab and extends towards Chandigarh through SBS Nagar and Rupnagar districts on one side and towards Ludhiana district on the other side. The growth and quality of poplar grown in this zone is better and it fetches higher prices in the market. The second major activity of poplar culture is seen around Yamuna and Ganga Rivers and surrounding their basins starting from Himalayan foothills down towards central Haryana and central Uttar Pradesh. This zone overlaps in three states, viz., Haryana, Uttarakhand and Uttar Pradesh and has maximum area under poplar farming. This zone is at a little lower latitude than the first zone, yet has maximum number of wood processing industries and also receives poplar wood from other locations and states. It constitutes Yamunanagar District of Haryana, Saharanpur and Muzaffarnagar districts of Uttar Pradesh and Haridwar District of Uttarakhand.

Zone-III lies in the plain region near foothills of Uttarakahnd and Uttar Pradesh states and known as Tarai region. It is a narrow belt between 27^{o} N and 30^{o} N latitudes at an altitude of about 160 to 260 m, along the foothills of Himalayas where water is available at a depth of 1 to 2 m below surface with further having underlying layer of sand and small pebbles to varying degrees. Unlike other two zones, soil at places is very heavy, yet it supports poplar culture on account of good water availability. Poplar (*P. deltoides*) were initially tested here before their culture was extended to other zones and locations in the RIPC and elsewhere. The zone lies in Udham Singh Nagar in Uttarakhand, and stretches to parts of Uttar Pradesh in Pilibhit and Bareilly on one side and some parts of Rampur on other side. The data gathered on fresh poplar plantations made during the last two years indicates that two third to three fourth of the total poplar planted throughout, is in these three zones. Around 29 per cent of total poplar is planted around Zone-II, 22 per cent around Zone-I and around 18 per cent around Zone-III. Recently, the share of fresh plantations has started increasing in the third zone because many new poplar based wood industrial units have been established in Uttrakhand and many others have expanded their capacity in Uttar Pradesh. Prices of poplar wood and labour wages are lower in Zone-III favoring increased poplar farming and its usage.

Extent of Nursery Production

Poplar is grown on non-forest land in many states for which a complete data on the volumes of its saplings production is not available. Till 1994, most of its plantations were grown by the farmers under WIMCO-NABARD refinance scheme. WIMCO was responsible for supplying its saplings to the growers under this project, which is also referred as PPP model, and the wood grown from these trees was purchased back by the company at already disclosed prices. The company was, therefore, the only source for supplying the saplings to the growers till that stage. The number varied from a few hundred in 1976-77 to around 250 thousand during mid 1990s. On termination of WIMCO-NABARD scheme, and with the success of the direct sale of saplings outside, the refinance scheme was started by the company in the year 1993, poplar sapling production expanded among the numerous nursery growers. It also provided opportunity to the separating company staff with technical skills to venture into growing and selling poplar saplings to the growers. As a result, the business of establishing private nurseries started growing. WIMCO, ex-Wimcoites, individual farmers and unemployed villagers are presently the main nursery growers. Haryana State Forest Department has now accelerated its sapling production on increasing demand within the RIPC and elsewhere. Jammu and Kashmir, a hilly state with most of its area land locked between hill ranges, has also started growing sizeable number of poplar saplings for local planting by the growers. There is migration of some of the poplar based industry to this state because of low value of wood available there, which has increased the rate of planting and demand of its saplings within Kashmir Valley. State forest departments in North India have also been growing poplar saplings for making their own plantations on forest land during this period. Some information on the availability of planting stock in U.P. State Forest Department nurseries is accessible from the state website (http://forest.up.nic.in/plantation.pdf) (Table 2). Similarly a detailed survey of poplar nurseries carried out by the Haryana State Forest Department during 2011-12 provided information on the extent of nursery stock grown in that state (Dhiman and Jagdish Chander, 2012).

The total poplar nursery stock presently available in the U.P. State Forest Department nurseries is given in Table 2 indicating that poplar constitutes less than 0.1 per cent (84,099 saplings in 52 nurseries) of the total planting stock (87,632,706 number for 72+ other species in 925 nurseries of 72 forest divisions) grown in the state. The major share of poplar nursery and plantation production in the state is in the private sector which grows poplar saplings as naked root plants in open beds and are called as entire transplants (ETPs) or saplings. Conservative estimates indicate that the private sector has grown around 15 million nursery saplings during the just concluded planting season in the state (Table 2). Among the private nursery growers, WIMCO is a leading player in nursery production throughout the RIPC and is growing 6.5 million saplings this year in its nurseries located in the RIPC. The company has been monitoring the extent of poplar nurseries grown by different sources in different states through its field staff. The information on nursery stock is collected from its field staff posted throughout the RIPC and the estimates of total poplar saplings grown in the state of Uttar Pradesh are given in Table 3. The names and the boundaries of WIMCO's operational districts do not synchronize with that of the administrative and revenue districts as per government controls but are overlapping with the adjoining districts in many locations.

Haryana is one of the leading states in poplar wood usage and also grows appreciable number of saplings for planting within the state and also for supply to some other states (Dhiman and Jagdish Chander, 2012). A detailed survey of all the poplar growing nurseries was carried out by the Haryana State Forest Department which confirms growing of approximately 13.4 million poplar saplings during the year 2011-12. A major share is grown in the private sector by small nursery growers (Table 4). In the organized sector, WIMCO and the state forest department were the leading nursery growers in term of number and diversity of clones grown in the state. Yamunanagar town is a major poplar growing and its usage centre in the state and the country. Yamunanagar District grows around 60 per cent of total poplar grown in the state. The district is also a main centre for seedling production and their supply to the adjoining states. It receives wood from all other poplar growing states including Punjab, Himachal Pradesh, Uttrakhand and Uttar Pradesh and wood traders also supply saplings to many wood procuring locations.

Uttrakhand state (earlier part of U.P.) has been growing poplar saplings from the very beginning when poplar research trials were initiated by the state forest department during the second half of 20th Century. The focus of the poplar programme in the state remained with testing of imported clones and development of mechanized plantations in and around Tarai region. The state has been growing poplar nurseries for own plantations on forest land near Kumaun foothills since 1970s. Presently, the state is growing around one hundred thousand saplings in its nurseries for own

Table 2. Poplar stock existing in the nurseries of U.P. State Forest Department

S. no.	Forest Circle	Forest Division	Nurseries (no.)	Plant stock (no.)	Average stock (per nry)
1.1	Agra	Firozabad	1	2,000	2,000
1.2		Mainpuri	1	558	558
2.1	Allahabad	Allahabad	1	700	700
2.2		Fatehpur	1	4,400	4,400
3.1	Azamgarh	Azamgarh	1	300	300
3.2		Baliyaa	4	1,965	491
3.3		Mau	4	1,816	454
4.1	Bareilly	Bareilly	15	49,776	3,318
4.2		Pilibhit SF	1	300	300
4.3		Shahajahanpur	1	293	293
5.1	Basti	Basti	1	1,000	1,000
6.1	Faizabad	Ambedkar Nagar	4	2,825	706
6.2		Faizabad	2	1,360	680
6.3		Sultanpur	8	10,000	1,250
7.1	Gorakhpur	Gorakhpur	2	8,600	4,300
8.1	Kanpur	Etawa	2	1,050	525
8.2		Dehat	2	850	425
9.1	Meerut	Bulandshahar	1	301	301
		Total (U.P.)	**52**	**88,094**	**1,694**

(Source: http://forest.up.nic.in/plantation.pdf).

Table 3. Estimated poplar planting stock produced by private growers in U.P. (2011-12)

S. no.	District	Locations	Stock grown (no.)
1.	Saharanpur	Saharanpur, Nakur, Deoband, Rampur	3,100,000
2.	Muzaffarnagar	Muzaffarnagar, Deoband, Barla, Bhopa, Jansath	450,000
3.	Meerut	Hastinapur, Mawana, Hapur, Garh, Ghaziabad, Sardana, Baghpat	1,300,000
4.	Bulandshahar	Toria, Khalout, Bateshwar (Agra)	300,000
5.	Agra	Bateshwar	50,000
6.	Aligarh	Atrauli	100,000
7.	Moradabad	Moradabad, Amroha	800,000
8.	Bijnor	Dhampur, Chandpur, Nurpur, Afjalgarh	600,000
9.	Rampur	Milak, Rampur, Chandaushi, Bilaspur, Kemri, Muda Pandey	3,400,000
10.	Bareilly	Bareilly, Baheri and Meerganj, Aonla, Faridpur, Bhojipura	1,050,000
11.	Pilibhit	Majhoula, Bisalpur, Tikri, Amaria, Khamria	550,000
12.	Badaun	Dataganj	150,000
13.	Sahajahanpur	Kot, Tilhat, Katra, Shehramau, Puvaya, Khutar, Nigohi, Bhawal Khera	550,000
14.	Lakhimpur	Lakhimpur, Dharaura, Palia	400,000
15.	Sitapur	Tambore, Sitapur	100,000
16.	Bahreich	Nanpara, Payagpur, Kesarganj, Econa, Bahreich	850,000
17.	Hardoi	Kothava, Badhauli, Sadabad, Pali	200,000
18.	Others		1,200,000
	Total		**15,150,000**

planting. Wimco Seedlings operates from Rudrapur, Uttrakahnd and is still the main player for supplying saplings to the growers along with some ex-Wimcoites and other small growers. Maximum private nurseries are located in Udham Singh Nagar and Haridwar districts, some of which also supply saplings to other states.

Punjab is the fourth leading state in poplar sapling production in the country. It grows nurseries in different locations. Around one hundred thousand saplings are grown by the government institutions that include Punjab Agricultural University, Ludhiana and the Punjab State Forest Department, together. The major share of sapling production is in the private nurseries located in Hoshiarpur, SBS Nagar and Roopnagar districts in the state. Some saplings are supplied to the adjoining poplar growing locations in Himachal Pradesh and Jammu and Kashmir states.

Table 4. Poplar saplings grown in Haryana state during 2011-12 planting season

S. no.	District	Nursery stock	Share (%)
1.	Yamunanagar	8,129,300	60.51
2.	Kaithal	37,500	0.28
3.	Karnal	1,766,000	13.15
4.	Panipat	961,000	7.15
5.	Rohtak	37,000	0.28
6.	Sonepat	220,000	1.64
7.	Panchkula	880,500	6.55
8.	Ambala	1,168,500	8.70
9.	Kurukshetra	234,000	1.74
		13,433,800	**100.00**

Jammu and Kashmir (J. and K.), a hill state, has traditionally been growing poplar. The state grows approximately thirteen to fourteen hundred thousand poplar saplings in the state. Recently, restrictions on transporting planting stock and wood across the state border have been imposed, hence, most of the planting stock is grown within the state itself. Some supplies of the planting stock, however, still take place from the adjoining RIPC to Jammu region where the tree is grown similar to that grown in the RIPC. Private nurseries now grow little more saplings compared to those grown by the Social Forestry Wing of the state forest department. Major share of private nurseries is concentrated in south Kashmir followed by central Kashmir, north Kashmir and Jammu region and Ladakh region. Many cities and locations in Kashmir Valley are affected by typical cotton storms during the dispersal of its seed in spring season. In the last couple of years, the Jammu and Kashmir State Forest Department and state university have been procuring the propagation material of male clones from WIMCO for raising their nurseries and field planting to avoid this problem.

The state of Himachal Pradesh (H.P.) has been making planting of around one hundred thousand saplings on the forest land and this planting stock is grown by the state forest department in its forest nurseries. A major share of the planting stock planted by the growers in the plain and in some valley areas of Himachal Pradesh is supplied by the private nursery growers from the adjoining poplar growing locations, like Hoshiarpur, Roopnagar, and Pathankot districts in Punjab and Yamunanagar and Panchkula districts in Haryana. The major part of poplar wood harvested in the state is traded at Yamunanagar wood market in Haryana and Hoshiarpur in Punjab. Both these locations are leading centers for poplar sapling production as well. Wood traders who transport wood from different locations of the state also carry saplings from these locations and supply them to the growers during the planting season. Many of good growers especially near the RIPC also directly procure planting stock from the branded nurseries located in the RIPC. Some private nurseries have also come up in Indora belt of Kangra, plain areas of Una District, Nalagarh area of Solan District, Paonta Valley of Sirmour District and Balh Valley in Mandi District to meet the increasing demand of the growers.

In Bihar, poplar saplings have been grown under the centrally sponsored project implemented by the Indian Council of Forestry Research and Education through its institute at Ranchi wherein approximately four hundred thousand saplings were grown in Vaishali District during last year. The state is also planning a Green Mission in which poplar is considered one of the potential species. A few poplar growers in the north Bihar have, however, been directly getting the planting stock from the RIPC for making plantations during the last two decades.

Some poplar saplings, in private and government nurseries, are also grown in Chandigarh, Delhi, Rajasthan, and even some northeastern states. There is also a regular movement of poplar saplings from the RIPC to central, north eastern states and other locations during the planting season each year.

Extent of Fresh Plantations

Poplar has been regularly planted in number of states and locations. Major among them have been hill states of Uttarakhand, Jammu and Kashmir, and Himachal Pradesh where poplar trees in isolated form or in groups could be seen in almost all the hilly districts. Poplar has also been planted in some parts of Delhi, Chandigarh, Rajasthan (Ganganagar, Hanumangarh, Bharatpur districts), north Bihar (Vaishali, Muzzafarpur, Samastipur, Champaran, etc.), north West Bengal and other northeastern states for quite some time now. Poplar plantations on forest lands have mainly been restricted to Uttarakhand and Himachal Pradesh states with some of them grown on road and canal sides, and railway-lines in some states in the RIPC and in hills. Some trial plantations of poplars have also been made in many other central and southern states with suboptimal field performances not at par with that grown in the RIPC.

Some figures of poplar plantations on forest land are available from Uttarakhand and Himachal Pradesh. First organized poplar introduction trial plantations were raised in hills and foothill locations of Uttarakhand (earlier part of Uttar Pradesh). The state of Uttarakhand played a significant role in the introductions, establishment and expansion of poplar programme in the country. There were sporadic plantations till 1977 and thereafter, a regular planting was included in the working plans of some of the forest divisions. The trial with introduced clones were tried near foot hills in 1966 and the growth and productivity of those clones was not very encouraging. G3 and G48 clones were introduced 1969 onward which proved very productive for these locations. There was 1,522 ha area under poplar plantation till 1982 (WoP, 1982) and around 3,500 ha by 1999 (Burfal, 1999). Later on Wimco Seedlings established its research base in Rudrapur which helped in its further establishment and expansion of the programme on farm fields.

Himachal Pradesh State Forest Department has been planting poplar since long. *P. ciliata* is largely planted on forest land by the state forest department and to some extent by the research organizations in their research trials. The interest in poplar as a plantation species dates back to 1950s when planting of *P. ciliata* along with some introduced species were explored as a nurse crop for regeneration of fir and spruce forests in the state (Agarwal and Patil, 1956). *P. ciliata* with introduced *P. monilifera* and *P. generosa* were tried and proved useful in regenerating fir and spruce in Kullu District but could not be replicated on a large scale. *P. deltoides*, is the main preferred species in poplar culture in the state. It finds favour among all growers, viz., farmers, state forest department and research organizations for growing in locations from cold desert to Himalayan foot hills and valley areas. It is mainly planted in Balh Valley of Sundar Nagar, Mandi District, Mand belt (Indora Division) of Kangra District, lower areas of Una District, Nalagarh Division of Solan District and Paonta Valley of Sirmour District. The species was also introduced in the Spiti cold arid region during early 1980s and some of its plantations are better grown than many plantations of other species. The main cultivars of poplar commercially grown in the state are the same which are grown in the RIPC. These include G48, Udai, WSL 22, WSL 39, etc. with some last year released clones specifically WIMCO 81, WIMCO 83 and WIMCO 110 are also now finding favour among the growers. UHF has developed and recommended some clones of poplar for growing in the state (www.yspuniversity.as.in).

Himachal Pradesh has documented plantation figures of poplar and other tree species made from 1950s and posted them on its website (http://himachal.gov.in). Out of a planted area of 1,026,776 ha under different schemes till date (w.e.f. 1950 to 2009-10), poplar plantations cover 14,958 ha which represents 1.46 per cent of the total plantations made in the state so far. Many of the species planted in the state are slow growing conifers and broadleaved species, the share of poplar and willow planted area is, therefore, likely to be very low as most of the earlier planted poplars could have lived their physical age or could have been harvested. The tree is highly sensitive to moisture status of planted sites, the initial and final survival is likely to be lower than the hardy conifers and some broad leaved trees. The state raises plantations with around 20 million plants per year, out of which poplar constitutes 0.58 per cent of total planting. During the last two years, there were 21 plantation schemes, out of which poplars were planted in 12 schemes. CAT plan had maximum plantation of poplars (28.40 per cent) followed by backward area sub plan (19.37 per cent), improvement of tree cover (12.93 per cent), plantation under MHWD project (9.08 per cent), soil conservation (7.61 per cent), enrichment planting (5.83 per cent), compensatory plantations (5.31 per cent), pasture development (4.57 per cent), reforestation of scrub areas (2.95 per cent), macro management (RVP) (1.66 per cent) and FDA samridhi yojna (0.56 per cent) (http://himachal.gov.in). Circle-wise data of poplar planting during these two years further confirm that poplar is planted for diverse purpose. Bilaspur and Hamirpur forest circles located in the lower Himachal Pradesh have some poplar plantations by the private growers though government figures do not show any planting in those areas. The plantation figures further confirm poplar planting under wildlife and watershed programmes. Kullu Forest Circle leads in the state with planting of 41.18 per cent of total poplar on government forests followed by Rampur (20.22 per cent), Shimla (9.70 per cent), MHWD Project (9.08 per cent), Wildlife Shimla (8.26 per cent), Nahan (5.96 per cent), Chamba (4.19 per cent), Dharamsala (0.76 per cent), wildlife Shamshi (0.76 per cent) and wildlife Dharamsala (0.27 per cent) of the total poplar planted in the state (http://himachal.gov.in). Poplar was one of the main tree planted in a centrally sponsored programme - Desert Development Project which was launched for Spiti Division of Lahaul and Spiti District in 1978 and for Pooh Division of Kinnaur District in 1982 with special emphasis on rehabilitation of cold desert. Under this programme, 1,636,735 plants were planted over 830 ha (Negi *et al.*, 1996).

Two regional centers of UHF, viz., RHRS, Jachh and HRRS, Dhaulakuan and its main campus at Solan have been producing poplar saplings for own use and to supply them to tree growers of the locality since mid 1990s. According to Chauhan (2012) Jachh and Dhaulakuan centers have produced and supplied 89,207 and 163,305 saplings respectively till date (total 252,512). The annual supply is worked out to be 8,600 saplings from Dhaulakuan and 5,500 saplings per year from Jachh, respectively. The university had a saleable stock of around 800 fully grown poplar trees that was put to auction during 2011. Himalayan Forest Research Institute is also raising poplar and willow nurseries which have been established in different locations including cold desert region. Some poplar has also been planted by the Public Works Department (PWD) along road side especially along national highway around Solan town.

Major share of poplar in India is planted in the RIPC. Though planting season is restricted to winter months, its harvesting and usage is spread throughout the year. It is harvested, transported, traded and used on day to basis. Harvesting decisions are driven by financial needs of individuals than strong silvicultural options. It is extremely difficult to capture these frequent changes from such a wide geographical area controlled by many states. This many a times has already affected the industry and growers by widening gap between demand and supply and also in crashing of its prices due to glut like situation in the market. National Poplar Commission, quoting Forest Survey of India, has reported 312,000 ha area under poplar in the country (NPC, 2012). Forest Survey of India first time reported inventory of 75,807,000 number poplar stems (with further classification into size classes as 74,150,000 in 10-30 cm dbh class, 1,644,000 in 30-50 cm dbh, 7,000 in over 50 cm dbh class) in its 2011 report which collectively represent 1.50 per cent of total stems recoded as ToFs in the country. The report further confirms the volume of 11.159 mm^3 of poplar trees in 10-30 cm dbh, 1.260 mm^3 in 30-50 m dbh and 0.023 mm^3 in over 50 cm dbh class for all the poplar trees as ToFs in the country. The total volume of poplar trees as ToFs is reported as 12.402

mm[3] representing around 0.8 per cent of total volume in ToFs in the country (IFSR, 2011). The districts once selected for surveying is likely to be surveyed after 10 cycles (20 years) with a further possibility of 25 per cent already surveyed districts being selected for saplings after eight years as per sampling procedure followed by the organization. The survey is based on the interpretation of photo-imagery recorded during October 2008 to March 2009. It records trees only over 10cm dbh class and when the harvesting of poplar in many locations is now being carried out at a young age as early as of four years. Many of the poplar trees thus get harvested even without getting a documentation in this report. These figures are just indicative numbers projected from limited information collected from limited sampled districts (178 districts from 2002 to 2009) and do not have much practical significance. The author, therefore, has been relying more on the interpretation of information collected on the nursery stock grown and that fresh planted in different locations. Most of this information is being regularly published for the benefit of others The information collected for the planting season 2011-12 from different locations is presented in the Table 5, which indicates that Uttar Pradesh is the leading state for growing 38.61per cent of total poplar in the country followed by Punjab (18.01 per cent), Uttarakhand (16.95 per cent), Haryana (16.33 per cent), Jammu and Kashmir (3.85 per cent), Himachal Pradesh (2.49 per cent) and other with collective share less than 5 per cent. A major share of poplar in Punjab is grown in compact blocks, whereas Jammu and Kashmir grows most of its poplar as shelterbelt around fields and orchards. The trend is mixed in most other states and is ever changing with change growers from year to year. These figures are again not absolute values on the status of surviving stems which undergoes a change every time, based on numerous factors.

Based on the above, published information and that collected from the field staff and personal contacts from different states, it is inferred that a total nursery stock grown in the country was 48 million, out of which around 25 per cent remain unsold especially from the low quality nurseries (WSD, 2011) (Table 6). Around 10 per cent stock is kept for multiplication for making next year nurseries. Further it is inferred that maximum poplar is planted on the farm land in association with agricultural crops and the share of poplar planted on forest land is very negligible. Like sapling production, there is also no database available for field planted poplar from most of the states.

Table 5. Estimated number of poplar saplings planted during 2011-12 planting season

State	Planted in block			Planted on boundary or row			Total	
	(No.)	Per cent of total	Per cent of state	(No.)	Per cent of total	Per cent of state	(No.)	Per cent of total
Jammu and Kashmir	100,000	0.56	8.33	1,100,000	8.17	91.67	1,200,000	3.85
Punjab	4,317,700	24.38	76.90	1,297,000	9.63	23.10	5,614,700	18.01
Haryana	2,635,000	14.88	51.77	2,455,000	18.23	48.23	5,090,000	16.33
Himachal Pradesh	430,000	2.43	55.48	345,000	2.56	44.52	775,000	2.49
Uttarakhand	2,625,000	14.82	49.67	2,660,000	19.75	50.33	5,285,000	16.95
Uttar Pradesh	7,253,800	40.96	60.26	4,784,500	35.53	39.74	12,038,300	38.61
Bihar	110,000	0.62	24.44	340,000	2.52	75.56	450,000	1.44
Rajasthan	115,000	0.65	51.11	110,000	0.82	48.89	225,000	0.72
Others	125,000	0.71	25.00	375,000	2.78	75.00	500,000	1.60
Total	**17,711,500**	**100.00**	**56.81**	**13,466,500**	**100.00**	**43.19**	**31,178,000**	**100.00**

Table 6. Estimated number of poplar saplings grown in nurseries and field during 2011-12

State	Nursery (No. in hundred thousand)			Field planting (No. in hundred thousand)		
	Government sector	Private sector	Total	Government sector	Private sector	Total
Jammu and Kashmir	4.00	9.00	13.00	0.00	12.00	12.00
Punjab	1.00	71.00	72.00	0.00	56.25	56.25
Haryana	20.00	114.00	134.00	0.00	5.00	51.00
Himachal Pradesh	1.00	8.00	9.00	1.00	6.75	7.75
Uttarakhand	2.00	90.00	92.00	2.00	51.00	53.00
Uttar Pradesh	1.00	150.00	151.00	0.00	120.00	121.00
Bihar	4.00	0.00	4.00	0.00	4.50	4.50
Others	1.00	3.50	4.50	0.50	5.00	5.50
Total	**34.00**	**445.50**	**479.50**	**3.50**	**260.50**	**311.00**

Nursery Production

Poplar is normally propagated by using hardwood stem cuttings collected from the last year nursery grown juvenile saplings. Stressed and desiccated cuttings or those collected from mature trees sprout late and cause variation in the nursery stock. Cuttings are planted in well prepared open nursery beds during January-February. With normal cultural operations of earth working, irrigation, weeding, and tending; saplings attain an average height of 3-6 m or sometimes more based on inputs and cultural operations provided to the nursery. Approximately 20,000 saplings are produced in an hectare nursery area. WIMCO now uses a different approach for growing saplings in its nurseries. The plantlets are first grown using reproduction means discussed above which are then planted in open beds any time till July depending upon the size of the saplings required in a particular locality (Dhiman and Gandhi, 2010). The saplings grown by the new means continue to grow sometimes till first week of November, remain in leaves till last week of December, lateral buds rarely sprout during the active growth period, have better diameter/ height ratio and looks fresh with soft bark compared to those planted by traditional stem cuttings route during January February. Terminal bud setting in traditionally grown saplings generally starts during the last week of October.

Plantation Establishment

Saplings are lifted during January and February, conditioned in fresh water for around 48 hours and are field planted after their nursery growth. The planting period is sometimes advanced to December and also extended to the first week of April depending on land preparation, occupation of fields with intercrops and other field conditions. The recent experimentation of planting poplar October onwards with certain innovations proved encouraging. Based on around half a dozen field trials across the RIPC, early planting of poplar saplings is now a reality and is being demonstrated to the farmers throughout the RIPC.

Poplar is planted inside and around agricultural fields. Land preparation near to poplar planting time, followed by one or two timely irrigation has a significant effect on initial survival of poplar. It is planted in augur made 7-10 cm round and 60-90 cm deep pits. Poplar develops major root system near the surface and the deep planting is followed for anchoring the trees against strong winds. On putting the sapling in the pit (hole), 3/4th of the pit is filled with top soil mixed with appropriate nutrient mixture that depends on the fertility of the soil. The fields are irrigated with surface water to an extent that some water stands inside pits which helps in settling the filled soil inside the pit. The remaining empty pit is filled after around a week with fresh soil and again irrigated for settling the soil. Irrigation, thereafter, is provided to agricultural crops till summers when additional irrigations are provided if intercrops are not grown along with poplar. Poplar is planted over a wide range of spacing and patterns. The most common spacing adapted are 5x5 m or 5x4 m or 7x3 m or 8x3 m in blocks and 2-3 m apart in lines and boundary plantations across the poplar growing region. Wider spacing favours growing agricultural crops with higher yields for longer period then closer spacing. Poplar grown in block plantations produces better quality timber with circular stem, less knots and other defects and therefore fetches higher price in the wood markets. Silviculturally, poplar grows better under mild competition in stands, whereas, trees tend to become branchier, if planted wide apart especially on boundaries. Experienced farmers who have grown it for 4-5 rotations by now still prefer to grow it in blocks for getting better returns and appreciation of their good quality timber value. Poplar timber from the state of PB still fetches relatively higher price in Yamunanagar (HR) poplar wood trading centre as most of it is grown in compact blocks in that state.

Poplar Based Agroforestry (PBA)

Growing intercrops is a normal practice and some aberrations of keeping fields without intercrops may occur occasionally. Crops grown in PBA are locality specific and originated through farmers innovations as these have been associated with their sustenance and life support system. Over 98 per cent poplar block plantations have been recorded to grow intercrops which vary with locality, age of trees, prevailing market conditions, season and economic conditions of the farmers (Dhiman, 2012). Farmers grow only those new crops which provide better returns compared to those traditionally grown by them (also see Chauhan *et al.* in this volume).

Plantation Management

Poplar is grown on agriculture fields and is a domesticated tree in India. It is grown on farm land with so many growth contributing variables in planting stock type, intercrops, cultural inputs, tending operations, insects and pathogens, climatic, edaphic and geological constituents that its productivity on any site is likely to vary with variation in any of these variables. The impact of these variables on poplar growth is easily exhibited in a very short span since the tree is very fast grown, and responds quickly to any of the management intervention. Higher timber productivity of 26.46 m^3 per hectare per year recorded for poplar on farm land compared to just 13.65 m^3 per hectare per year on forest land (Singh and Jhajaria, 2001) justifies the importance of management inputs applied in the fields having both tree and intercrop culture together. Better growth of poplar obtained along water channels and poor growth in fields with top soil scraped and also on uncultivated fields indicate that even small changes in any of the growth variables has significant impact on the overall productivity of poplar. Variable silvicultural quality of the planting stock of same clone grown in different nurseries showing differential field survival and growth justifies the claim of higher sale price for its saplings by certain branded and established nursery growers. A good agriculturist has been proved a good tree grower since he better understands the needs of both intercrops and trees than most of the absentee land owners and casual growers due to their casual approach on poplar farming. Dhanda and Verma (1995) reported productivity of poplar grown with intercrops in PBA as 444.1 m^3 at years with MAI of 49.3 m^3 per ha per year and 292.0 m^3 at five years rotation with MAI of 58.4 m^3 per year and indicated the reasons for this variation in productivity due to harvesting age, management inputs and locations of fields along river beds or away on upland. The data on poplar farming available from other locations especially, Bihar (Dhiman, 2010b), Chhatishgarh (Puri *et al.*, 2002; Mishra *et al.*, 2004), and Maharashtra (Gogate and Deshpande, 1994) indicates lower growth and yield compared to that obtained in the RIPC. These warmer and drier sites are located at much lower latitudes than that of 28°N lower latitudinal limit for *P. deltoides* in its natural range in the USA and in its introduced locations in the RIPC. In addition, better agriculture production facilities and system in the RIPC encourages better growth of poplar and intercrops in this region.

Pruning poplar trees is an essential component of plantation management for improving the quality of timber and also to protect them from wind damage by reducing wind pressure on their crown. Wind damage to poplar is common throughout the RIPC. Generally, young trees of 1-2 years age get broken from the main stem, whereas, old trees get uprooted or bend with the wind pressure. In many locations, fields inundate with water for many days during rainy season forcing trees to bend or fall with gentle wind pressure. Two types of pruning are *in vogue*, namely lateral pruning and vertical pruning. The former is used to facilitate apical growth by lengthwise trimming lower side branches/ shoots just after planting and also to reduce wind pressure by reducing the crown size. Lateral pruning is again applied during tree dormancy stage in the following two winter seasons. Vertical pruning is used for improving the wood quality by selectively removing co-leaders and a few thick branches in the first and second year winter season and thereafter in alternate years to lift the crown to the stem thickness of around 30 cm girth since logs below this size are sold as firewood. In some locations, farmers have developed thumb rules to prune trees to the height near the transition of smooth bark to corky one. In lateral pruning, all lower branches are half cut, whereas, in case of vertical pruning thick branches are cut touching main stem with sharp tools. Lateral pruning is increasingly applied in wind prone areas, whereas, vertical pruning is applied throughout the RIPC. Anchoring trees with the support of ropes is a regular practice in many flood prone areas having heavy soils to save them from lodging with wind pressure. Young dislodged trees during rainy season are heavy pruned, erected and tied with ropes and many of them survive and grow till their final harvesting.

Poplar is normally harvested during pre- and post-winter cropping seasons in order to avoid damage to agricultural crops standing in the fields. For harvesting trees, the basal thick and side roots of the trees are exposed, cut with axes and the trees are made to fall on one side with their main root system (Fig. 1). Left over tree parts including roots are immediately cleared to make fields ready for growing next season crops including fresh poplar plantations. Of late, some farmers have started keeping their poplar fields free from agricultural crops during the harvesting year to take advantage of escalated wood prices during off-season harvesting season. Poplar trees grown on field boundaries sometimes felled without uprooting and many farmers now manage the coppice shoots arising from the stumps as a fresh crop. Like other trees, coppicing in *P. deltoides* also depends on age, season and clone type (Sharma *et al.*, 1996). Poplar harvested during monsoon or winter season coppices well, whereas, its capacity to give new shoots decreases significantly in hot and dry season. All stumps do not sprout and some gaps are created which the farmers try to fill with fresh planting or simply ignore gaps created after felling. As a result, the quality of wood produced from such coppice origin trees is poor because of high degree of branching, knots, and taper and it fetches low value in the market. The proportion of the coppice origin poplar is now increasing and constitutes a fairly significant component of poplar culture; i.e., approximately 5-8 per cent of total standing poplar in the RIPC (Fig. 2). The share of coppice origin poplar is more towards eastern limits of RIPC and also in some locations within this region where some casual poplar growers and those with low land holdings and poor economic conditions retain coppice shoots to avoid expenditure on making fresh plantations.

Rotation and Yields

Poplar is extremely fast grown and attain marketable size timber at very young age. It is generally harvested at six to eight years of rotation which sometimes is extended from four to twelve years. The tree is mainly grown as a cash crop for sale of timber to wood based industry. The main factors that determine the harvesting age of trees are the economical conditions of the grower, his immediate financial needs, market conditions, land holding size and his interest in agricultural crops. Farmers, in some locations where market for the under sized wood is now well developed, have started harvesting poplar at even four years of age to take early advantage of fluctuating wood prices in the market and also realize better value for cash intercrops like sugarcane which could be economically grown at the young age of trees. Farmers with good land holding size and better economic conditions prefer to harvest trees at old age and get better appreciation of the timber. Some farmers also postpone harvesting of trees to later age if the prices of wood are low in the market. Good growing plantations attains 5 m average height and 5 cm average diameter per annum with a ratio of around 100:1 for the first half of the rotation age of poplar growth. Current annual and mean annual increments culminate at a very young age in poplar (Fig. 4) in comparison to most other forest tree species. Current and mean height growth culminates faster in comparison to current and mean diameter growth. Dhanda and Verma (1995) reported that MAI of DBH is more for boundary trees (5.2-9 per annum) than in block plantations (3.8-7.8 cm per year).

Poplar logs of thick girth size are sold at higher prices throughout the RIPC. Percentage of logs with thick girth sizes increases with increase in the harvesting age of trees. A comparison of six plantations harvested at different ages from five years to 10.5 years during 2011 surrounding Bareilly location, Uttar Pradesh and monitored for log size-wise yield including that of firewood is given in Tables 7 and 8 (Fig. 3). The ratio of over (over 60 cm mid girth) and under size logs (between 50-60 cm mid girth) varies from 55 per cent in 5 years old trees to 95 per cent in 10.5 years old trees.

Marketing

Poplar logs are usually processed when these are fresh. The wood is harvested during the day hours, transported to the local wood markets or industrial units during the night and auctioned/sold in the early morning hours. Almost all components of poplar trees including logs, roots, lops and tops

Table 7. Timber volume (cmh-ub) in selected plantations with different harvesting ages

Location	Age (yrs)	Tree (no.)	Log. vol. (cmh-ub) for logs with mid girth		Ratio for mid girth logs	Timber vol./tree(cmh-ub)		
			(>60cm) (mid girth)	(<60 cm) (mid girth)	(<60/>60) (mid girth)	(>60cm) (mid girth)	(<60 cm) (mid girth)	Total
Atrauli, Aligarh, U.P.	8.5	2,880	1,534	82	94.93	0.533	0.028	0.561
Bhuta, Bareilly, U.P.	7	2,200	216	114	65.45	0.098	0.052	0.150
Shahajahpur, U.P.	6	630	62	30	67.39	0.098	0.048	0.146
Hardoi, U.P.	5	225	17	14	54.84	0.076	0.062	0.138
Bareilly, U.P.	5.5	170	16	8	66.67	0.094	0.047	0.141
Milak, Rampur, U.P.	10.5	150	82	4.5	94.80	0.547	0.030	0.577

Table 8. Total tree yield (by weight) in selected plantations with different harvesting ages

Location	Age (yrs)	Tree (no.)	Log weight in qtls				Weight in qtls	
			(>60cm) (mid girth)	(<60 cm) (mid girth)	30-50 cm (mid girth)	Firewood	Total	Per tree
Atrauli, Aligarh, U.P.	8.5	2,880	2.16	0.40	0.91	1.24	4.71	4.71
Bhuta, Bareilly, U.P.	7	2,200	1.53	0.81	0.80	1.00	4.15	4.15
Shahajahpur, U.P.	6	630	1.48	0.71	0.70	0.90	3.79	3.79
Hardoi, U.P.	5	225	1.16	0.96	0.71	0.87	3.69	3.69
Bareilly, U.P.	5.5	170	1.36	0.68	0.70	0.94	3.69	3.69
Milak, Rampur, U.P.	10.5	150	8.50	0.50	0.67	0.67	10.33	10.33

along with bark separated at processing sites or at harvesting sites are sold in the market. These are sold on weight basis which is recorded just before finalizing the deal for sale/purchase. Any delay in its sale results in weight loss due to loosing moisture and ultimately low value for the produce. The weight loss in logs is fast on thin logs and firewood than thick logs. Approximately 16.23 per cent overall weight loss was recorded in 35 days period from different components during the month of October (Dhiman, 2012). The growers therefore prefer to sell fresh wood on day to day basis. The wood is sold in around a dozen wood markets where rates for each thickness and quality grade (mainly based on knots and straightness) change on day to day basis. Yamunnagar in Haryana, Hoshiarpur in Punjab, Rampur and Hapur in Uttar Pradesh are the well established main markets for trading poplar wood and are also barometers for the poplar wood prices to local growers. Many wood based industrial units also make direct contacts with the poplar growers, purchase trees on lump-sum deals or weight basis and arrange their harvest and transport. The log grade is decided on its girth, namely over grade with girth thickness +60 cm, under grade with 50-60 cm girth thickness and 'sokta' with 30-50 cm girth thickness. The wood is also sold as a mixed lot of all tree components together and it attracts lower value than the graded lots. The thickness limits and their measurement points like thin, thick or mid end of logs have been changing over the years with ever changing demand and supply scenario of its wood in the local markets. These limits tighten during the period of surplus supplies and relaxed during the period of scarcity. Thick logs are usually used for peeling purpose and thin logs for making filling material for ply-board. Billets below this size, roots, lops and tops are sold as pulpwood and firewood. Wood is also traded on volume basis(cmh-ub) in forest corporations of a couple of hill states where some of it obtained from trees grown on government land is periodically auctioned from their wood depots around winters. Numerous traders have developed their business throughout the RIPC and farmers are at ease in selling most of their plantations on lump-sum basis to them. The entire operations and controls thereafter are arranged by the contractors. These contractors supply wood to main contractors operating from the main marketing centers which charge a percentage of commission from the sub contractors and supply wood to the industrial units on day to day basis. There is a lot of movement of poplar wood within and the RIPC (Fig. 4).

Economics

Poplar based agroforestry is reported to be economically viable and more profitable than many other land use options with minimum risks (Jain and Singh 1999, 2000; Dhillon *et al.*, 2001). Economical returns from poplar farming depends on a very large number of factors of which tree harvesting age, density and geometry of tree planting, land-use (forest or farm land), clone type, intercrops, plantation management, cultural inputs, market prices for input material and farm produce both of trees and intercrops at certain period of time are the major contributors. There have been numerous attempts from the very beginning of poplar culture on forest and farm land to estimate its economic viability. The economic viability of first large scale poplar plantation established over 20 ha forest land in 1966 and harvested in 1981 was reported to have 28 per cent internal rate of return and B:C ratio of 3.19 per cent at 13 per cent rate of interest (Chaturvedi, 1982a and b). The economic returns from poplar culture with and without intercrops were reported to vary with tree rotation (Mathur and Sharma 1983). For 8 years rotation, higher B:C ratio of 3.22 was reported for poplar culture on farm plantation with intercrops compared to 2.15 for forest plantation and with intercrops and 1.51 for forest land without intercrops (Mathur and Sharma, 1983), whereas, Dhillon *et al.* (2001) reported cost benefit ratio of 1: 1.92 and 1: 2.13 for pure poplar and for poplar and intercrops together. Cost benefit ratio on farm land at eight years rotation was reported as 1.86 and 1.70 for 12 per cent and 15 per cent discount rate of interest by including Rs. 5,000 as opportunity cost against a net loss due to agricultural crops (Chandra, 1986). Singh *et al.* (1988) reported that five year old poplar planted at 5x4 m spacing along with mentha intercrop under agroforestry gave net returns of Rs. 44,385 per ha through trees and Rs. 65,886 through crops. The single row plantation along with field bunds gave a net return of Rs. 11,067 per ha and Rs. 41,250 per ha over a period of three and seven years, respectively. Benefits from raising nursery stock are much higher (100.9 per cent) within one year (see Kiswan and Dinesh Kumar, [n.d.]).

The economical returns from poplar farming fluctuates with marketing conditions for sale of tree and intercrop yield components. There are daily, monthly, seasonal and annual variation in wood prices and these affect returns to poplar growers during the sale of their produce. Any change in the demand and supply system that even affect daily supply of the wood to the market affects its prices. The sale value of the wood from the plantations given in Table 8 based on the prevailing market rates during their sale time is given in Table 9. It is evident that the value of trees increases with age of harvesting, though the farmer has to incur some loss on loosing the yield of crops if trees are retained for long period.

PBA has already established benchmarks of high economical returns in agroforestry systems practiced in

Table 9. Economical returns (Rs. per tree) from selected plantations with different harvesting ages

Location	Age (yrs)	Tree (no.)	(>60cm) (mid girth)	(<60 cm) (mid girth)	30-50 cm (mid girth)	Fire-wood	Total value (per tree)
Atrauli, Aligarh, U.P.	8	2,880	1,728.33	237.29	365.83	148.88	2,480.33
Bhuta, Bareilly, U.P.	7	2,200	1,225.45	485.45	320.00	120.55	2,151.45
Shahajahpur, U.P.	6	630	1,180.95	428.57	280.00	108.00	1,997.52
Hardoi, U.P.	5	225	924.44	573.33	284.44	104.00	1,886.22
Bareilly, U.P.	5.5	170	1,091.76	409.41	280.00	112.94	1,894.12
Milak, Rampur, U.P.	10.5	150	6,800.00	300.00	266.67	80.00	7,446.67

India. Many of the average poplar growers are now realizing around Rs. one hundred thousand per acre per year (one US $=Rs. 53) net returns from PBA when its timber prices have touched all times high prices for over size logs as Rs. 1,100 per quintal in Yamunanagar, Haryana a poplar market. There is also a shift for harvesting poplar early at even four years age in some locations with the sole objective that growing of cash crops like sugarcane becomes uneconomical when the net returns per unit area and per unit time decreases after two harvests - the 2nd harvest being ratoon (coppice) origin. Appreciation of prices for even undersize poplar wood harvested at young stages is also motivating for this change.

Growers are getting a lump sum amount from the sale of poplar trees. Many growers believe that the income from the trees is net profitability from the PBA and the expenses from the beginning of poplar and intercrop culture in a rotation period are recovered from intercrop yields itself. Money received from the sale of poplar and intercrops being agriculture income is treated tax free and many growers have gainfully used it for diversifying their business activities and making assets.

Usage

Poplar wood is used for manufacturing around three dozen products (Dhiman, 2004). Poplar has now developed a complete use of its all tree components (Table 10). Even leaves and foliage with thin branches are lopped and converted into chips for sale to wood based industry as fire wood. Paper pulp is the third major use of poplar wood after panel industry and firewood in India (Fig 5). Fiber dimension, proximate chemical composition (Milea, 1980), and characteristics of lignin (Singh *et al.,* 1982) and hemicelluloses (Singh *et al.*,1982) in poplar wood make it one of the favored raw material for making paper of different grades, viz., wrapping /writing paper (Einspahr *et al.,* 1970), grease proof paper (Rai and Ilam Chand, 1988), and news print (Singh *et al.*,1981). Poplar is not grown exclusively for paper pulp and it is either the industrial wood waste or the left over material from plantations that is used as pulp wood. Most of poplar wood collected from sawmill waste, veneer waste, plywood trimming, and especially those parts which are not used either for sawing and peeling in poplar based industry are accepted raw material by the paper industry. From trees, only those rejected wood pieces with heavy defects like knots, bends, hollowness and those billets below 45 cm mid girth up to 30 cm mid girth or sometimes even less than that find use as raw material for paper and pulp industry. Poplar wood was exceptionally used for making paper by many paper industrial units within RIPC and as far as South India during 2003-05 when its prices were very low due to reduced demand on temporary closure of veneer industry.

Poplar protection

Two chapters, one each on insects and diseases are specifically devoted in this issue (see Ahmad and Faisal; Singh *et al.*). However, poplar being a very fast growing tree species is affected by numerous other biotic and abiotic agents (Table 11) of which the damage from wind, fire, insects, diseases, animals, and birds sometimes attain economical proportions.

However, there are numerous other biotic and abiotic agents which cause damage to poplar, some of which have been documented (Dhiman, 2011) and some others are identified separately through a diagnostic survey conducted among the progressive growers and its results reported here. A diagnostic survey was conducted among 178 progressive poplar growers and leading nursery

Table 10. Commercial and domestic use of poplar tree components

S. no.	Tree part	Use
1.	Leaves/foliage	Fodder, and firewood on chipping
2.	Bark	Firewood, and carrier for mosquito quails, etc.
3.	Branches	Firewood, pulpwood and timber
4.	Stem	Timber, firewood, and pulpwood
5.	Roots	Firewood, and timber

Evolving Business Models in Poplar Culture

Many farmers are now reporting lucrative returns from poplar nursery and plantation. Poplar culture, primarily in the private sector, is mainly driven by the economic considerations from the sale of nursery saplings to trees/wood. Besides the regular growers, poplar culture, over the last two decades, has evolved as business opportunity and a mean of self employment for numerous farmers and non-land owners. It is also an excellent opportunity to remain engaged in poplar related activities for remunerative returns. One such real case study indicating handsome net returns of Rs. one hundred thousand from 0.4 ha^{-1} yr^{-1} from PBA with cultivation of traditional sugarcane and wheat crops under poplar plantation is presented in this volume (Chaudhary and Chaudhary in this issue). There are numerous other growers with experience of even better returns with introduction of summer intercrops and even high value crops throughout the RIPC. There are numerous variants of business models in poplar nursery production, trading in saplings, plantation production and maintenance, wood trade including outsourcing in all these activities. Business models with variations exist in nursery production both on private land and hired land such as selling the entire nursery on hectare basis on lump-sum deals much in advance of lifting the saplings, their delivery on negotiated price without and with support in getting them planted on farmer's land by both the nursery growers and service providers with variable earnings from commissions or margins. Many nursery growers and traders are trying to reach the growers and markets to make their business models financially lucrative. For example, large scale selling outlets are created during planting season on the road heads at number of locations across the RIPC. A couple of cases have also recently emerged in Uttar Pradesh. where some absentee landlords and even some businessmen have taken up poplar plantations through service providers with the condition that the saplings to be used for planting on their fields are procured from the branded nurseries and the payment is released only on presentation of receipts of sapling purchase and also when the service provider has ensured expected final survival of planted saplings. The margin money for the service provider in this case is higher but the growers are happy in ensuring better survival and expected returns from their plantations. Similar variants also exist in growing poplar plantations which are grown on hired lands for different years with variable terms and conditions. One such real case is summarized below (Dhiman, 2012).

Mr. R. Singh took up poplar plantation as a business on leased land from one of his old known farmer in Pilibhit District in U.P. during 2004 when poplar prices were very low in the market. He entered an unwritten understanding with the farmer that the former will pay Rs. 15,000 from 0.4 ha^{-1} yr^{-1} for seven years to the latter during the beginning of each year. Mr. Singh planted 500 saplings of WSL 22 at 4.5m x 4.5m spacing in February, 2004 and finally harvested 95 per cent of the trees, in April 2011. Farmer took up sugarcane in the first two years and wheat, thereafter, till sixth year as intercrops at his own costs. Mr. Singh pruned the poplar trees during the second, fourth, and fifth years as practiced in the area. There was no cost involved in pruning and the labourers got the pruned branches as fuelwood free of cost. Mr. Singh spent Rs. 8,000 on cost of saplings and Rs. 1,500 on its planting during the first year. The cumulated cost when compounded to 7 per cent inflation was Rs. 26,215, Rs. 44,100, Rs. 63,237, Rs. 83,714, Rs. 105,624, Rs. 120,624, Rs. 129,067 and Rs. 154,152 at the end of year 1, 2, 3, 4, 5, 6 and 7 respectively. Total cost of production on 2 acre poplar plantation compounded with 7 per cent inflation was Rs. 271,552 that also includes an expenditure of Rs. 117,400 on harvesting of trees. The sale proceed from timber, roots and firewood was Rs. 1,150,472 from 0.8 hectare giving him a net profit of Rs. 878,920 in seven years and Rs. 62,780 from 0.4 ha^{-1} yr^{-1} with provision of 7 per cent inflation. The cost-benefit ratio is calculated as 1:3.24 with- and 1:3.40 without- considering 7 per cent inflation.

Similar variants with some modifications of understanding and arrangement for growing poplar as business opportunity exists in different parts of the RIPC. One landless entrepreneur in Udham Singh Nagar, Uttarakhand has been regularly growing poplar on leased land for over a decade period now. He is taking land on lease for 6-7 years, making and maintaining poplar plantation himself but subletting intercropping to other growers at some lease amount. Presently, he is earning Rs. 3,000 from 0.4 ha^{-1} $month^{-1}$ as income. He is having number of plantations under this arrangement. The present poplar wood prices are in the upper band and fluctuate periodically, seasonally, and daily. Some experienced entrepreneurs' have now learnt the trick of the trade to take up the lands on hire when poplar wood prices are low in the market and many of the growers restrain from planting at that stage.

Table 11. Major causes of damages to poplar

S. no.	Cause	Agents causing	
		Major damage	**Minor damage**
1.	Abiotic agents	Wind, fire, floods, hails	Sun scorch, high temperature
2.	Animals and birds	Blue bull, monkeys	Rabbits, rats, pigeons, crows, wild bores, porcupines.
3.	Insects	*Clostera* species, red mite, termites, shoot borer, leaf sap sucking insects, mango mealybug	Leaf miner, bark borer, stem borer, san jose scale and others
4.	Pathogens	Fungi causing leaf blight, blistering, set rot; damping off to seedlings; MLOs causing flattening	Fungi causing leaf spots, cutting rot, bacteria causing canker
5.	Physiological	Zn and S deficiency, moisture stress	Bark burst
6.	Human beings	Physical damage during cultural operations	Thefts
7.	Parasites	Mistletoe, *Cuscuta* spp.	*Ipomea* sp.

Table 12. Biotic and abiotic agents causing damage to poplar

Biotic and Abiotic agent	State				
	Punjab	**Haryana**	**Uttar Pradesh**	**Uttarakhand**	**Overall**
Wind storms	1	2	1	2	1
Water stress (both excess and deficit)	2	1	2	1	2
Blue bull	14	3	3	6	3
Termites	3	4	4	3	4
Shoot/stem borers	8	6	6	4	5
Theft and damage for revenge	16	10	5	9	6
Clostera spp. (poplar leaf defoliator)	7	7	8	5	7
Fire	6	5	7	12	8
Root rot	4	8	9	7	9
Monkeys	12	21	10	8	10
Zinc deficiency	5	9	11	15	11
Leaf spots	10	23	12	14	12
Sap suckers including red mite	18	22	14	11	13
Mealybug	15	16	17	13	14
Hails damage	9	13	13	18	15
Flattening	23	12	18	10	16
Sulfur deficiency	11	19	15	17	17
Domestic animals	24	17	16	20	18
Leaf miner	17	11	19	16	19
Blistering	19	24	20	19	20
Poplar fever	20	22	21	22	21
Others	25	18	22	21	22
Rats	22	21	23	23	23
Parrots	13	20	24	24	24
Crows	21	25	25	25	25

growers in four states, viz., Punjab, Haryana, Uttarakhand, Uttar Pradesh, and throughout the RIPC to identify the agents responsible for damages to poplar as perceived by the growers. Response was obtained on a format having listing of 25 biotic and abiotic agents (Table 12) and the respondent were requested to enlist them in the order of their potential to cause damage to poplar nurseries and plantations. The overall rank of the agent was calculated to two decimal points and the serial number as given in the table was decided based on its absolute value. It revealed that abiotic agents like wind, water stress (both excess and deficit) leads the table in term of their potential to cause damage. During discussions with many of the growers, the identification of damages and causal agents for disease was extremely difficult for them and they tried to group them in order of their field observations than scientific terminology. The potential of some agents like bull is very high in Uttar Pradesh and Haryana, but very low in Punjab and little in Uttrakhand. Besides these agents poplar wood is also subjected to attack and degradation during storage in log yards and depots. This damage was restricted to some specific locations and factories and was included in the survey.

Fig. 1. Tree harvesting operation includes felling trees along with main root system.

Fig. 2. A third rotation coppice variable growth of poplar trees retained on field boundaries along a roadside in Rudrapur, U.S. Nagar, Uttrakhand.

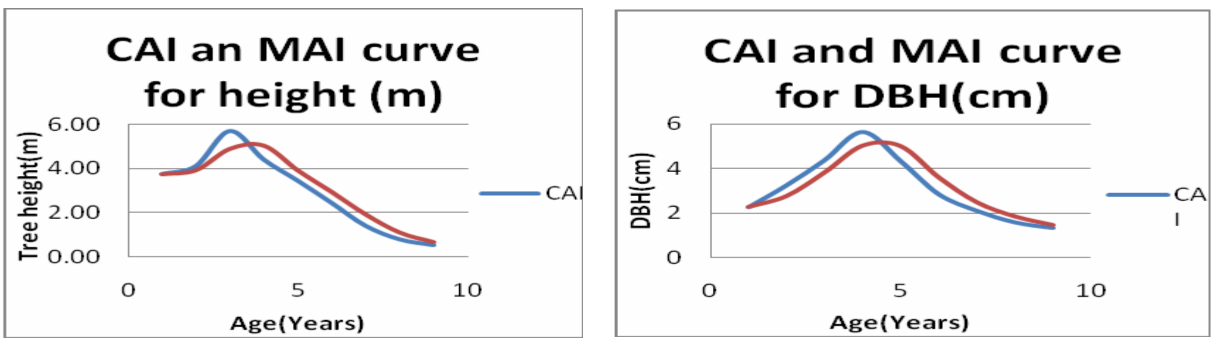

Fig. 3. CAI and MAI curves for height (H), and diameter (D) at 8 years rotation.

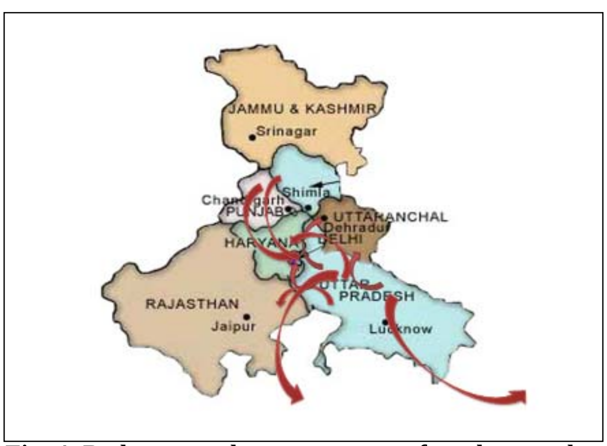

Fig. 4. Red arrows show movement of poplar wood to other states

Fig. 5. Peeling waste from veneer industry for pulpwood in the RIPC.

Conclusion

Firmly established poplar culture with introduced germplasm of *P. deltoides* is a source of numerous goods and services at local, regional, national and global level. Poplar culture is largely in the private sector and immensely helping the country in mitigating chronicle shortage of wood raw material for domestic and industrial use. The unique success of establishing poplar culture on farm land with active participation of numerous growers is path breaking for initiating similar programmes under synergic partnerships between industry and farmers. Poplar is grown as a cash crop and providing remunerative returns to its growers, generating employment in rural areas, raw material for wood based industry, revenue through taxations for the state governments, increased tree cover to meet the objectives of the National Forest Policy 1988 and rehabilitation of river banks for their protection and averting soil erosion. With increasing demand for its wood, poplar culture is likely to expand within the RIPC and also to new locations in northeastern states along the Himalayan range for the benefit of the people and the country.

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Status of Poplar Breeding in India with Special Reference to Work Done at Dr. Y.S. Parmar University of Horticulture and Forestry

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Looking at the diverse plantation requirements and the species involved, different short and long-term strategies for their breeding and improvement were adopted at the university

Introduction

Poplars have become an important resource for the wood based industry in northern India since many industrial units are now dependant on it, as forest grown wood has almost become out of reach these industries. The ban imposed by the Supreme Court of India on green felling and efforts by various governmental agencies to increase the forest cover and reduce dependence on wood have made them look for alternative sources. Since the liking and dependence on wood cannot be separated from the mindset of the people, the only alternatives left are fast growing trees outside forests or farm grown woods. Amongst which poplars in India have become one of the important species. It's a long way from the negligible dependence on poplar wood in 1970s to almost total dependence on poplar wood by 2012 most of plywood, ply-board industries and some pulp wood industries in northern India; that too in just a span of 40 odd years.

The poplar growing is basically dependant on vegetative propagation where clonal propagules play an important role in plantations. Since vegetative propagules need to be upgraded sequentially on their loosing vigour and vitality, it is but imperative to have a breeding programme in place to deliver new and vigourous clones for plantations as the old clones become irrelevant over time. Whereas, most of the poplar growing countries with elaborate poplar plantation programmes, have some poplar breeding or clonal development programmes. Unfortunately in India, though poplar clones were imported time to time the well defined breeding programme for development of new and vigorous clones never existed at national level. For example, clones of poplars have been imported by the Forest Research Institute, Dehradun (Mathur and Sharma, 1983; Khurana *et al*., 1992; Tiwari, 1993; Chaturvedi and Rawat, 1994) with similar effort by the private industry, particularly WIMCO Ltd., in the early seventies (Dhiman, 2008).

All the clones being planted were selected elsewhere with different climatic conditions, particularly photoperiod and latitudes, therefore, their responses were varied. In an effort to develop locally adapted clones to local climatic and photoperiodic conditions, a significant initiative was taken by the Dr. Y.S. Parmar University of Horticulture and Forestry in collaboration with the Canadian agency – International Development Research Centre of Canada (IDRC) during 1989-1995, by collecting 103 open pollinated families from the USA (Khurana and Narkhede, 1995).

The programme was designed to supply clones on a regular basis to the plantation agencies. Later on, the programme of clonal development was supported in the late 1990s by the World Bank Forestry Research, Education and Extension Project (FREE project) at the ICFRE.

In India, most of the commercial poplar plantations are in the Gangetic plains and foothills of the Himalayas and constitute predominantly of exotic eastern cottonwood species (*Populus deltoides* ssp. *deltoides*). Whereas, the native species that are used as nurse crop for the silver-fir regeneration in high mountainous region, stabilization of hill slips and as a main source of timber in arid dry zone found only passing references till the improvement programmes on the native species, particularly the Himalayan poplar (*P. ciliata*) and white poplar (*P. alba*) were initiated by the Dr. Y.S. Parmar University of Horticulture and Forestry, Solan (Fotidar, 1983; Ramesh and Khurana, 2003, 2006, 2007). However, the productivity levels of clones of these various species vary according to site conditions and type of rooting ability and rooting behaviour. Clones have been categorized into five categories depending upon the plunging and anchor root behaviour, and thus dividing them into plantation categories (Khurana, 1994; Bhrot and Khurana, 2001). The productivity levels vary with various rooting categories, clones in question and site conditions from 15-30 m^{-3} ha^{-1} yr^{-1}. Alternatively, the trees were found to be yielding wood at the rate of anywhere between 0.5 to 1 m^3 per tree and the tonnage yield was also 0.5 to 1.0 t per tree. The productivity levels with Australian clones from Punjab and Haryana are reported to be much higher at 25 to 40 m^{-3} ha^{-1} yr^{-1} with some farmers reporting productivity levels of about 60 m^{-3} ha^{-1} yr^{-1} with intensive farming and supplementation of macro- and micro-nutrients under rigorous silvicultural practices (Dhanda and Verma, 1995; Kumar *et al*., 2004; Dhanda *et al*., 2008; Dhiman, 2008; Rizvi *et al*., 2011). The productive rotation age of eastern cottonwood ranged between 7-9 yrs in foothills, at higher elevations in Kullu Valley and Nauni (Solan) for *P. deltoides* and its hybrids it ranged from 9-15 yrs. The rotation cycle with *P. ciliata* and its hybrids was even higher at 15-25 yrs, again dependant on site, soil, moisture level and the clone planted. Looking at the diverse plantation requirements and the species involved, different short and long-term strategies for their breeding and improvement were adopted.

Breeding Strategies

Basically, the outline of the different breeding strategies adopted for the poplar improvement programmes are outlined in Fig. 1 conceived at the Dr. Y.S. Parmar University of Horticulture and Forestry, Solan and also adopted at other institutes involved in the poplar improvement programmes in India. This followed somewhat similar strategies for both indigenous and exotic species for wood production with singular objective of wood production outside natural forests depending upon genetic resources. The foremost amongst them was the enrichment of the genetic resources.

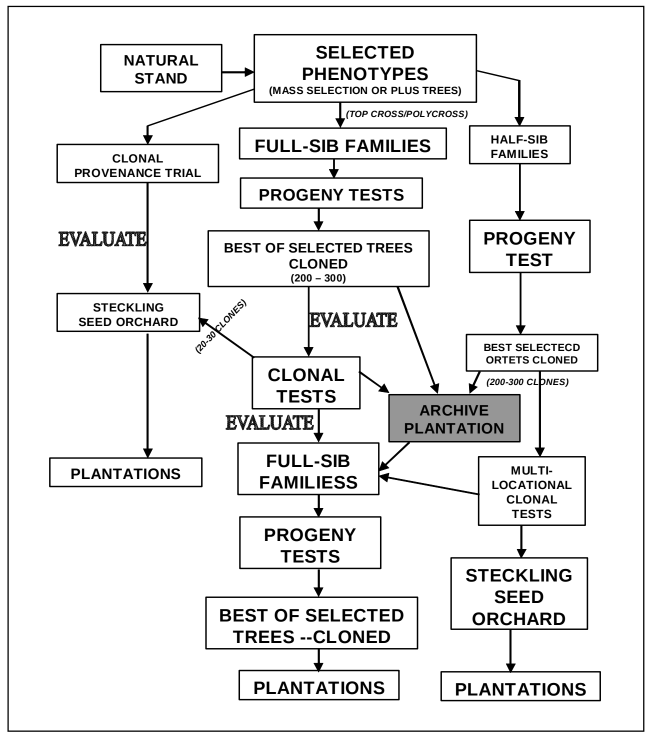

Fig. 1. Breeding strategy adopted for the improvement of poplars in India.

Genetic Resources

India is endowed with five native species and has a rich resource of other exotic species of poplars which have been brought into India since almost 15th century when Mughal first introduced *P. nigra* cv 'Italica' to the Kashmir Valley and other species (Fotidar, 1979) and clones introduced from Great Britain, Germany, Netherlands, Sweden, France, Italy, USA, and Australia, so that, India could become self-sufficient in the poplar wood requirements. However, disagreements over the species classification of poplars show no sign of abatement. The wide distribution of many poplar species, frequent introgressive hybridization (Broeck *et al*., 2005), a long history of cultivation and ease of vegetative propagation has led to much confusion in the nomenclature of poplars. Numerous synonyms exist, hybrids and cultivated varieties have often been named as species. Thus, species counts for the genus range from the low 20s to over 80, depending on the authority. However, generally 30 species are well recognized of which six species, as given in Table 1, are represented in India with large number of species and cultivars being introduced from time to time as research initiatives.

Table 1. Species of *Populus* available in India

S. no.	Native species	Exotic species	Legitimate cultivar
1.	*P. euphratica*	*P. nigra* cv. Italica	*P*. 'Canescens', *P*. 'Eugenei'
2.	*P. ciliata*	*P. deltoides*	*P*. x *euramericana* cv. 'I-214', 'I-455', 'I-67' 'I-67/55', 'I-145'
3.	*P. alba*	*P. yunnanensis*	*P*. 'Lux', *P*. 'Oxford'
4.	*P. jaquemontiana* var. *glauca*	*P. trichocarpa*	*P*. 'Regenere'
5.	*P. gamblei*	*P. tremuloides*	*P*. 'Robusta'
6.	*P. suaveolens*	*P. maximowiczii*	*P*. 'Roxbury'
7.		*P. simonii*	*P*. 'Serotina'
8.		*P. grandidentata*	More than 300 cultivars imported over the years

Natural Genetic Variation

The natural genetic variation in two indigenous species, *P. ciliata* and *P. alba* has been studied. *P. ciliata* was found to have a 3: 2 male female sex ratio (Khosla *et al*., 1979) female trees had better growth rate (Khosla *et al*., 1980), edaphic conditions and water availability affected the overall growth of the trees and provenance variation with respect to growth, rust resistance (Sharma and Sharma, 2000), and infestation of the branches and leaves with galls was more (Chauhan and Khurana, 1992; Chaukiyal *et al*., 1995; Uniyal and Todaria, 2006).

Reproductive Biology

The reproductive biology of *P. ciliata* was analysed over a long period of time to look at its behaviour with respect to environment and stability of sex only one case of switching of sex was observed when a female tree turned monoecious (Khurana, 1985), otherwise trees showed consistency in their behaviour. Phenologically, the growth initiation and bud break is 2 to 3 weeks earlier at lower altitudes than higher altitudes. The average number of phenological growth period varied from 260 to 320 days, again with variation in altitudes, with most active growth period of 5 to 6 months. Species to species variation in phenological growth days was also found with maximum value being observed in *P. yunnanensis* compared to *P. alba* and *P. ciliata* (Mohanty and Khurana, 2000a and b). In *P. ciliata* flushing differences of one week with every 600 m elevation has also been found (Khurana and Mohanty, 2000).

The studies in reproductive biology of *P. ciliata* also reveal the species to be dioecious with a single case of sexual dimorphism (Khurana, 1985). The female trees were more prevalent on relatively exposed sites and were much healthier compared to the male trees which were found to be in competition with surrounding population. Whereas, Chaturvedi and Rawat (1992) has listed various clones which are male or female on the basis of flowering at Lal Kuan, Kalika and Gaja. Normally, the clones of poplars do not flower at lower elevations of less than 1,000 m regularly. But they have been flowering at Lal Kuan nursery of the Uttar Pradesh State Forest Department off and on at an elevation of 256 m.

Pollination in the species is normally by wind. In *P. ciliata,* it takes place 15 days after the floral bud break with a receptivity period of the female catkins being extended from 2 to 3 days (Khurana, 2000). Pollen size normally varies between 25-28 μ with larger pollen grains being observed in monoecious tree (31 μ). Unlike many other species of poplars, the pollen of *P. ciliata* has been difficult to store and looses its viability very rapidly (Dhir *et al*., 1982) thus, hampering long-term breeding programmes.

Half-Sib Families

Open pollinated seeds from 83 marked plus trees of *P. ciliata* were collected from the states of Jammu and Kashmir, Himachal Pradesh and Uttarakhand during different years (50 families during 1991 and 33 families during 1992) and after raising nurseries, the selections were made based on stem straightness, rust resistance and gall infestation of leaves (Khurana and Narkhede, 1995). Only one clone could be selected for rust resistance (Surkhigala-5) and one for leaf gall resistance (Chhatri-3), and 45 clones were selected for growth form. The best clone selected (Surkhigala-5) had almost three times more growth than of average clones.

The open pollinated seed collections for *P. deltoides* Bartr. ex Marsh ssp. *deltoides* (Eastern cottonwood) from the USA have been many. Initially, the Y.S. Parmar University of Horticulture and Forestry, Solan with the help of the IDRC, and USDA Forest Service collected seed from 103 sources in the states of Texas, Lousiana and Mississippi (Farmer and Khurana, 1990; Khurana and Narkhede, 1995) which was raised in India at Parmar University and in China at Nanzing Forestry University. Based on their nursery performances, selections were made amongst clones akin to our photoperiodic and environmental conditions and at many places the plantations have also been raised from these indigenously selected clones (Chaturvedi and Rawat, 1992). After extensive and rigorous selection, 300 clones were selected from which 25 clones were used in the All-India

Co-ordinated trials under the FREE Project on poplars by the ICFRE (Rawat *et al.,* 2001) and 100 clones were given to M/S Wimco Seedlings Ltd. for adaptive trials (Wimco Seedlings Ltd., 1997).

Later, on open pollinated seeds from 104 candidate plus trees growing in 44 natural stands in the USA were brought by Singh *et al.* (2002) at the FRI, Dehradun from them 100 clones have been selected out for further trials (Kumar *et al.,* 1999).

The data on some of the earlier plantations have become available and 1st cycle of raised plantations has been harvested. There were significant differences among clones for height and diameter growth along with crown shape; i.e., crown width, leaf quality and photosynthesis rate. The average diameter of these clones ranged from 20 to 45 cm at Nalagarh, Paonta Sahib and Narainti, as is also evident from Fig. 2 (Khurana, 2007).

Hybridization

Natural hybrids in poplars is a common phenomenon, but ever since Moench in 1785 reported the hybrids between *P. deltoides* and *P. nigra,* intra- and inter-specific hybridization has been a prime research occupation amongst poplar geneticists.

In India, intra-specific hybridization amongst best 40 clones of *P. deltoides* has been carried out and amongst these 289 clones from control-pollination and 111 clones from open-pollination have been selected at the FRI, Dehradun for field trials (Singh *et al.,* 2002). The success of inter-clonal hybrids of *P. deltoides* has been more optimistic, which were labeled as Lal Kuan clones with L-series. These performed quite well under plantations at various places (Chaturvedi and Rawat, 1992, 1994), as well as some clones developed by M/S Wimco Seedlings Ltd. like 'Udai', 'Kranti' and 'Bahar'.

The inter-specific hybridization programme had problems while dealing with *P. ciliata* flowering branches. Unlike the flowering branches of *P. deltoides* which could be easily brought to the laboratory and stored and then at appropriate time could be raised by the twig-in-pot method for convenient breeding programmes, the flowering twigs of *P. ciliata* have to be grafted or buded on to the established stock for breeding purposes.

Inter-specific hybridisation between *P. ciliata*, *P. maximowiczii* (three provenance collections), *P.* x *euramericana* 'I-455', *P. deltoides*, *P. yunnanensis*, and through hybrid embryo-rescue for *P. ciliata* x *P. deltoides* was carried out at Dr. Y.S. Parmar University Horticulture and Forestry, Solan (Khurana, 1989; Khosla and Thakur, 1991; Khurana and Thakur, 1995). The pollen for *P. maximowiczii* was received from the Oji Paper Co., Japan and the pollen sources of *P. yunnanensis* and *P. deltoides* were earlier collections growing in the Populatum at Forest Nursery, Shilli (Solan).

Jha and Kumar (2000) also raised inter-specific hybrids in different cultivars of *P. deltoides*, *P. ciliata*, *P. yunnanensis* and *P*. x *euramericana* 'Robusta', including reciprocals and backcross. Earlier, Chaturvedi and Rawat (1992, 1994) had also reported on the inter-planted open pollinated hybrids of *P. ciliata* and *P. deltoides* as well as on the inter-clonal hybrids of *P. deltoides*. While both Chaturvedi and Rawat (1992, 1994) and Jha and Kumar (2000) reported full compatibility between *P. deltoides* and *P. ciliata* and their reciprocals, Khurana and Bhanwara (1982) were able to show that only one way cross was possible between them. Embryo rescue by Khosla and Thakur (1991) was adopted to get the hybrid seedlings. Hybrid seedlings of *P. deltoides* 'G-48' x *P. euphratica* have also been produced to combine the rapid growth of *P. deltoides* and stress tolerance of *P. euphratica* (Singh *et al.,* 2002).

The most successful amongst inter-specific crosses have been between *P. ciliata* x *P. maximowiczii* (M-1016) and *P. x euramericana* 'I-455' x *P. deltoides* with very promising growth results in mid-hills (Khurana and Thakur, 1995; Khurana *et al*., 1995). The hybrid clones which have been selected for trials under various conditions based on their rooting pattern and behaviour are - CM-3183, CM-3108, CM-3254, CM-3120 and CM-3213 having category-A type of rooting pattern with a dominant vertical sinker root at the base for interplanting conditions in agroforestry systems, clones CM-3226, CM-3246, CM-3122, CM-3239, CM-3195 and CM-3287 showing category B of root pattern and clones CM-3160, CM-3203, CM-3162 and Hyb-I showing category-C of root pattern for block planting (Khurana, 1994; Bhrot and Khurana, 2001). The clones Hyb-III, CM-3167 and CM-3130 with category-D type of root pattern have been selected for loose soil conditions. The rooting pattern of these hybrids was very strong as can be seen from a comparison of the rooting of hybrids, *P. ciliata* and *P. deltoides* ETP's in Fig. 3.

Hybrids of *P. ciliata* x *maximowiczii* were raised for the sites not amenable to either *P. ciliata* or falling outside its zone and where *P. deltoides* clones were found unsuitable. Initial growth differences in the nursery (32.60 N, 77.30 E) were reported to be greater by the parent at one site. Subsequently, these were planted at three sites: (i) Katrain (31.45 N, 77.30 E) representing river floodplain deposits, (ii) Palampur (32.60 N, 77.30 E) representing a tea garden with no irrigation, and (iii) Nauni (31.10 N, 77.20 E) representing a) seasonal water source, and b) dry fallow land. Growth differences were site specific,

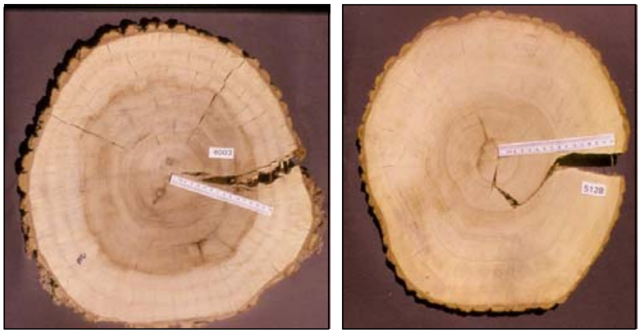

Fig. 2. Productivity of selected clones from open pollinated families of *P. deltoides.*

Fig. 3. Showing the rooting differences in the ETP's of *P. ciliata* on the left, *P. deltoides* on the right and *P. ciliata* x *maximowiczii* in the centre which had stronger and more profuse secondary and tertiary roots.

Fig. 4. Pattern of bark of the inter-specific hybrids of *P. ciliata* x *maximowiczii.*

Fig. 5. Differences in the colour, shape, size and number of leaves at each node in the hybrids of *P. ciliata* x *maximowiczii.*

and poor performance with diameter growth of less than 10 cm in 4 years was observed at site II. The growth at site I varied between 15 and 20 cm at 4 years, and the growth at site III-a ranged between 20 and 25 cm with a good height growth of about 20 m. After 20 years of growth, the average height of clones at Katrain was 25 m with diameter range of 40 to 50 cm, but at site III-a; i.e., Nauni (seasonal water source), though height was 20-25 m but the diameter growth ranged between 30 to 40 cm. The rooting was profuse in these hybrids in comparison to *P. ciliata*; the leaf size was double that of *P. ciliata* and four times than that of *P. maximowiczii*. Siblings showed a range of variation in branching pattern from the rosette shape of branching in *P. maximowiczii* to the simple alternate type in *P. ciliata*, and at maturity the bark pattern also varied from smooth to ribbed (Fig. 4 and 5).

Molecular Characterization

Genetic evaluation of 24 of these interspecific hybrids along with the two mother trees (*P. ciliata*), and five male-parent (*P. maximowiczii*) genotypes was carried out using the AFLP marker assay. Eight AFLP primer combinations detected 428 markers, of which 280 (66 per cent) were polymorphic. The phenetic dendrograms, as well as the PCO plots, separated the hybrids and the two parent species into three distinct clusters. The hybrids grouped closer to the *P. ciliata* (female parent) cluster as compared to the *P. maximowiczii* (male parent) cluster. The hybrid cluster contained internal groupings, which correlated to some extent with growth performance. The four best performing hybrids (42 M_1, 65 M_1, 23 M_2, CM_2-5-20/91) formed a distinct sub-cluster. Data from a single primer combination was sufficient for distinguishing the hybrids from the parents and assigning paternity. The hybrids showed 22 markers that were absent in *P. ciliata* but were monomorphically present in all the hybrids, suggesting outcrossing and common paternity. Further, these 22 markers were found in all the *P. maximowiczii* genotypes confirming it as the male parent (Chauhan *et al.*, 2004).

Genetic diversity analysis with the help of AFLP was also performed on 43 of *P. deltoides* accessions introduced in India. Three other species, viz., *P. ciliata, P. maximowiczii* and *P. euphratica* genotypes were included as outgroups in the study for forming a long term breeding strategy. The AFLP successfully discriminated all the genotypes and outliers were distinguished very easily from the rest of the *P. deltoides* clones. The species *P. euphratica* was especially found to be very distinct from all the genotypes analyzed. All the ten AFLP primer combinations employed were found to be able to discriminate all the different clones. Statistical analysis indicated very high genetic similarity within the *P. deltoides* clones grown in India (0.775-0.978 similarity value). This was surprising considering they have been introduced/developed from different sources. Few of the clones, especially '65/27', 'PD-345/183', 'C-181' and 'A-50 (89)', were found to be very distinct among the *P. deltoides* clones and may actually be hybrids. The reason may be mislabelling/misidentification of the clones during their introduction or propagation or planting (Wilson, [n.d.]). The study showed that there should not be random mating of different clones, as is being done at present, but they must be first screened so that the situation of monoclonal plantations with very narrow genetic base could be avoided.

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Clonal Development and Diversity in WIMCO's Poplar Programme

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Introduction

WIMCO - a safety match company with one of its factory located in Bareilly, Uttar Pradesh (U.P.) started working on poplars during 1970s to develop it as match wood plantation tree on farm land in North India. Field performance of WIMCO's introduced two poplar (*Populus deltoides*) clones, viz., G48 and G3 in 1969 from Australia (Chaturvedi, 1982) paved the way for its culture on farm land in the country. Fast growth of these clones impressed the management of the company to initiate a planned programme for promoting its plantations for matchwood production. Swedish Match, the parent company of WIMCO in those days, had keen interest in poplar and aspen plantations to support its match business in many countries. The promotion of poplar plantations in India was an extension of the company's commitment to develop matchwood resources with backward linkages to ensure sustained wood raw material production and availability. WIMCO created an Agroforestry Extension Division in 1976 with a strong team of field extension workers and a research facility in 1982 which later on was upgraded into an independent company – Wimco Seedlings Ltd. in 1984 for the focused research on poplar and a few other socially and industrially important tree species. Wimco Seedlings Ltd. was merged with WIMCO Ltd. in 2005 and is operating as one of its division since then. However, these organisational changes did not have any effect on its research and development activities including poplar improvement which maintained constant continuity till date.

WIMCO is employing a simple and realistic but exhaustive screening process for clone development in poplar and a few other tree species. In case of poplar, seed obtained from manipulated crosses and selected half-sib parents are germinated

Clonal Development Programme

WIMCO is employing a simple and realistic but exhaustive screening process for clone development in poplar and a few other tree species. In case of poplar, seed obtained from manipulated crosses and selected half-sib parents are germinated (Fig. 1) and the new populations are followed for 18-20 yrs; i.e., 3-4 yrs in nurseries, 8 years in local level and remaining period in multi-location trials for screening desired individuals. Poplar improvement is presently based on *P. deltoides* whose clones are well adapted throughout the region of intensive poplar culture (RIPC) (Dhiman, 2012), where none of the indigenous species have ever thrived before their introduction. The initial programme was restricted to screening of seedling populations obtained from half-sib parents on noticing first time seeding on G48 clone in 1982 and later on, manipulated crosses were started among the available clones of *P. deltoides* w.e.f. 1989. Inter species crosses are now being made for over a decade period and their progenies are followed for favourable characters related to growth, form and resistance to diseases and insects. Most of the seedlings raised from crosses of *P. deltoides* with *P. ciliata, P. sauveolens* and *P. nigra* failed to tolerate the hot and dry weather conditions those exist in the RIPC. Some hybrids developed between *P. ciliata* and *P. sauveolens*; and *P. nigra* and *P. sauveolens* are neither well adapted nor productive in these locations. Some of these are maintained to attain reproductive phase for making backcrosses. During 2008-9, some seed were produced from crosses made between *P. gamblei* and *P. deltoides*, by manipulating delay in reproductive bud break in *P. gamblei*. Some seed and seedlings were also produced from the crosses between *P. gamblei* and *P. ciliata* and they also failed to survive warm and humid weather conditions in our operational area in plains.

Nursery Screening

Poplar program in the company employs traditional methods and materials to develop new clones. Each year, shoots with reproductive buds collected from trees of selected parents are cleft grafted on root stock already established in open nursery beds. Pollen collected from the identified parents is used for making crosses. Flowering shoots are covered with the muslin cloth bags during flowering and pollination. Capsules develop and expand quickly after fertilization. Mature capsules are collected during late April, May and June; seed on separation from the cotton is immediately sown in very light soil media. Seed germinate in two days period of sowing. Seedlings at 2-4 leaf stage are shifted in the cavities (root trainers). Seedlings are screened for disease and pest resistance in the first year itself. Selected seedlings are, then, planted in the nursery beds during the following February and are followed for further screening for diseases and insects resistance and form (Table 1). At the end of the growing period only the selected individuals are multiplied in good number in next year nurseries for field trials in the following years when they are planted in 2-3 sites for local level field trials. Newly developed seedlings are also sometimes placed under the saplings of susceptible clones or sprayed with the water suspension of *Bipolaris* spp. fungus causing leaf blight. Field trials are monitored for a full rotation of 8 years when the selections of desired individuals is made. Selected trees are rejuvenated by serial propagation, clubbed with selections of some of those from preceding or following years and are grown and monitored in the multi-location trials in the entire RIPC. Selected individuals based on the performance in multi-location trials are rejuvenated and produced in commercial nursery for supply of saplings to the growers. Each year a new trial is added in the system as per the procedure outlined above. The actual multiphase screening of each population is illustrated with data in the following pages.

An exhaustive multiphase screening process is followed for 18-20 years to make selection of suitable individuals from nursery and field trials. A major screening is carried out in the newly produced population on completion of first year growth in the nursery beds (2nd year from seedling production from seed). Some screening is already carried out during the first year when the seedlings are maintained in the cavities from their shifting from germination trays. Some individuals are also screened during the third and/or fourth year in nurseries when only the selected ones are moved for local level field trials. The screening percentage is quite high in the nursery stage itself. For example, the screening percentage carried forward after 1st, 2nd, 3rd and 4th screening were 80.11 per cent, 70.80 per cent 1.05 per cent, 1.05 per cent, and 0.12 per cent respectively, of the original population of year 2000 population (Table 1).

A liberal screening process is followed in case of populations produced from the manipulated crosses made between different species (Table 2). This is with the simple intention that most of the commercially grown clones still belong to introduced *P. deltoides* origin. The need is felt that if some of the crosses with other species especially with indigenous poplars are found suitable for commercial production or for back crosses, then it could significantly help in broadening the limited genetic base. *P. gamblei* is an

Table 1. Multistage screening of full and half-sib population (year 2000) in the nursery

Population	Seedling produced	Nursery screening (after yr)				
		1st	2nd	3rd	4th (Final; local level field testing)	5th (for multi-location field trials)
Half-sib	-	17,220	15,315	129	128	19
Full-sib	-	406	261	103	102	7
Total	21,512	17,626	15,576	232	230	26
Selection (%)	489	80.11	70.80	1.05	1.05	0.12
Rejection (%)	22,001	19.89	29.20	98.95	98.95	99.88

Table 2. Multistage screening of full and half-sib population (year 2009) in the nursery

S. no.	Parent	Seedling produced	Nursery screening (after yr)			
			1st	2nd	3rd	4th (Final)
1.	G-48 X G-3	40	16	7	1	1
2.	WSL-39 X G-3	120	66	52	3	2
3.	WSL-39 X WSL-A/26	90	51	32	4	2
4.	WSL-39 X *P. ciliata*	10	8	8	0	0
5.	S7C8 X G-3	160	90	90	15	15
6.	S7C8 X WSL-A/26	330	233	191	20	20
7.	S7C8 X S7C15	160	136	136	9	15
8.	S7C8 X *P. ciliata*	240	202	194	7	5
9.	WSL-32 X G-3	80	10	46	12	11
10.	WSL-32 X S7C4	16	52	10	3	3
11.	Wimco-110 X G-3	28	11	20	13	13
12.	Wimco-110 X WSL-A/26	200	21	170	36	34
13.	Wimco-110 X *P. ciliata*	38	175	21	1	1
14.	Wimco-62 X *P. ciliata*	15	22	10	0	0
15.	*P. tricocarpa* X *P. ciliata*	96	66	35	0	0
16.	*P. ciliata X G-3*	12	8	8	0	0
	Total	**1635**	**1167**	**1030**	**124**	**116**
	Selection (%)		71.38	63.00	7.58	7.09
	Rejection (%)		28.62	37.00	92.42	92.91

ideal but difficult material to handle in this regard. It has fast growth and adapted to low latitudinal locations in subtropical conditions. The species differs in rooting ability, flowering period and duration from most other introduced and indigenous species. A very early flowering in *P. gamblei* during late December relative to very late in March-April in all other indigenous and introduced species grown in the RIPC has critically affected breeding programmes with this species. Further flowering period in *P. gamblei* at Rudrapur, Uttarakhand is restricted to around one week period compared to its staggered period for around 1.5 months in case of *P. deltoides* grown under different altitudinal locations. In 2009, full and half-sib population with crosses made between *P. deltoides, P. ciliata and P. tricocarpa*, 71.38 per cent, 63.0 per cent, 7.58 per cent and 7.09 per cent after 1st, 2nd, 3rd and 4th screening respectively of the original population was retained for the local level trial.

Screening at Local Level Field Trials

The second phase screening is carried out in the local level field trials. Individuals selected from the nursery screening are multiplied in adequate number and planted in 2-3 sites on the company's farms or in some farmers' field near our operational area. The individual tried in these trials are many and well replicated single tree plots with increased replications are established inside the normally grown poplar plantations to avoid the boundary and side effects. Data is mainly recorded for growth and form and the selection is made at the end of the rotation mostly at 8 years on company's farms and for varying rotation on farmers' land. An example of such trial with selected individuals from multiple trials is given in Table 3. The individuals from such trials are selected based on a composite growth index of height and DBH+2SD.

Screening at Multilocational Field Trials

Third phase screening is carried out in the multi-location trials which are conducted simultaneously throughout the RIPC or, sometimes, in certain isolated locations in view of specific objectives associated with that site. Presently, three multi-location trials established in the Region of Intensive Poplar Culture (RIPC) during 2002, 2003 and 2007 on 12, 16 and 40 sites, respectively are being monitored. The overall ranking of the clones during different years and sites in 2002 trial is given in Table 4. The data in the Table indicate a variable harvesting time by the growers based on their financial needs. These trials are planted inside the normal plantations made on farmers' fields and, therefore, farmers start harvesting them as per their convenience. The data in the table indicate that the harvesting of the trial plantations was started from 4th years by one grower, by one more in 5th year, one in 6th year, three in 7th year and four in 8th year. Two of the plantations which are still maintained have been planted in the forest, are still growing and are likely to be harvested at 12 years of rotation age followed for such plantations. Overall ranking of the tested clones in these trials based on height and diameter growth clearly indicates a

Table 3. Performance of 25 clones in a local area trial at Chandain Farm, Bilaspur, Uttar Pradesh

Clone	Initial		Growth at 96 months (8 yrs)	
	Height (m)	DBH (cm)	Height (m) MEAN (SD) CV%	DBH (cm) MEAN (SD) CV%
Wimco-81	4.4	2.8	27.2(2.25) 08	28.8(3.47) 12
Wimco-98	4.6	2.7	25.5(2.16) 08	27.5(4.06) 15
Wimco-A/26	4.4	2.5	25.4(1.05) 04	24.9(1.97) 08
Wimco-85	4.5	2.6	24.9(2.08) 08	24.5(2.93) 12
Wimco-84	4.6	2.7	25.7(1.29) 05	24.4(2.14) 09
UDAI	4.2	2.3	24.9(1.88) 07	24.2(1.79) 07
Wimco-91	4.4	2.9	24.5(1.73) 07	23.9(1.98) 08
Wimco-82	3.6	1.9	23.9(0.49) 02	23.8(0.21) 01
Wimco-A/49	4.2	2.6	24.4(1.11) 04	23.5(1.75) 07
Wimco-103	4.0	2.4	23.9(1.05) 04	22.9(0.67) 03
Wimco-90	4.0	2.5	24.6(0.95) 04	22.9(1.72) 07
Wimco-94	3.9	2.4	23.3(1.71) 07	22.5(2.58) 11
Wimco-14/2	4.2	2.2	23.2(1.09) 05	22.4(1.31) 06
Wimco-88	4.4	2.6	23.6(2.50) 10	22.4(2.88) 13
Wimco-99	3.9	2.3	22.5(0.84) 04	22.2(1.22) 05
Wimco-96	3.9	2.2	23.4(1.66) 04	21.6(2.42) 11
Wimco-97	4.4	2.6	23.3(0.53) 02	21.4(0.39) 02
Wimco-102	3.6	2.1	22.6(1.54) 07	21.1(2.30) 11
Wimco-101	3.7	2.3	22.3(3.19) 14	21.0(4.62) 22
Wimco-6/24	4.5	2.5	21.8(1.35) 06	20.4(1.10) 05
Wimco-86	4.8	2.5	22.3(0.82) 04	19.9(0.74) 04
Wimco-87	3.9	2.3	21.9(1.65) 07	19.9(1.84) 09
Wimco-92	4.2	2.4	21.7(2.22) 10	19.0(2.68) 14
Wimco-89	3.7	2.2	21.3(1.57) 07	18.6(1.99) 11
Mean	**4.1**	**2.4**	**23.7(1.44) 06**	**22.7(2.35) 10**
SE Diff.			**1.24**	**1.77**
CD (0.05)			**2.43**	**3.47**

consistency for two clones, viz., Wimco 81 and Wimco 83 till 6th year of growth. The two remaining sites have produced trees of less height and DBH with very low management inputs which also indicates that appropriate cultural operations are necessary for exhibiting the actual potential of clones on tested sites. In addition to above, the screening of clones is also done for specific objectives like against red mite which is common in eastern locations due to warm and dry weather conditions (Dhiman, 2007). Wood testing for end use is also an isolated trial conducted in specific poplar based units (Dhiman and Gandhi, 2006).

From these trials, two clones Wimco 81 and Wimco 83 were selected based on six years performance, rejuvenated and multiplied for commercial production and for supply of the saplings to the growers. We prefer to monitor our clonal trials to full rotation of 6-8 years, though, some recommendations are available for early selection for fast mass multiplication of leading clones (Kumar and Singh, 2001). We also believe in conducting repeated clonal trials to avoid loss to growers from premature testing and release of new clones. Numerous growers have already had a very bad experience of growing tissue cultured poplar which repeatedly performed very poor (Dhiman and Gandhi, 2010).

The company includes selected clones from these trials in its germplasm and regularly updates and monitors them for various characters. The germplasm is maintained in the nursery by replanting five to 10 cuttings each year and also as a field plantation in one to two sites on company's

Table 4. Ranking of clones in 2002 multi-location trial on12 trial sites

Clone	Ranking among the tested clones									1st position among the tested sites								
	Nry	1	2	3	4	5	6	7	8	Nry	1	2	3	4	5	6	7	8
Wimco-27	V	VI	V	III	V	II	IX	VII	V	2	-	1	-	-	-	-	-	-
Wimco-28	VII	II	II	II	II	VII	V	IV	IV	-	-	-	-	-	1	1	-	-
Wimco-38	XI	VIII	VIII	V	III	V	VII	VII	VII	-	1	-	-	2	2	1	1	-
Wimco-39	VI	IV	IV	III	III	IV	IV	III	VI	2	1	-	-	1	-	-	2	1
Wimco-80	III	VII	VI	VIII	VIII	VIII	III	II	III	1	2	-	-	-	-	-	-	-
Wimco-81	IV	IX	IX	VIII	VI	III	II	VI	VII	1	-	1	-	1	2	4	1	-
Wimco-82	XII	XI	XII	XII	VII	XII	VII	X	X	-	-	1	-	-	-	-	-	-
Wimco-83	VII	I	I	I	I	I	I	I	I	-	5	6	6	7	2	3	1	1
Wimco-84	IX	XII	X	X	XI	X	XI	XI	XI	-	-	1	2	-	1	-	-	-
Wimco-A/26	X	X	X	XI	X	XI	X	IX	IX	-	1	-	-	-	-	-	-	-
Wimco-A/49	II	III	III	VI	VII	VI	VI	XII	XII	4	1	-	-	-	1	-	1	-
G-48	I	V	VII	VII	IV	IX	VIII	VIII	II	2	1	2	4	-	1	-	-	-
Site (no.)										**12**	**12**	**12**	**12**	**11**	**10**	**9**	**6**	**2**

A Case Study of 1997 Full-Sib and Half-Sib Population

Ninteen thousand one hundred ninty five seedlings were produced from manipulated crosses involving 9 female clones (G48, Wimco 62, St121, 3201, S7C13, S7C8) and 6 male clones (St3, St63, S7C3, S7C4, S7C20, 112910) of *P. deltoides* in 39 attempts made between 17-2-1997 to 26-3-1997. There were 36 unsuccessful attempts of making crosses between 22^{nd} February to 26 March, 1997 with some female clone's mainly; St12, St75 and L34 and some male clones. One lakh thirty six thousand seven hundred forty two seedlings were also grown from the seed collected from open pollinated G48 (117577 number seedlings) and S7C13 (19195 seedlings) parents. During nursery screening (4 time screening) in three years, 41.39 per cent, 0.16 per cent, 0.16 per cent and 0.04 per cent individuals were selected after the screening process for overall disease rating (scale 0-4) against fungal pathogens viz., *Phoma* spp., *Bipolaris* spp., *Cercospora* spp.), and stem straightness (scale 0-4). Fifty four individuals from this population were selected and planted in two local level field trials in Uttarakhand. The trials were monitored for growth, form and reproductive behaviour for full rotation; i.e., 8 years. A female individual flowered in third year, 29 individuals (53.7 per cent) by 5^{th} year, 35 (64.8 per cent) by 6^{th} year and 53 (98.1 per cent) by 7^{th} year. Out of the total of 53 individuals attaining reproductive age by 7^{th} year, 30 (58.5 per cent) were male and 23(41.5 per cent) were female. Individual number 86 was leading performer producing 1.438 m^3 timber volume (down to 30 cm mid girth merchantable log thickness) with 30.8 m height and 41.5 cm DBH at 8 years rotation. Nine individuals were selected out of this trial for multi-location trial which was established on 40 sites across the entire RIPC. Three individuals now named as WIMCO 108, WIMCO 109 and WIMCO 110 have been selected based on overall performance in multi-location trials for the commercial production. These clones were also screened for red mite infestation which is very common in warm locations towards eastern limits of RIPC. WIMCO 110 (earlier coded as individual No. 163) has been found highly resistant to red mite infestation (Dhiman, 2007). These three clones are now commercially produced and being supplied to the growers.

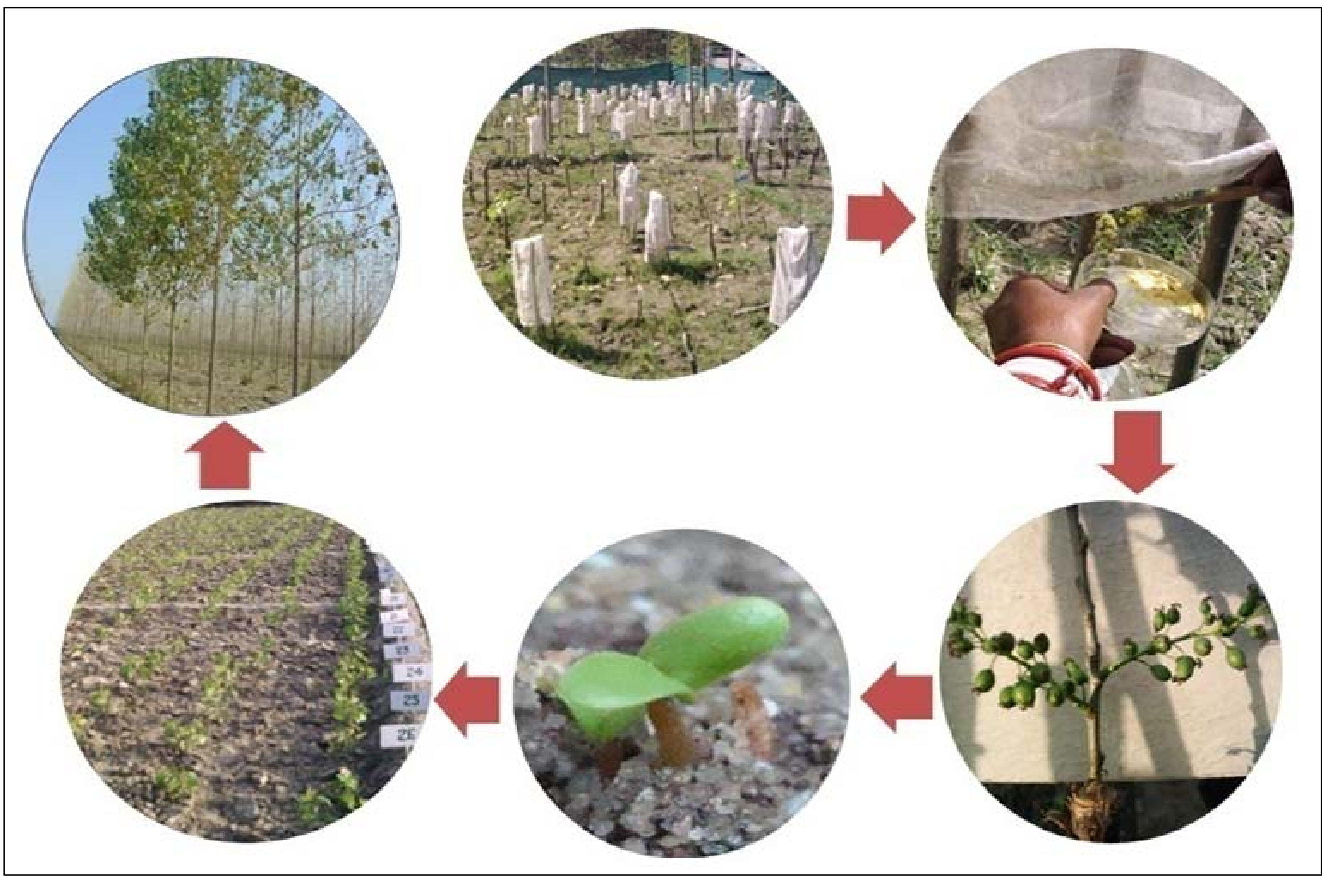

Fig. 1. Hybridization work followed at WIMCO.

farm. We closely and regularly monitor the clones numbering 492 maintained in germpalsm, out of which 344 were included from our own poplar improvement programme, 57 procured from UHF, 15 from Uttarakhand Forest Department and 76 exotic clones introduced at different periods. These clones exhibit wide variation in growth, form and their response to diseases and insect attack. For example, the nursery performance of these clones during the year 2011-12 indicates three clones with a height: DBH ratio of 125-150, six with 151-175 ratio, 93 with 176-200 ratio, 228 with 201-225 ratio, 149 with 226-250 ratio and 13 with more than 250 ratio at one year seedling production phase. These clones are also regularly monitored for disease resistance every year. The ranking index (Kotle, 1985) for diseases for all these clones is given in the Table 5. Leaf blight caused by *Bipolaris* spp. is a serious disease and is rigorously monitored in our tree improvement programme. Most of the clones in our tree improvement programme are screened out against its infection and, therefore, it includes only a few susceptible clones for this fungus. Blistering and *Sclerotium* leaf spots are posing new threat and these have now been included for screening in the poplar improvement programme. *Phoma* leaf spots are now recorded widespread towards the fag end of the growing season when most of the lower leaves start dropping prematurely. Blistering is developing as a potential damaging disease wherein some mortality of field planted saplings is carried forward from the infected nurseries. It now finds equally good space in poplar improvement programme. Other diseases are though noticed widespread but their damage on the existing clones has not been found very serious and is being monitored for maintaining the history of disease in reference to clones. *Phoma* leaf spot is also on the watch list in the improvement programme.

Clonal Diversity

Numerous poplar species, hybrids and clones have been introduced in India from various countries during the last 60 years. Out of these, clones of *P. deltoides* developed from its low latitudinal populations have proved successful in the country. Clones presently that find mention in India belong to many series, viz., WSL, Wimco, G, L, EL, D, St, S, I, IC, FRIAM, FRIFS, PL, Pant, UFC, UCM, UD, and even simple named and numbered series (D series clones are also mentioned as St series in some publications). G, St, D, S, I and IC are introduced series clones and the remaining are indigenously developed ones. Many clones especially picked up from WIMCO are used in research trials before their final release and are quoted by their original numbers. WSL, Wimco and named series like Udai, Kranti and Bahar clones have been released by WIMCO and many of these are widely grown and preferred clones throughout the RIPC. The next preferred series of poplar clones is S series which were introduced from the USA. Numerous clones under this series were tested across the RIPC and two widely grown ones are S7C15 and S7C8. The former is widely grown throughout RIPC, whereas, S7C8 finds preference with growers in UP and UK states. L and EL series clones are from Uttar Pradesh (UP) Forest Department; FRIAM and FRIFS from the Forest Research Institute (FRI), Dehradun; PL from Punjab Agriculture University, Ludhiana, Punjab; Pant series from G.B. Pant University of Agriculture and Technology, Uttarakhand; and UFC, UCM, and UD series clones from the University of Horticulture and Forestry Solan, Himachal Pradesh. Performance of introduced G3 and G48 clones laid down the base for the poplar culture in plain areas in India. G3 was the main clone till mid 1990's whereas G48 became widely preferred clone thereafter. Some space created by the exit of G3 on developing susceptibility to leaf blight, was quickly occupied by Udai clone. Of late, the share of G48 in field plantations is decreasing on developing susceptibility to many pathogens and insects. Besides, there are now many other equally good indigenously developed clones, some of which have both wide scale and endemic acceptability. Some L series clones especially L34, L13 and L49 were also grown in some locations during some period. Saplings of L34 clone produced from tissue culture originated mother plants were also supplied in large number across the RIPC and their performance was

Table 5. Annual screening (2011-12) of germplasm clones for major diseases

Infection (%)	No. of plant infected with disease					
	Blistering	*Sclerotium* leaf spots	*Phoma* leaf spots	*Cercospora* leaf spots	*Aletrnaria* leaf spots	*Bipolaris* leaf blight
No infection	281	488	1	47	291	486
0-20	52	3	1	39	80	3
21-40	54	0	3	38	64	1
41-60	36	1	10	57	32	0
61-80	37	0	35	94	18	0
81-100	32	0	442	217	7	2
Total	**492**	**492**	**492**	**492**	**492**	**492**

subnormal compared to the traditionally propagated saplings from stem cuttings (Dhiman and Gandhi, 2010). Clones which were introduced in the initial phase of poplar planting or field trials, viz., *P. deltoides* 'IC', I, D series and even 65/27 are still spotted in some field locations and are grown by some private nurseries ignorantly or even may be regenerating from root suckers. The present nomenclature of poplar clones creates a lot of confusion and the use of different names for the same clones by different organization is also not ruled out.

WIMCO raised first ever poplar nursery outside government sector with its introduced G48 and G3 clones at Bareilly, U.P. during 1969. A few saplings out of this production were planted on farmers fields around Bareilly during the following years. The early performance of these saplings on farmer's fields boosted the confidence of the management of the company to initiate a planned programme for poplar culture on farm land. U.P. Forest Department was already conducting trials on forest land with the introduced clones of *P. deltoides,* viz., I-488, I-214, I-215 and I-15-II initially (1965-1968) and then with 'IC', St121, G3 and G48 clones (Chaturvedi, 1982). The department introduced G3 clone in its programme in 1972 and G48 in 1975. A total of 1,355 hectare forest area in U.P. was planted with 29 poplar clones till 1981, of which the maximum 35.21 per cent area was with clone 'IC' followed by 21.80 per cent with G3, 8.62 per cent with D121, 6.64 per cent with D124 clone and remaining with others. The share of G48 was only 3.36 per cent during this period (Chaturvedi, 1982). WIMCO also supplied saplings of St121, and 'IC' clones initially to the growers in the states of Punjab, Haryana, U.P. and elsewhere under its regular extension programme w.e.f. 1976. The share of St and 'IC' series clones sharply declined and G3 and G48 clones developed preference among the growers. During 1990's clone G3 constituted more than 90 per cent planting stock in many locations including in Yamunanagar district of Haryana which is the main poplar wood trading centre in the country. Clones G-3, St-100, St-121, L-34, etc. have now some isolated presence but are not recommended for plantations in greater part of RIPC because of low productivity, threat of insect and disease infestations to these clones.

Presently, around two dozen clones are commercially grown in the country. WIMCO this year (2012) is growing approximately 6.5 million saplings in around 40 nurseries throughout the RIPC. These will be supplied to the growers and a few thousands of them would be used for planting in its own farms and multiplication. Share of different clones in the company's poplar programme implemented throughout the major part of its growing region in the country especially in the RIPC (between and within states, Table 6) indicates a complex matrix of their acceptability. Company's developed and introduced clones including clone G48 are still the leading clones demanded by the growers. G48 followed by WSL 22, Udai, WSL 39, S7C15, Wimco 81, WSL 32, S7C8, Kranti, Wimco 108, WSL A/26, WSL A/49 and around a dozen others are grown by the company. Clones G48, WSL 22, Udai, WSL 39 and WSL 32, Wimco 81and S7C15 together constitute over 90 per cent of the total planted poplar in the country. Out of 6 recently released clones, viz., Wimco 81, Wimco 83, Wimco 108 and Wimco 110 are now being demanded by the progressive farmers. Some clones like L34 developed by Uttar Pradesh Forest Department and introduced S7C4, St 121 also demanded by a very few growers and are grown and supplied

Table 6. Share of clones in sapling production between and within states in WIMCO's poplar programme (2012)

Clone	Clone share (%) among states				Clone share (%) within states				Total
	UP	UK	Pb	HRY	UP	UK	Pb	HRY	
G-48	19.41	37.31	32.87	10.41	19.98	47.18	52.58	27.89	36.22
Udai	43.49	15.51	19.06	21.93	14.71	6.44	10.02	19.30	11.90
S7C8	75.55	14.18	1.65	8.63	3.97	0.91	0.13	1.18	1.85
S7C15	85.13	2.97	10.35	1.55	13.93	0.60	2.63	0.66	5.76
WSL 22	41.01	24.08	20.44	14.47	21.87	15.77	16.94	20.07	18.76
WSL 32	34.32	42.85	2.61	20.22	2.85	4.36	0.34	4.36	2.92
WSL 39	39.60	40.61	12.72	7.07	10.19	12.83	5.08	4.73	9.05
WSL A/49	87.87	12.13	0.00	0.00	2.61	0.44	0.00	0.00	1.04
WSL A/26	0.00	31.04	52.33	16.58	0.00	1.16	2.47	1.31	1.07
Kranti	50.92	4.24	4.22	40.63	2.31	0.24	0.30	4.79	1.59
Bahar	98.03	1.97	0.00	0.00	1.42	0.04	0.00	0.00	0.51
Wimco-81	25.05	41.39	16.95	16.61	3.80	7.71	4.00	6.56	5.34
Wimco-108	14.39	9.56	30.71	45.34	0.56	0.46	1.85	4.57	1.36
Wimco-110	45.13	12.90	22.37	19.59	1.15	0.40	0.88	1.30	0.90
G-3	100.00	0.00	0.00	0.00	0.48	0.00	0.00	0.00	0.17
Wimco-83	4.76	33.63	37.77	23.84	0.09	0.82	1.16	1.23	0.70
Wimco-109	0.00	9.40	51.43	39.17	0.00	0.23	1.62	2.06	0.71
Others	21.02	78.98	0.00	0.00	0.09	0.42	0.00	0.00	0.15
Total	**35.18**	**28.65**	**22.64**	**13.52**	**100.00**	**100.00**	**100.00**	**100.00**	**100.00**

UP=Uttar Pradesh, UK=Uttarakhand, Pb=Punjab and HRY=Haryana to them on their demand. Data on location-wise clonal production and supply from so many field sites is difficult to accommodate in this paper. The data in the Table 6, however, clearly indicates wide spread and endemic acceptability of many clones. Whereas, G48, WSL22, WSL39 have widespread acceptability, many others are restricted to a few locations. Clone G3, once a dominate clone in poplar culture over the greater part of the poplar growing region, is now restricted to U.P. and that too to only Aligarh/Bulandshahar locations in U.P. where it does not attract infestation from *Bipolaris* spp. due to drier weather conditions. Some saplings of G3 clones are also reported to be grown in the drier part of Haryana. Similarly, clone G48 the most preferred clone among the growers over the great part of RIPC is not grown towards eastern limits of poplar culture especially eastward of Bareilly (U.P.) because of its high susceptibility to sap sucking insects including red mite (Dhiman, 2007). WSL22 is now becoming more acceptable in its place in many locations. Similarly, S7C8, WSL A/49 and Bahar are mainly grown in the states of U.P. and Uttarakhand and they are almost non-existent in the states of Punjab and Haryana.

WIMCO has released 15 indigenously developed clones from its improvement programme and two introduced clones (G48 and G3) for field planting. Three clones, viz., Udai, Kranti and Bahar were released during the year 1992, six clones, viz., WSL 22, WSL A/26, WSL 27, WSL 32, WSL 39, WSL A/49 were released during the year 2000 and six others, viz., Wimco 62, Wimco 81, Wimco 83, Wimco 108, Wimco 109 and Wimco 110 were released during the year 2010. Many of these clones are in the data base of IPC whereas the last lot of five Wimco series clones has been sent for registration. G48 has already phased out from some locations and is declining in many others.

Choice of clones being grown is specifically driven by the demand from the growers. The fact that the company still grows a few thousands saplings of some introduced and those developed by other agencies, viz., L34, S7C15, S7C8, S7C4, etc. indicates that there is some demand of these clones from the growers and are produced to meet the requirement of growers. The demand for the above mentioned clones is realistic as has been found from an exhaustive survey that was conducted in all the poplar growing nurseries in that state by the Haryana Forest Department during 2011-12 (Dhiman and Jagdish Chander, 2012). The survey confirms that G48, WSL 22, Udai were the leading clones with 95 per cent of the total stock production belonging to these clones. Yamunanagar District in Haryana is one of the main centres of poplar nursery and plantation culture and also as a main centre of poplar wood trading and its processing in the country. The outcome of the survey on sapling production of clones in demand is, therefore, a realistic indicator of the choice of clones being grown. Some other interesting observations from this survey indicates that St121 and IC clones are still being grown in many nurseries and these were not recorded by the field staff during this survey. On the other hand, WSL34 and SAI43 clones recorded in the survey are not standard clones and are being ignorantly mentioned by some of the nursery growers. It is believed that most nursery growers lack knowledge and identification of the clones and they name their ETPs to any standard clone which finds market. Most poplar growers and its wood users know mainly G48 clone and many nursery growers supply their unknown origin saplings on the name of this clone. The percentage and share of clones as shown in the Fig. 2 is just indicative trend and G48 is not necessarily occupying 56 per cent share in clonal culture in the state as appeared from the data of the survey.

The grower's choice for clones has been slowly changing over the time. Poplar is now grown by numerous growers numbering a few hundred thousands in India. Many of them have planted and harvested poplar numerous times. They, therefore, have developed likings for some clones which have been grown on their fields and avoid taking risks with new clones. The farmers show great interest in new clones yet follow a conservative approach in view of emergence of many nursery growers supplying spurious planting material on the name of hybrids and tissue cultured poplar. The acceptability and adoption of new clones is, therefore, very slow and highly complex mechanism among so many growers in the country. WIMCO released its six clones, viz., WSL 22, WSL A/26, WSL 27, WSL 32, WSL 39, WSL A/49 during the year 2000 for supply to the farmers. The slow progression in the adoption rate of individual clones in this complex farmer based poplar farming is indicated in Fig. 3. It is only after a successful and better production of new clones on farmer's fields that they start accepting good performing ones.

Poplar is the most domesticated forest tree in India and has better synergy with agriculture system than forestry operations. Replacement of old clones is expected fast in this domesticated tree than in many slow growing trees. Like agricultural crops, it is strongly felt that poplar farming also needs to have continuous development of new clones which are site matched, more productive and resistant to pests. WIMCO's poplar programme is simple but realistic technical programme which is immensely helping in sustaining poplar culture supported by numerous growers in the country. It is also a mean for livelihood for thousands of nursery growers who freely grow WIMCO's developed clones as a part time

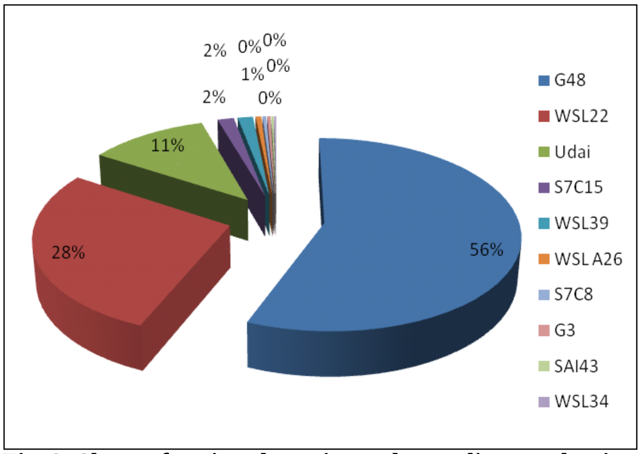

Fig. 2. Share of major clones in poplar sapling production in the state of Haryana.

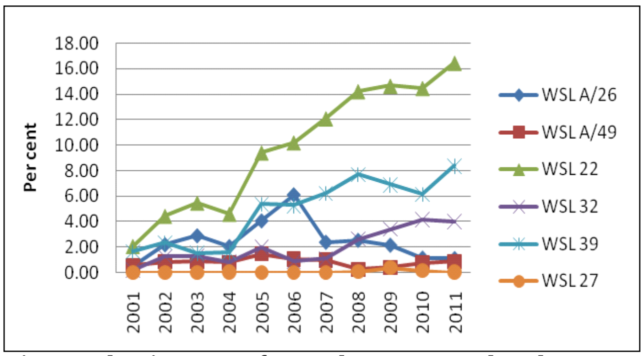

Fig. 3. Adoption rate of new clones over a decade among growers in WIMCO's programme.

business activity. WIMCO's poplar programme is a complete package of its improvement, nursery and plantation culture integrated with agriculture crops on farm land and wood procurement. Its backward and forward linkages with nursery production and wood usage helps in developing operationally acceptable technologies. Integration of research and development at every level adds value to the programme. Multi-location trials being conducted on farmer's fields act as demonstration plots and as a mean for fast acceptance of good performing clones. Further the testing of the new clones is on the actual land use where they are grown after the release. Acceptance of its numerous clones in nursery and plantation culture over its entire growing locations in the country is an indication of the success of this programme.

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Status of Intercropping in Poplar Based Agroforestry in India

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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

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 unmatchable 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 over come 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 (3^{rd} 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., 4.55t per ha, which was higher than the crop grown under boundary

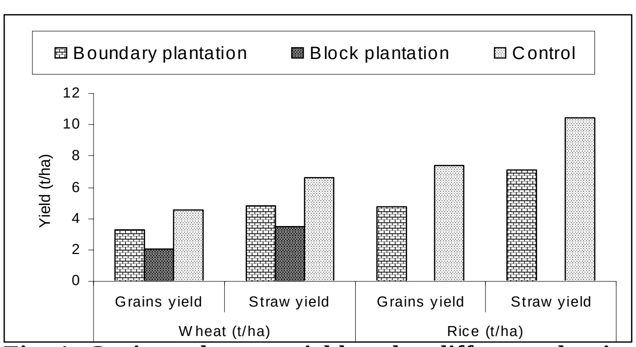

Fig. 1. Grain and straw yield under different planting methods.

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 4^{th} 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 (Ralhan *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 1m^3 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 fibrosity 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)

Pit size	Plant height (m)	Collar girth (cm)	Root spread (m^2)	Total root fresh weight (kg)	Lateral root fresh weight (kg)	Root number	Total stem dry weight (kg)
Auger hole 1m (15cm diameter)	5.5	16.7	4.4	1.4	0.70	35.7	1.4
45cm pit + auger hole 55cm	5.9	18.0	4.5	1.7	0.81	24.8	2.1
1m^3 pit	6.0	24.0	6.7	2.8	1.42	32.3	4.9
45cm pit with polythene lining +55 cm auger hole	5.0	19.7	5.4	2.5	1.07	38.7	2.5
1m^3 pit with polythene lining	5.8	21.0	6.1	2.2	0.94	31.5	2.6
CD 5%	NS	NS	1.5	NS	NS	NS	1.73

1 m^3 pit without polythene lining

1 m^3 pit with polythene lining

Fig. 2. Rooting behavior of poplar roots.

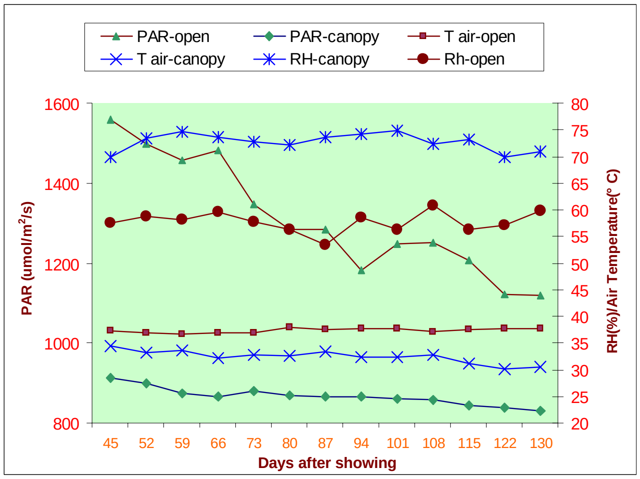

Fig. 3. Micro-environmental parameters in open and under poplar tree canopy (Dhilllon *et al.,* 2007).

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 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

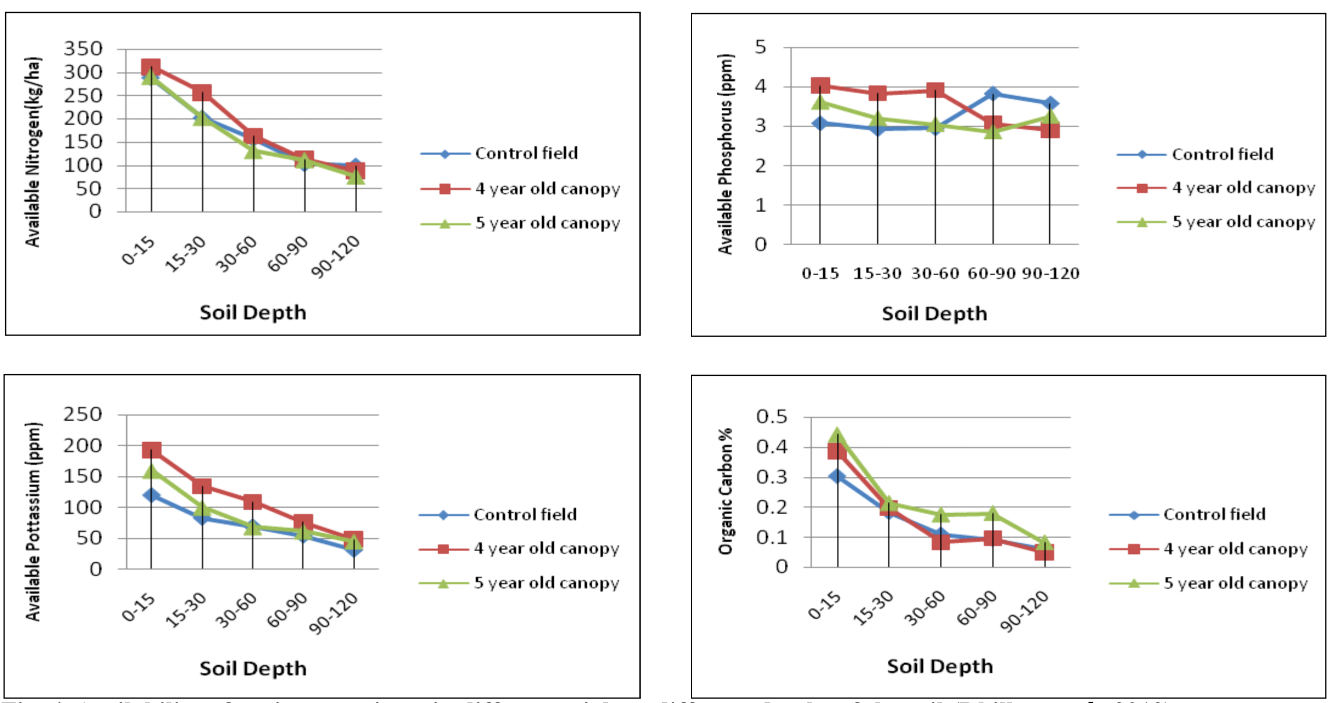

Fig. 4. Availability of various nutrients in different trials at different depths of the soil (Dhillon *et al.,* 2012).

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-silvicutural system.

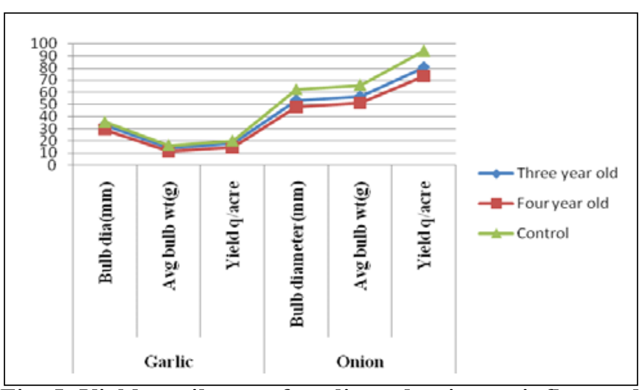

Fig. 5. Yield attributes of garlic and onion as influenced by poplar canopy (ICAR, 2010).

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.

Table 2. Diurnal variation in eco-physiological parameters of turmeric and colocasia crops (Dhillon *et al.*, 2009; Chauhan *et al.*, 2011a)

Time	PAR ($\mu molm^{-2}s^{-1}$)	Photosynthesis rate ($\mu molm^{-2}s^{-1}$)	Transpiration rate ($mmolm^{-2}s^{-1}$)	Stomatal conductance ($mmolm^{-2}s^{-1}$)	Temp. air (°C)	Temp. leaf (°C)	Internal CO_2 (ppm)
Turmeric under canopy							
9AM	240.27	3.30	0.91	112.92	31.10	32.00	373.23
12 Noon	487.06	5.20	2.71	239.16	33.20	35.17	321.27
4PM	119.40	2.02	1.54	149.48	32.27	33.00	404.77
Turmeric without canopy							
9AM	648.38	11.19	1.19	154.21	36.42	39.76	264.90
12Noon	1005.77	3.69	3.69	220.25	34.70	39.40	313.67
4PM	554.63	1.61	1.69	27.71	38.57	44.60	372.13
Colocasia under canopy							
9AM	276.78	0.75	0.53	156.87	31.30	32.18	374.85
12 Noon	529.34	2.12	2.73	277.14	35.16	36.96	368.03
4PM	125.83	1.61	1.04	124.03	33.00	35.75	335.70
Colocasia without canopy							
9AM	676.20	12.82	3.52	161.27	34.23	38.63	341.97
12 Noon	1110.80	5.12	4.26	82.27	39.57	43.67	190.33
4PM	538.13	9.44	2.80	181.88	35.43	38.60	374.07

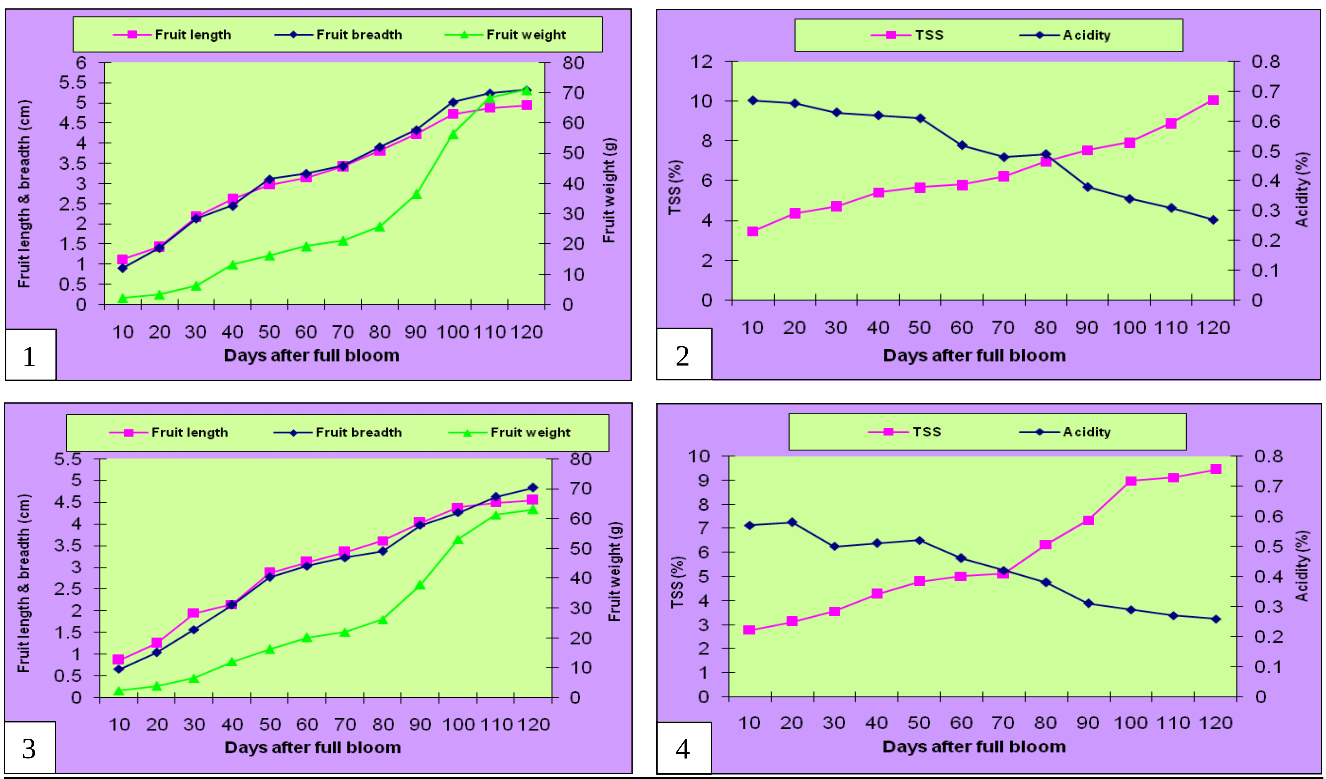

Fig. 6. Fruit development in guava under open (1 and 2), and under poplar canopy (3 and 4).

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

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

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 20m^2 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,

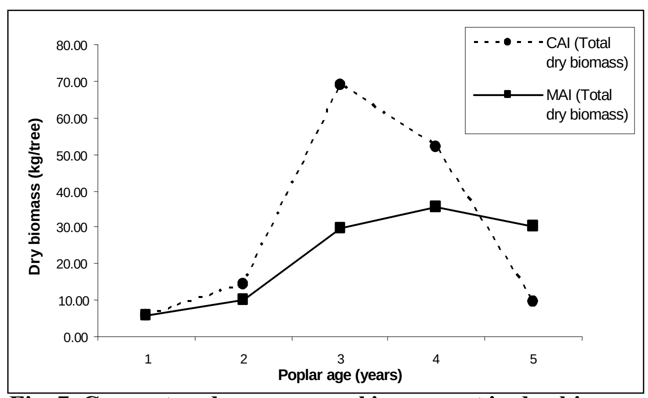

Fig. 7. Current and mean annual increment in dry biomass in poplar trees of different ages (Chauhan *et al.,* 2012a).

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

Tree age (yrs)	Ludhiana (flood plain-bet area)		SBS Nagar (Shiwalik foothills-irrigated)		Amritsar (North central)		Bathinda (semi-arid)	
	Height (m)	DBH (cm)	Height (m)	DBH (cm)	Height (m)	DBH (cm)	Height (m)	DBH (cm)
1	6.64	5.83	4.93	5.36	*	*	4.81	5.42
2	9.90	11.64	11.98	11.29	11.80	10.56	9.48	10.17
3	18.04	17.51	15.44	14.37	14.66	15.92	11.59	12.40
4	20.04	21.00	18.12	18.26	16.37	18.27	15.43	14.56
5	21.80	21.37	20.30	19.20	17.57	21.53	*	*
6	21.98	22.00	22.58	21.75	20.96	22.60	*	*

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

Tree age (yrs)	Tree height (m)	DBH (cm)	Clear bole (m)	Crown spread (m^2)	Dry biomass (kg/tree)			
					Timber	Branch wood	Small wood (lops and tops)	Lateral roots
1	6.6	5.8	2.9	8.0	3.8	0.6	1.2	0.1
2	9.9	11.6	2.9	22.8	21.5	3.5	4.5	1.0
3	18.0	17.5	3.8	38.0	68.2	8.4	6.9	5.8
4	20.0	21.0	4.4	45.3	107.3	13.1	9.7	10.9
5	21.8	21.4	6.5	56.6	115.3	13.3	9.4	12.5
CD 5%	0.5	0.6	0.4	3.1	13.4	4.0	1.8	2.2

2011; Pande and Dhiman, 2011), therefore, comprehensive clone-wise volume/biomass tables with broader practical applicability are still required. It would be more appropriate to develop biomass table on the basis of basal area at collar region instead of breast height for easy measurements by the illiterate farmers. Diameter at breast height was standardized (1.37 m above ground level) to avoid inconvenience for measurements in forests, which is not the situation in agroforestry plantations.

Poplar Based Agroforestry Farms as Carbon Sinks

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 (Schoreder, 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 17.8t 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

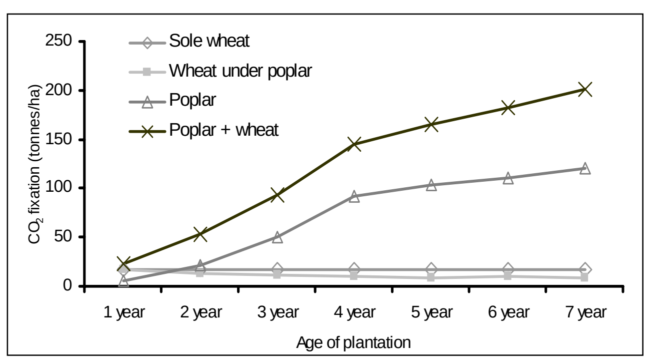

Fig. 8. Total CO_2 assimilation (t ha^{-1}) by poplar-wheat (above- and below-ground biomass) in agroforestry system and sole wheat cultivation (Chauhan and Chauhan, 2009).

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 23.57t 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 mono-cropping 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) 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 sequesteresd 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 6. Carbon sequestration in poplar based agroforestry models

Treatments*		Total biomass** (t/ha)	Long lived timber C storage (ton C/ha)	Heat from biomass combustion (x10^9)	Carbon storage from coal substitute (ton C/ha)	Total C sequestration*** (t C/ha)	Total C sequestration (t C/ha/yr)
Block plantation	Trees + wheat straw	154.3	18.7	2041.4	34.3	55.4	9.2
	Trees without wheat straw	125.7	18.7	1525.7	25.6	46.8	7.8
Boundary plantation	Trees +wheat + rice straw	101.8	4.4	1657.4	27.8	32.7	5.5
	Trees + rice straw	72.8	4.4	1135.8	19.1	23.9	4.0
	Trees without rice and wheat straw	30.1	4.4	367.9	6.2	11.0	1.8

* 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 tree 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 uncertainity (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 accountable 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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Poplar Culture on Farmland: Farmer's Experience from Uttar Pradesh

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Introduction

The increasing pressure of growing population and demand for food and wood had resulted in conversion of large areas of forests to agriculture, industrial and urban development. This further led to scarcity of fuel wood, timber for construction and wood for many commercial uses. In order to save forests and trees for an important role that they play in climate change mitigation, prevention of soil erosion, etc., measures have been taken by several countries to conserve them and this has further reduced the supply of wood. The shortage of supply of timber is likely to increase in India making it difficult for the country to meet its requirements from both domestic and international front. Hence, partial solution to the above problems could be to increase area under tree cover by either growing trees on farm boundaries or by integrating them with agricultural crops on farmland. In other words, there is a need for wide scale adoption of agroforestry as land use.

Agroforestry is a land use system in which trees are grown with agricultural crops. The agroforestry, which has gained wide popularity in north-western India, is cultivation of poplar trees for timber along with other crops like wheat, sugarcane, turmeric, etc. Poplar is a major agroforestry tree species grown in Punjab, Haryana, western Uttar Pradesh (U.P.) and Uttarakhand due to its fast growth, profitable returns and high industrial demand. Poplar is one of the world's fastest growing industrial softwood and can be harvested at short rotations depending on the end use of its tree components. Its wood is light, homogenous, odorless and is excellent for manufacturing matches, pencils, plywood, light constructional timber, paper, and packaging cases. Poplar is deciduous in nature and therefore it adds leaf litter during winters thereby adding fertility to the soil. Its leaf shedding characteristic allows intercrops to be grown in winters. Wheat is the most preferred winter crop grown with poplar.

Poplar based agroforestry is not only economically very attractive but also beneficial to environment

According to Hara (2006), agroforestry has contributed immensely to society by way of providing good returns to farmers, supported wood industry thereby providing employment to millions, has given cheaper wood products to consumers and reduced India's dependence on wood imports.

Poplar Based Agroforestry (PBA) in the Terai Plains of Western Uttar Pradesh and Uttarakhand

As early as 1970s progressive farmers in the Terai region of U.P. started planting poplar with intercrops (Chandra, 2001). Since then there has been rapid adoption of poplar based agroforestry (PBA) in this region. The system adopted here is of taking sugarcane as intercrop for first two years followed by wheat as winter crop until the harvest of poplar trees.

Wood based industry in the region has been depended on the state forest departments for raw material until the late 1970s. Later on, the green felling was banned in state forests which meant that wood based industry had to go to farmers for their raw material needs (Chandra, 2003).

In 1976, an extensive publicity campaign was initiated by WIMCO to promote poplar cultivation. It decided to give farmers genetically superior quality poplar plants to grow, for them (Hara, 2006). WIMCO distributed 126,000 seedlings of poplar free of cost to farmers in the year 1983 in north-western India.

In 1984, WIMCO together with NABARD worked out a poplar refinance project. As per the project:

1. WIMCO supplied ETPs to the farmers.
2. It also transported the ETPs free of cost to the farmer's field.
3. It provided technical know-how to farmers for the entire growth period of the trees.
4. Damaged ETPs were replaced by WIMCO in the farmers' fields in the first two years.
5. Insurance cover for tree damage was arranged by the company.
6. WIMCO paid Rs. 500 or market price whichever was higher once the trees met the requisite parameters (during the first phase of the project period).

Extensive work done by WIMCO led to emergence of poplar based agroforestry as a major farming practice in North India which has made great strides in India in the last three decades.

Poplar Based Agroforestry at Our Farm

Chaudhary Farm is one of the leading well managed farms of the locality. The farm has all ingredients of modern agriculture that include intensive and mechanized farming with heavy inputs, farm site for testing and growing latest varieties in association with the leading agricultural university of the locality, organic farming with vermicompost and farmyard manure, diverse land use practices of horticultural crops like mango, litchi, guava; and agroforestry with poplar, eucalypts, teak, kadam, etc. The farm is located in Majhola belt of Pilibhit District of northern Uttar Pradesh. The locality falls in the Terai region with water table close to surface. The soils are loamy to clayey loam. It is one of the agriculturally productive belt of northern India known to grow wheat-paddy crop combination and sugarcane as annual crop.

We at Chaudhary Farm have been planting poplar since 1987 and there is no denying that a well-managed farm gives economic returns much more than the conventional crops and this will be shown by comparison that we have made through our calculations. Our poplar plantations have been giving returns in excess of Rs. one hundred thousand per acre per annum consistently since last 3-4 yrs, whereas paddy-wheat rotation gives us a return of about Rs. 25,000 per acre per annum. Clearly, returns from poplar are four times higher than that of paddy-wheat rotation. This is studied in detail in later sections.

There are other benefits of poplar based agroforestry over paddy-wheat rotation. We have found that the soil health improves under poplar plantations, whereas repeated practice of rice-wheat rotation depletes the soil health. The crop yields taken after the harvest of poplar have been much higher than those taken on plots where poplar was not planted.

We have 12,000 poplar trees of high genetic quality planted at our farm. Spacing pattern of 4m x 5m, 4m x 4m and 7m x 3m are being followed and plantations are harvested in seven years yielding about 1,000 q of timber per acre on harvest.

We first came to know of poplar from WIMCO. In the face of acute shortage of timber in late 1970s WIMCO took steps to promote poplar based agroforestry on commercial scale in the Terai districts of U.P., many of which are now part of Uttarakhand. High yielding clones of poplar were introduced and farmers were encouraged to plant them.

Poplar was planted at our farm for the first time in the year 1987. We purchased 800 ETPs of D-121 clone from WIMCO at buy back arrangement and we were promised Rs. 500 per tree after 8 years provided certain parameters specified by WIMCO were met. The important parameter was that the trees should attain a girth size of 90 cm at a height of four and a half feet from ground level. The supervisors from WIMCO prescribed farmers the standard package of practices to be followed for the maintenance of poplar plantations and the farmers who didn't comply with the right techniques and failed to achieve the expected girth size were not paid the full amount.

Once we purchased poplar seedlings from WIMCO, supervisors used to visit our farm every 15 days to see the progress of our poplar and tell us how and what can be done to grow poplar successfully. We were updated with all the latest techniques of managing these trees. Because of WIMCO's support, timely guidance and advice we have been able to raise good plantations. Hence, WIMCO's role has been immense in enabling us to earn remunerative returns from PBA. It has played a significant role in popularizing poplar among farmers and is largely responsible for the adoption of PBA in north-western India.

D-121 was the first variety that we planted on our farm. This variety had a strong root system and lodging was little, however, its growth was slow. Then we shifted to G-3 clone. It gave very good volume of wood, grew fast and tapering was less. However, after few years the clone became susceptible to leaf spot disease (which caused premature defoliation in case of heavy attack) and this disease was difficult to control through chemical sprays, WIMCO stopped producing this variety and came up with new disease resistant clones. L-49 was another clone that we planted on our farm. It grew very fast and gave very good volume of timber in a shorter period but had a weak root system. Hence, damage due to winds was high. Once, 50 per cent trees of a block of L-49 clone were lodged in the winds and rains in September. This variety was also phased out from our farm. Then we shifted to clones like Kranti, G-48, S7C8 and S7C15. G-48 proved to be the most successful variety on our farm. Presently, we are planting new varieties developed by WIMCO seedlings - WIMCO-39, WIMCO-81 and WIMCO-110 and these are showing promising results in clay loam and clay type soil of our farm.

Our Package of Practices

Our raising of poplar plantations involves intensive investment and care in plant nutrition, plant protection, pruning, irrigation and other aspects of plant management to attain high rates of timber growth. We have been planting 200 to 250 trees per acre.

High quality poplar ETPs purchased from WIMCO Ltd. are planted in January and sugarcane is sown as intercrop in first week of February. In first two years sugarcane is grown and after the ratoon has been harvested, wheat is taken in winter until the harvest of poplar.

ETPs are lifted during the last week of December and on their receipt on the farm site these are immediately placed horizontally in pits filled with fresh water to prevent dehydration and then the transplanting begins in the first week of January. We store ETPs in fresh water for a minimum of 3 days. ETPs can be safely stored under fresh water for 10 to 12 days before transplanting.

Pretreatment of ETPs

All thick long and damaged roots of ETPs are pruned. Those thick roots that are likely to interfere with normal placing of ETPs in the pits are trimmed. All small, fine roots are left untouched. ETPs are then treated with an insecticide and a systemic fungicide by dipping the roots in the solution containing chlorpyrifos 20 per cent EC (insecticide) and carbendazim 50 per cent WP (fungicide). For every 100 ETPs, a solution of 100 l of water mixed with 200 ml of chlorpyrifos and 200 g carbendazim is prepared. These ETPs are kept for about 10 minutes in this solution.

Transplanting of ETPs into Pits

About one meter deep pits are dug with augurs having a diameter of 15 cms. The ETP is then placed vertically into the pit which is then filled with the mixture of top soil, 5 kg. FYM, 25 g MOP, 200 g SSP, 25 g micronutrients (zinc, iron, copper, etc.) and *Trichoderma*. One month before transplanting, we mix farmyard manure with *Trichoderma* and keep it in shade in a way that the moisture is maintained in the mixture. In this one month, *Trichoderma* multiplies itself. The pits should not be filled completely and the top 15 cm is left unfilled to allow maximum availability of water to the plant for their better survival and soil should not be compacted at this stage. However, before second irrigation, we fill the pits and again water the filled soil.

Post Transplanting

After ETPs have been transplanted flood irrigation of the field is done. Sugarcane sowing is done in the first week of February. Water channels along the trees are maintained to ensure timely irrigation of trees without flooding the entire field.

During first two years trees are prone to wind damage especially during monsoon and, therefore, a lot of care has to be taken to maintain right balance of branches along the main trunk and has to be assured that the top of the trees are light so that the wind damage is minimized. Tree roots are susceptible to fungal attack in the first two years, hence, are regularly treated with a systemic fungicide - carbendazim and an insecticide chlorpyrifos.

Irrigation and Fertilizers

Regular irrigation (2-3 per month) during summer months is very important for optimal growth of poplar trees. During winters, irrigation is done once a month.

Our poplar trees are regularly provided with recommended doses of nitrogen, phosphorus, potash, zinc, iron, calcium and boron along with FYM and bone-meal. From third year different doses of fertilizers are given per acre per year (Table 1).

Table 1. Nutrient application to poplar plantation (kg per acre) from third year onward

Fertiliser/Month	April	May	June	July	August	September
Single super phosphate	500	-	-	-	-	-
MOP	50					
Urea	-	-	50	50	50	50
Zinc sulphate	-	-	10	-	-	-
Ferrous sulphate	-	-	10	-	-	-
Calcium	25					
Boron	2					
Bone-meal			100			

In late April, after intercropped wheat has been harvested, full doses of phosphorous, potash, calcium and boron are added and mixed in soil by harrowing at zero cut. Field is then irrigated followed by 2-3 irrigations per month until arrival of monsoon. To maintain soil health and fertility, we add sufficient quantities of dairy manure in our soil. Bone-meal has also been found to be very beneficial for overall growth of poplars.

Pruning

It is very important to judiciously follow the practice of pruning of branches along the main trunk of the tree to attain maximum volume and quality wood production. It is very important that timely pruning of branches is done. In the first year of growth debudding is carried out in the lowest one third part of the stem during June-July and leader training is simultaneously done. We prune all the competing branches of the leading shoot during winter.

Intercropping Pattern

For first two years, sugarcane is grown as intercrop. After the ratoon of sugarcane is harvested at the end of second year, wheat is sown. From beginning of third year onwards wheat is taken as intercrop during winter months as poplar shed their leaves and sunshine reaches the ground. During summer months the leaves of trees reduce sunshine and only shade tolerant crops can be grown. Where soils are sandy to sandy loam, turmeric and ginger are very remunerative shade bearing inter-crops. But, our soil being clay loam to clay it is not possible to plant them and we have been taking only wheat as intercrop. Recently, we have also started taking fodder oats and barseem as intercrops during winter months.

Economics of Poplar Based Agroforestry

Our period of study is seven year period from 2004 to 2011. We maintained records of year wise cost of cultivation for paddy, wheat, sugarcane and poplar separately from the farm during the given period. Year wise yields of these crops and respective sale prices for the same have been used to calculate the yearly returns. Annual net returns from PBA, paddy-wheat rotation and sugarcane crop for seven years from 2004-05 to 2010-11 are adjusted at a discount rate of 12 per cent to get the net present value for each farming option. The intercrops grown with poplar plantation under study, their yields, cost of production and returns are given in Table 2. The total returns from intercrops for the full rotation of seven years of trees have been worked out to be Rs. 118,799 with approximately Rs. 17,000 per acre per year at discounted rate of 12 per cent.

The details of wood yield and return, therefrom, are given in the following pages. Trees were harvested during January 2011 through a contractor and segregated to marketable lots of oversize logs, undersize logs, roots and firewood and sold to the local contractor at negotiated prices as per details given below.

Wood Sale Proceeds

Out of 250 saplings planted per acre, finally survived 238 trees were harvested. The girth of these trees varied between

Table 2. Discounted returns from intercrops 2004-2010 for one acre

Year	Intercrop	Yield of intercrop (q)		Price of intercrop (Rs.)		Returns from intercrop (Rs.)	Cost of intercrop (Rs.)	Net returns (Rs.)	NPV taking 12% discount rate (Rs.)
		wheat/sugarcane	straw	-	straw	straw			
2010-11	Wheat	14	10	1,120	2.5	18,180	10,722	7,458	7,458
2009-10	Wheat	15	11	1,100	2	18,700	9,501	9,199	10,303
2008-09	Wheat	15	11	1,080	2	17,200	8,639	8,561	10,701
2007-08	Wheat	17	11	1,000	1.5	18,950	8,193	10,757	15,060
2006-07	Wheat	18	14	750	1.5	15,600	7,453	8,147	12,791
2005-06	Sugarcane ratoon	175	NA	110	NA	19,250	7,500	11,750	20,680
2004-05	sugarcane	350	NA	110	NA	38,500	19,550	18,950	37,142
									114,135

75-90 cm at breast height. Trees yielded 940 q of timber (3.94 q per tree), out of which, 658 q was as oversize (>60 cm mid girth) and remaining 282 q as undersize (50-60 cm girth). We also got 58.6 q roots and 62 q firewood. Price that we received for oversize logs was Rs. 813 per q, Rs. 550 per q for undersize logs, Rs. 180 per q for roots and Rs. 200 per q for firewood. Total value realized was Rs. 713,000 out of which, Rs. 534,954 was for oversize logs, Rs. 155,100 for undersize logs, Rs. 10,546 for roots, and Rs. 12,400 for firewood. Based on money realized from the sale of wood logs, roots and firewood and that from the intercrops, Table 3 was drawn for the economical analysis for the PBA system for the full tree rotation period. Overall, the PBA gave us Rs. 700,455 per acre discounted value for seven years and a net returns of over Rs. one hundred thousand per acre per year. This realization is very high in comparison with other existing land use options from the similar fields and a motivational factor to continue with poplar based agroforestry.

We also tried to compare these returns from sole sugarcane production (Table 4) and wheat-paddy rotation from the adjoining fields which are the common crops grown in the locality. Detailed economical analysis for sugarcane alone is given in Table 4, and for wheat-paddy rotation in Table 5 to Table 7. There have been fluctuations in crop yields, input prices, sale prices and, therefore, in returns from sugarcane and wheat production during the study period. In general, fresh sugarcane crop gives better returns as yields are higher than the ratoon. The total returns of sugarcane cultivation have been worked out to be Rs. 188,684 for seven years with average returns of approximately 27,000 per acre per year.

In order to compare the economical analysis of PBA with the traditional paddy-wheat rotation separate costs and returns for these two crops were maintained and are presented in Table 6 and Table 7. Out of these two tables, Table 7 gives returns from paddy-wheat rotation.

The returns from paddy crop which is grown in summer season only is worked out to be Rs. 68,387 for the seven years of study period. To these values returns from wheat growing for the corresponding years (Table 7) was added.

The discounted benefits of paddy-wheat rotation at 12 per cent over 7 year period worked out to be Rs. 359,901 against the discounted costs of Rs. 187,863. Cost-benefit ratio turned out to be 1.92. The net returns from this crop production were Rs. 172,038 for seven years and approximately Rs. 24,500 per acre per year.

Table 3. Net present value (NPV) of poplar based agroforestry (in Rs.)

Year	t	Returns from intercrop	Cost of intercrop	Returns from poplar	Cost of poplar culture	Total returns poplar and intercrop = B	Total cost poplar and intercrop = C	Net returns B-C	$(1+r)^t$	NPV (B-C) $(1+r)^t$
Jan-11				713,000	61,170	7,13,000	61,170	651,830	1	651,830
2010-11	0	18,180	10,722		7,300	18,180	18,022	158	1	158
2009-10	1	18,700	9,501		5,442	18,700	14,943	3,757	1.12	4,208
2008-09	2	17,200	8,639	900	7,864	18,100	16,503	1,597	1.25	1,996
2007-08	3	18,950	8,193	700	7,066	19,650	15,259	4,391	1.4	6,147
2006-07	4	15,600	7,453	390	6,970	15,990	14,423	1,567	1.57	2,460
2005-06	5	19,250	7,500		3,588	19,250	11,088	8,162	1.76	14,365
2004-05	6	38,500	19,550		9,108	38,500	28,658	9,842	1.96	19,290
Total										**7,00,455**

Hence, returns per acre per year comes out to Rs. 100,065.

Table 4. Cost of production (per acre, r=12%) for sugarcane crop during the study period

Year	Crop (type)	Yield (q)	Price (Rs./q)	Returns (Rs.)	Cultivation cost (Rs.)	Net returns (Rs.)	NPV (Rs.)
2004	Fresh	350	110	38,500	19,450	18,950	37,142
2005	Ratoon	250	110	27,500	13,100	14,400	25,344
2006	Fresh	302	130	39,260	22,002	17,258	27,095
2007	Ratoon	150	130	19,500	11,708	7,792	10,909
2008	Fresh	330	140	46,200	26,134	20,066	25,083
2009	Ratoon	175	230	40,250	13,713	26,537	29,721
2010	Fresh	325	210	68,250	24,557	43,693	43,693
	Total						**188,684**

Table 5. Cost of production (per acre, r=12%) for wheat crop during the study period

Year	t	Wheat yield (Rs.)	Price (Rs.)	Value of produce (Rs.)	Yield of straw (q)	Net price of straw (Rs.)/kg	Value of straw (Rs.)	Total value of produce (Rs.)	Cost of production (Rs.)	Net Returns (Rs.), J	NPV = $J(1+r)^t$
2010-11	0	21	1,120	23,520	9	2.5	2,250	25,770	10,722	15,048	15,048
2009-10	1	21	1,100	23,100	9	2	1,800	24,900	9,501	15,399	17,247
2008-09	2	20	1,080	21,600	8	2	1,600	23,200	8,639	14,561	18,201
2007-08	3	20	1,000	20,000	8	1.5	1,200	21,200	8,193	13,007	18,210
2006-07	4	19	750	14,250	8	1.5	1,200	15,450	7,453	7,997	12,555
2005-06	5	19	650	12,350	8	1	800	13,150	7,323	5,827	10,256
2004-05	6	20	600	12,000	8	1	800	12,800	6,609	6,191	12,134
Jan-11										**$\Sigma J(1+r)^t$**	**103,651**

Table 6. Cost of production (per acre, r=12%) for paddy crop during the study period

Year	t	Yield of paddy (q)	Price (Rs.)	Value of produce (Rs.)	Total cost (Rs.)	Net Returns (Rs.), G	NPV = $G(1+r)^t$
2010-11	0	25	1,100	27,500	13,489	14,011	14,011
2009-10	1	24	980	23,520	12,149	11,371	12,736
2008-09	2	23	880	20,240	11,262	8,978	11,223
2007-08	3	25	675	16,875	10,527	6,348	8,887
2006-07	4	23	610	14,030	10,042	3,988	6,261
2005-06	5	22	600	13,200	9,728	3,472	6,111
2004-05	6	23	600	13,800	9,127	4,673	9,159
Jan-11						**$\Sigma G(1+r)^t$**	**68,387**

Table 7. Cost of production (per acre, r=12%) for wheat-paddy rotation

Year	Returns from wheat	Returns from paddy	Benefits paddy+wheat	Cost of wheat	Cost of paddy	Total costs wheat+paddy
2010-11	25,770	27,500	53,270	10,722	13,489	24,211
2009-10	24,900	23,520	48,420	9501	12,149	21,650
2008-09	23,200	20,240	43,440	8,639	11,262	19,901
2007-08	21,200	16,875	38,075	8,193	10,527	18,720
2006-07	15,450	14,030	29,480	7,453	10,042	17,495
2005-06	13,150	13,200	26,350	7,323	9,728	17,051
2004-05	12,800	13,800	26,600	6,609	9,127	15,736

Table 8. Cost benefit ratio of wheat-paddy rotation

Year	t	$(1+r)^t$	Costs = C paddy + wheat	NPV of costs = $C_t(1+r)^t$	Benefits = B paddy+wheat	NPV of benefits = $B_t(1+r)^t$
2010-11	0	1	24,211	24,211	53,270	53,270
2009-10	1	1.12	21,650	24,248	48,420	54,230
2008-09	2	1.25	19,901	24,876	43,440	54,300
2007-08	3	1.4	18,720	26,208	38,075	53,305
2006-07	4	1.57	17,495	27,467	29,480	46,284
2005-06	5	1.76	17,051	30,010	26,350	46,376
2004-05	6	1.96	15,736	30,843	26,600	52,136
				187,863		**359,901**

Conclusion

From the above data the following conclusions are drawn. NPV of PBA for the seven years period turned out to be Rs. 700,455. Hence, returns are Rs. 100,065 per acre per year. Sugarcane crop gave returns of Rs. 188,684 for the corresponding period with net returns of approximately Rs. 27,000 per acre per year whereas, paddy-wheat rotation gave total returns of Rs. 172,038 for the corresponding period and Rs. 24,500 per acre per year. Net present value of returns for PBA including intercrops is 4.07 times higher than the wheat paddy rotation and 3.71 times higher than the sugarcane crop farming for the corresponding period. Cost-benefit ratio for wheat-paddy rotation and for sugarcane are much below 3.96 for PBA for the corresponding period. Based on more than two decades of our experience with PBA, we can very confidently say that this farming practice is not only economically very attractive but also very beneficial to the environment. The wide adoption of PBA in north-west India is a positive development. This will not only save our forests but will also bridge the increasing gap in demand and supply of the wood.

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Poplar Culture for Speedy Carbon Sequestration in India: A Case Study from Terai Region of Uttarakhand

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The countries like India that has chosen the lower limit of 15 per cent as crown cover could potentially include more agroforestry systems into the REDD-plus mechanism

Introduction

Kyoto Protocol recognizes forestry as an acceptable mean of carbon sequestration, and the sector offers possibilities for significant climate change mitigation. During the Seventh Meeting of Conference of Parties (CoP 7) held at Marrakesh (Morocco) in 2001, it was decided that only afforestation and reforestation (A and R) project activities would be eligible under LULUCF sector of the clean development mechanism (CDM). The A and R project activities eligible under CDM include agroforestry, farm forestry, plantations of mixed species, and orchards. There are enough evidences to show that individuals and communities can use tree plantations sustainably to support livelihoods besides carrying out agricultural and horticultural production. However, the studies on the amount of carbon stored and trading of this carbon in international markets to provide considerable income and overall sustainable development of area are lacking. Intensive field investigations are also required to assess the suitability of different plantation models, which the individuals and communities may like to plant on different lands under CDM forestry projects. Such studies would not only provide valuable information on the scope of CDM A and R projects for sustainable livelihoods, but also encourage the marginal communities to contribute to mitigate global carbon emissions and expanding forest and tree cover (Ravindranath and Murthy, 2003).

The progress on preparation of A and R CDM projects in the recent past had been much below the expected levels as the methodologies and the procedures applicable to such forestry projects are seen as complex by the project developers. Limited demand for carbon credits emanating from forestry sector has further restricted the scope of forestry CDM projects. Despite these limitations, by now, ten large-scale, two consolidated, seven small-scale methodologies and a number of tools are available for this sector to assist in project development. Besides, 40 forestry projects have already been registered by the Executive Board of CDM (UNFCCC, 2012). The Kyoto Protocol's continuation up to 2020 is likely to further benefit the development of CDM forestry projects in future.

Populus deltoides, commonly called eastern cottonwood and referred as poplar hereafter is an important agroforestry tree species, especially in the northern alluvial belt of India. It is very commonly seen along with *Eucalyptus* spp. on agricultural fields in Punjab, Haryana, Uttar Pradesh and Tarai region of Uttarakhand and Uttar Pradesh. The species is very popular among farmers, as it offers minimum interference with the agricultural crops due to its straight bole, limited crown, and silvicultural characteristics (Gera *et al*., 2006). Poplar was introduced in the country about six decades back and has received wide acceptance during the last three decades because of its compatibility with agricultural crops and high productivity. Although harvested at short rotation of 6-7 yrs, poplar can attain 90 cm girth and mean annual increment of 20 m^3 per ha at 8 years rotation under good care (Lal, 1991). The wood obtained from poplar is eminently suitable for manufacture of match splints, veneering products, artificial limbs, interior panelling, cheap furniture and packing cases (Singh and Negi, 2001).

With this background, the present study was undertaken to estimate carbon sequestration potential, cost-effectiveness and carbon benefits of different A and R options as available to individuals and communities by planting of poplar on farmlands. Other aspects such as eligibility of poplar plantations under CDM, carbon sequestration potential at national level as well as opportunities under REDD-plus are also discussed.

Methodology

Poplar is planted in blocks, rows and on bunds of fields and intercrops such as wheat, paddy, sugarcane, maize, mustard, pulses and others are grown along with the trees. In blocks 500 trees per ha are planted at a spacing of 5×4 m with rotation age of 6 years, whereas in rows and bund planting is carried out at a distance of 2 m. After every rotation the trees are harvested and the stumps are uprooted to prepare for fresh planting. Poplar is planted only in irrigated lands as the water requirement is high owing to its being a fast growing species. Though the farmlands vary in size, but for the purpose of calculations, all values have been recorded on per hectare basis.

a. Study Site

The study was carried out in Ramnagar block of Nainital District of Uttarakhand (Fig. 1) during the period of 2006-07. The study site consisting of three villages, viz., Kanchanpur (gram panchayat-Choi), Nandpur (gram panchayat-Khempur) and Kyaribandobasti (gram panchayat-Kyari), is located on Bail Padav-Ramnagar road in Ramnagar block of Nainital District in south of Kumaon region. The area is representative of farmlands of Uttarakhand with almost 80 per cent area dedicated to agriculture. Though, the annual rainfall in the region varies between 900-1,000 mm with uneven distribution and spread over 40-45 rainy days, there are good facilities of irrigation and land productivity is high. Geographically, the area represents Bhabar and Tarai regions with in the altitude of 1,000 m. The location of the selected villages is presented in Table 1.

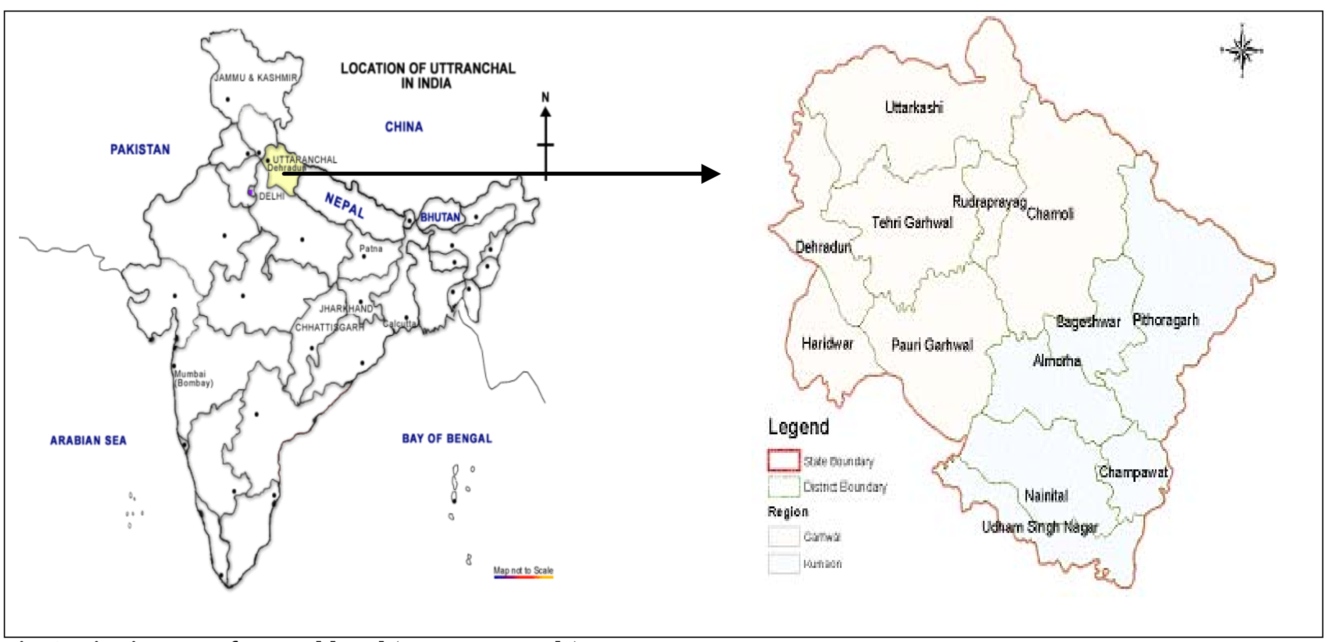

Fig. 1. District map of Uttarakhand (map not to scale).

Table 1. Location of selected villages

Name of the village	Gram panchayat	Latitude	Longitude	Altitude (m above msl)
Kanchanpur Choi	Choi	29°21'46''	79°08'52''	369
Nandpur	Khempur	29°20'13''	79°11'30''	314
Kyaribandobasti	Kyari	29°21'59''	79°11'30''	361

Source: GPS readings.

The tree species commonly grown with agricultural crops on farmlands are poplar, eucalypts and aonla, besides horticulture crops such as litchi, mango and some citrus varieties, are also planted. The agricultural crops include wheat, paddy, maize, sugarcane, mustard and pulses.

b. Proposed A and R Interventions

Rapid rural appraisal and group discussions with the community and the forest department staff revealed that poplar is the most desired tree species as a plantation intervention in the event of CDM forestry project. Growers expressed willingness to plant the species as a block, rows and on farm periphery as bund plantation. The silvicultural details of selected plantation interventions of poplar and the planting stock available are presented in Table. 2.

c. Recording of Field Observations

The field observations on growth of selected plantation interventions was taken as per the structured data sheets prepared for recording of data to estimate the eligible carbon pools under CDM, viz., above ground biomass (AGB), below ground biomass (BGB), woody litter and the soil carbon. Similar observations were also recorded for the selected areas where there would be no plantation, to act as a baseline data.

In order to estimate the above ground biomass for the selected plantation interventions, the existing stands of three different ages of poplar blocks were selected from within the available plantations on farmlands, and data on girth and height was recorded for all the trees in randomly selected quadrates of 25 x 20 m size. For bund plantations, the data was recorded from boundary plantations as existing on the farmlands by laying out linear strips of 10 x 125 m. A minimum of 3 quadrates/strips for three different ages representing tree growth were taken for recording field observations for both the plantation interventions. For calculating the mean annual increment (MAI) on the farmlands under bund plantations, it was assumed that the farm size is 0.25 ha (50 x 50 m) and 96 trees are planted at a spacing of 2 m as commonly practiced in the selected villages. The data was used to estimate the MAI for both the plantation interventions, which was calculated through the already published volume equation by Dhanda and Verma (2001). Calculated stem volume was converted to biomass by multiplying it with biomass expansion factor and wood density as per good practices guidelines provided by Intergovernmental Panel on Climate Change (IPCC, 2003) to obtain above ground biomass (AGB). The below ground biomass (BGB) was calculated by multiplying the AGB with IPCC default value of 0.27 (IPCC, 2003). The carbon sequestered was calculated by multiplying the biomass by 0.45, which is again an IPCC default value.

d. Estimation of Soil Organic Carbon

Three soil samples were collected from each plantation site selected for estimation of above ground biomass at three different depths; i.e., 15, 30 and 45 cm for analysing the soil organic carbon (SOC), which was estimated as per Walkley and Black (1934) and Walkley (1947).

e. Observations on Costs and Benefits

Data on planting and silvicultural management costs involved in raising and maintenance, of the selected poplar plantation interventions, and on all costs related to harvest and marketing along with the benefits likely to be received at the end of the rotation period were also recorded so as to assess the cost effectiveness of these plantations, exclusive and inclusive of carbon benefits.

f. Model approach

The spreadsheet model PRO-COMAP, acronym 'project based comprehensive mitigation assessment process' was employed for analysis of data. The model is based on the description, instruction and explanations as given by Sathaye *et al.* (1995) and Makundi and Sathaye (1999). The excel spread sheet model has been designed specifically to undertake a

Table 2. Brief silvicultural details of selected plantation interventions

Plantation intervention	Spacing (m)	Trees/ha	Survival (%)	Rotation (yrs)	Planting material	Harvest and planting
Poplar block	5×4	500	100*	6	ETP of G3, G48 and other clones	Uprooted and planted fresh on completion of every rotation during the CDM project period.
Poplar bund	2	384**	100*	6	ETP of G3, G48 and other clones	Uprooted and planted fresh on completion of every rotation during the CDM project period.

* Failed plants assumed to be fully replaced
** For bund plantation, a farm size of 0.25 ha was assumed

comprehensive assessment of the role of tree plantations in climate change mitigation. The model uses data on selected carbon pools as collected from the field, viz., above ground biomass, below ground biomass, soil carbon and woody litter along with data on costs and benefits throughout the life of the selected plantation interventions, as input. The costs include those incurred on initial planting, silvicultural operations, harvesting, marketing and other recurring costs on maintenance and protection, monitoring of biomass, soil carbon and the opportunity cost of the land. The benefits were calculated on the basis of prevailing market rates of wood products, viz., veneer log, chip log and the fuel wood, besides carbon benefits, which were estimated separately. The relevant data, provided as key input to the model is presented in Tables 3 and 4.

The model estimates the carbon stock changes based on the rotation age and mean annual increment in biomass growth of species planted and decomposition rate of litter and accumulation time of carbon in soils. Since the study involved plantation intervention on farmlands, it was assumed that the baseline carbon stock would only be the soil carbon, and would remain static during the period of assessment. The static baselines are valid under CDM for projects where no changes in anthropogenic or natural activity are expected over the project period (Richards and Anderson, 2001) as is the case for plantation on farmlands. During the plantation period, the major changes in carbon stock accrue due to the changes in above ground and below ground biomass. The falling woody litter from time to time also contributes to the carbon pool, which though minimal, has been accounted for on annual basis, along with soil uptake, during accumulation period of 6 years.

The analysis period selected for the study was 30 years (2008-2038) and the model was run for the selected period. The model carry out the analysis under two scenarios, viz., Baseline scenario, which is the carbon mitigation under the 'business as usual' scenario, where no deliberate effort is made to increase carbon sequestration, and the 'Mitigation scenario', where mitigation options, viz., tree plantation activities are undertaken for carbon mitigation over a defined period of time. Although carbon sequestration due to harvested wood products is not eligible for first commitment period; i.e., 2008-2012, the model was run to calculate output for both the cases; i.e., 'with' and 'without wood products'. The output of the model consists of values with respect to annual incremental carbon sequestration, cost effectiveness indicator, viz., Internal rate of return (IRR) 'with' and 'without carbon benefits', and the likely carbon benefits under the selected carbon price scenarios for both the plantation interventions.

Three different carbon price scenarios were assumed to assess whether the carbon benefits as estimated under these scenarios can provide significant incentives to the growers so that they get motivated to go for the selected plantation interventions. The three carbon price scenarios are Scenario I, where the carbon price remains fixed at $5 per t CO_2, Scenario II, where the price begins at $5 per t CO_2 and increases every year at the rate of 2 per cent and Scenario III, where the carbon price begins at $5 per t CO_2 and increases at the rate of 5 per cent every year. A back stop price of $50 per t CO_2 was assumed for Scenarios II and III. The cost effectiveness indicator, viz., IRRs were also calculated for the plantation interventions with carbon benefits under these three carbon price scenarios.

Results

The carbon sequestration potential and average annual incremental carbon stock along with estimated carbon benefits for the two plantation interventions is given in Table 5. A sequestration potential 'without wood products' for the analysis period of 30 years is observed to be 39.76t C per ha for block plantation which was substantially lower when compared with 'with wood product' case; i.e., 72.17t C per ha, whereas sequestration potential of 31.48t C per ha has been observed for bund plantation under 'without wood products' and 58.86t C per ha 'with wood products', respectively.

The carbon benefits calculated on the basis of carbon price of $5 per t$CO_2$ and at dollar rate of Rs. 55/-

Table 3. Key input data on carbon pools to PRO-COMAP

Plantation intervention	Mean annual increment (t/ha/yr)	Baseline AGB (t/ha)	Baseline soil carbon (t/ha)	Soil carbon uptake (t/ha/yr)	Woody litter (t/ha)
Poplar block	19.35	0	29.60	0.93	0.26
				(6)*	(2.94)**
Poplar bund	14.86	0	33.75	0.56	0.21
				(6)*	(2.94)**

* Accumulation period in years

** Decomposition period in years

Table 4. Key input data on wood products to PRO-COMAP

Plantation intervention	Wood product as per cent of MAI		
	Chip logs	Veneer logs	Fuel wood
Poplar block	20 (30)*	60 (30)*	18 (0)*
Poplar bund	20 (30)*	60 (30)*	18 (0)*

* Product life in years

are Rs. 1,337 per ha per yr and Rs. 1,060 per ha per yr for poplar block and bund plantations respectively, in the absence of wood products. Higher benefits of Rs. 2,428 per ha per yr and Rs. 1,817 per ha per yr have been estimated with the inclusion of wood products under the poplar block and bund plantations, respectively.

The data in Table 6 shows the IRRs 'with' and 'without carbon benefits' under the three carbon price scenarios. The poplar block plantation showed an increase in IRR from 61.20 per cent to 69.5 per cent, 70.9 per cent and 74.3 per cent for the three price scenarios respectively, 'without wood products' while, for the 'with wood products' case the increase recorded is to 69.8 per cent, 71.5 per cent and 75.4 per cent, respectively. The poplar bund plantation showed an IRR of 52.2 per cent 'without carbon benefits' which increases to 58.3 per cent, 59.6 per cent, and 62.7 per cent respectively, for the three price scenarios when wood products are not included. Under the 'with wood products', a similar trend was seen for this intervention, which showed an IRR increases to 58.6 per cent, 60.2 per cent and 63.9 per cent, respectively.

Discussion

a. Carbon Sequestration Potential

The interventions on poplar block and bund plantations showed a sequestration potential of 1.33t C per ha per yr and 1.05t C per ha per yr respectively, when wood products are not included and 2.41t C per ha per yr and 1.80t C per ha per yr respectively, along 'with wood products'. The sequestration potential depends on the MAI of tree growth; i.e., above and below ground biomass growth in terms of t/ha/yr. Though, woody litter and soil carbon also have been taken into account for calculations, their contribution has been observed to be small and rather negligible as compared to wood growth. Higher the MAI, higher will be the sequestration potential, provided there is no harvest during the analysis period. In case of harvest during the analysis period, the carbon pools get adversely impacted due to IPCC default approach which says that, the moment trees are harvested, the equivalent CO_2 is deemed to have been emitted in to the atmosphere (IPCC, 2003). The present model used for calculation of sequestration potential is programmed for IPCC default approach. Therefore, the plantation interventions on poplar, which is short rotation fast growing species, have given a low sequestration potential. The MAI, which is estimated in terms of t per ha per yr is also influenced by density of plantations, and for this reason, bund plantation are expected to show lesser sequestration potential as compared to block plantations of the same species.

Table 5. Annual incremental carbon, total carbon sequestered, and likely annual carbon benefits

Plantation intervention	Initial cost^ (Rs/ha)	Incremental carbon		Annual sequestration (tCO_2/ha/yr)*	Benefit @\$5/t CO_2 (Rs/ha/yr)**
		Per unit-area (tC/ha)	Annual (tC/ha/yr)		
Poplar block	13,700	39.76 (72.17)	1.33 (2.41)	4.86 (8.83)	1,337/- (2,428/-)
Poplar bund	7,450	31.48 (53.86)	1.05 (1.80)	3.85 (6.61)	1,060/- (1,817/-)

^ Includes all costs incurred for establishment of plantations.
* 1tC = 3.67tCO_2 ** 1\$ = Rs. 55/-
Figures in parenthesis refer to values for 'with wood products' case

Table 6. Internal rates of returns under different carbon price scenarios

Plantation intervention	Internal Rate of Return (IRR %)			
	Without carbon benefits	With carbon benefits		
		Scenario I	Scenario II	Scenario III
Poplar block	61.20	69.5(69.8)	70.9(71.5)	74.3(75.4)
Poplar bund	52.20	58.3 (58.6)	59.6 (60.2)	62.7 (63.9)

Scenario I - Carbon price \$5, 1US \$ = Rs. 55/-
Scenario II - Carbon price \$5 + 2% annual increase (backstop price \$50/tCO_2)
Scenario III - Carbon price \$5 + 5% annual increase (backstop price \$50/tCO_2)
Figures in parentheses show values for the 'with wood products' case.

These findings are supported by Hooda *et al*. (2007), who reported a sequestration potential of 1.98t C per ha per yr for poplar block plantations for similar area of Uttarakhand. A few other studies, viz. Gera *et al*. (2006) have reported a sequestration potential of 2.54 and 1.42t C per ha per yr for poplar block, and bund plantations, respectively for farmlands of Rupnagar, Punjab. Ravindranath *et al*. (2007) reported an average sequestration potential of 2.23t C per ha per yr for short rotation interventions involving fast growing species, such as *Eucalyptus*, *Casuarina*, *Acacia* and *Gmelina arborea*, planted for the purpose of fuel wood, industrial wood and poles. The sequestration potential in the same range with an average of 1.55t C per ha per yr has also been reported by Makundi and Sathaye (2004) for agroforestry species. Another study by Updegraff *et al*. (2004), from Minnesota, USA, reported that a short rotation plantation of hybrid poplar was estimated to yield sequestration levels of 1.8 to 3.1t C per ha per yr.

It is observed in the present study that the selected plantation interventions have recorded substantially higher sequestration potential when the harvested wood products are included in the sequestered carbon pools. Poplar, which is harvested in six years, start giving wood products immediately after harvest and the harvested wood product carbon pool starts growing with every harvest, and adds to the total carbon sequestered pool. Therefore, a substantial increase in sequestration levels 'with wood products' as compared to the sequestration levels 'without wood products' is observed in the study. Several research findings support the increased sequestration levels when wood products are also accounted towards calculation of sequestration potential for a given analysis period. Hooda *et al*. (2007) reported a sequestration potential of 3.33t C per ha per yr for poplar block plantation 'with wood products', which was much higher as compared to 1.98t C per ha per yr reported 'without wood products'.

b. Carbon Benefits

The carbon benefits on account of carbon sequestration directly depend on the sequestration rate per unit area per unit time. Though, farmers may not plant a particular intervention squarely for carbon benefits, significant economic returns on account of carbon benefits can be a motivating factor in these plantation interventions. It would be important to note here that unless the individual farmers and communities get sufficient monetary returns, besides being convinced of the carbon benefits, they would be unlikely to participate in the CDM like projects. Makundi and Sathaye (2004) have also highlighted the importance of agroforestry as a mitigation option and observed them to be more cost effective than afforestation and reforestation of degraded or wastelands.

Due to very high price of poplar wood in Indian timber markets presently, the economic returns from agroforestry and farm forestry poplar plantations are very high and are in the range of around Rs. 150,000 per ha per yr (ICFRE, 2012). These returns are huge compared to likely carbon benefits of around Rs.1,000-2,500 per ha annually, as estimated in the present study. This huge difference of comparative benefits may not motivate farmers to opt for forestry CDM projects involving fast growing species like poplar. These interventions could face another problem of addressing 'additionality', which is a must for CDM projects. The conditions of 'additionality' disallow financially most attractive plantation interventions on the basis that they would form a 'business as usual' scenario and hence not eligible to be considered under CDM. However, there are ways to address 'additionality' when small and marginal farmers are involved. A case of CDM forestry project namely 'Reforestation of Severely Degraded Landmass in Khamman District of Andhra Pradesh under ITC Social Forestry Project' will be appropriate to site here. The project deals with planting of eucalypts on four years rotation, which is also a fast growing tree species with handsome economic returns. The project proponents have addressed the requirement of 'additionality' by following 'barrier analysis' and have demonstrated that lack of investment, technological knowhow, institutional framework and prevailing market risks are the key barriers, which would be dealt with only, if there is a CDM forestry project involving eucalypts plantations. Therefore, CDM like forestry projects can be developed for the poplar based agroforestry systems also.

c. Eligibility of Studied Plantation Interventions under CDM

The eligibility of the plantations depends on the definition of 'forest' as accepted by the host country for forestry CDM projects. India's definition of 'forest' is: A forest is a minimum area of land of 0.05 ha with tree crown cover (or equivalent stocking level) of more than 15 per cent having trees with the potential to reach a minimum height of 2 m at maturity *in-situ* (UNFCCC, 2008). This definition requires that any land devoid of adequate tree cover, say agriculture, wasteland or forest will have to be either afforested or reforested on a minimum area of 500 sq. m with such trees with a potential to reach a minimum height of 2 m at maturity and so densely planted that the crown cover reaches from less than 15 per cent before planting to more than 15 per cent during the maturity of the tree crop.

Out of the three parameters of minimum area, crown cover and tree height on maturity, the requirement of tree crown cover is crucial. Since, a lot of poplar plantations are preferred on bunds, it is necessary to ensure that such plantations qualify under CDM. A poplar tree achieves a crown diameter of 5.8 m on maturity (Dhiman, 2006). When the trees are planted on bunds the effective value of crown cover will gradually decrease as the farm size increases. Accordingly, it has been calculated that if poplar trees are planted on bund at a spacing of 2 m the crown cover achieved by the plantation on 0.5 ha of farmland would be 15.77 per cent which qualifies the requirement of CDM. As observed in the field, the farm sizes are seldom bigger than 0.5 ha in case of small or marginal farmers and we can easily say that most of these plantations are likely to be eligible under CDM.

d. C-Sequestration Potential of Poplar Plantations at National Level

Available literature on carbon sequestration potential of different poplar plantation models is limited. The carbon-sequestration potential of the species as estimated by the recent studies is presented in Table 7. The variation in the sequestration potential as reported by the different studies may be attributed mainly to the mean annual increment which varies with site, density of plantation as well as quality of planting stock utilized for raising the plantations.

Table 7. Carbon-sequestration potential as reported by different researchers

S. no.	Species	Nature of plantation	C-sequestration potential tC/ha/yr	Reference
1.	Poplar	Block Bund	2.54 (4.42)* 1.42 (2.46)	Gera *et al*., 2006
2.	Poplar	Block	1.98 (3.33)	Hooda *et al*., 2007
3.	Poplar	Block	1.33 (2.41)	Gera *et al*., 2011a
4.	Poplar	Block Bund	2.20 (3.83) 1.23 (2.13)	Gera *et al*., 2011b
Average sequestration potential		Block Bund	2.01 (3.50) 1.33 (2.30)	

* Figures in parenthesis are for 'with wood products' case.

Out of an area of 362,700 ha estimated to be under poplar plantations in India, an area under commonly planted with *P. deltoides* is 312,000 ha (ICFRE, 2012), which is mainly planted on farmlands as a cash crop in various combinations along with agricultural crops. It is further estimated that 60 per cent of this area is planted as block plantations and 40 per cent as bund plantations (ICFRE, 2012).

Utilizing the above data on extent of plantation and average values of carbon-sequestration potential, it is estimated that at national level, planting of poplar as a block may lead to a sequestration of 376,272t C per yr 'without wood products' and 655,200t C per yr 'with wood products'. The sequestration potential in case of poplar bund plantation could be 165,984 tC per yr 'without wood products' and 287,040 tC per yr 'with wood products'. Overall the existing carbon sequestration levels due to poplar plantations under agroforestry is 542,240t C per yr when wood products are not accounted for and 942,240t C per yr inclusive of wood products. These levels can however be raised multifold by bringing in more and more agricultural lands under agroforestry and farm forestry.

e. Agroforestry in REDD-Plus: Opportunities and Challenges

Reduced emissions from deforestation and degradation (REDD-plus) envisages a mechanism in which countries chose to reduce national level deforestation to below an agreed baseline or increase removals by conservation of forest carbon stocks, sustainable management of forests and enhancement of carbon stocks; and receive compensation or rewards. Agroforestry can be a part of REDD-plus depending on the definition of forest chosen by a given country. Agroforestry has not explicitly been mentioned as part of REDD-plus or any current United Nations Framework Convention for Climate Change (UNFCCC) mechanism. However, considering the UNFCCC definition of forest, a great deal of existing agroforestry systems worldwide could qualify to be an integral part of a REDD-plus. Though the term 'forest' under REDD-plus is yet to be defined, the forest definition agreed to by UNFCCC in the context of the Kyoto Protocol define forest in terms of minimum area, crown cover and tree height on maturity.

Taking India's definition of forest into consideration, many agroforestry systems would automatically qualify for REDD-plus. Zomer *et al*. (2009) found that about 46 per cent of agricultural land globally has at least 10 per cent tree cover. The tree cover on 50 per cent of agricultural land in Southeast Asia and Central America is at least 30 per cent, while in Sub-Saharan Africa, it is about 30 per cent on 15 per cent of agricultural lands. This implies that most tree crop production and agroforestry systems meet the minimum requirements of forest. The countries like India that has chosen the lower limit of 15 per cent as crown cover could potentially include more agroforestry systems into the REDD-plus mechanism. Agroforestry can reduce emissions from forest degradation through increased production of on-farm timber and fuel wood especially in instances of restricted access to forests or limited supply in 'open access' forests (Minang *et al.*, 2011). Fuel wood, charcoal and small timber have been documented as frontline drivers of forest degradation in several countries including India and to some extent a driver of deforestation

(Minang *et al.*, 2011). Therefore, increasing on-farm timber and fuel wood production is likely to relieve forests of pressures from an increasing demand for timber and fuel wood.

Agroforestry has strong implications for sustainable development because of the interconnection with food production, rural poverty, and environmental degradation. It may provide a viable combination of carbon storage with minimal impact on the food production. Policies that promote agroforestry will help to increase carbon sequestration in agro-ecosystems, thereby providing climate change mitigation benefits (Watson *et al*., 2000). Sudha *et al*. (2006) also reported that agroforestry systems provide significant sustainable development benefits such as food security and secure land tenure in developing countries, increasing farm income, restoring and maintaining above-ground and below ground biodiversity, maintaining of watershed hydrology, and social conservation. Agroforestry also mitigates the demand for wood and reduces pressure on natural forests (Pandey, 2002).

Success of agroforestry, however, is based on an enabling legal and policy environment that guarantees tree rights and ownership, investments and a market infrastructure suited to agroforestry and tree-based systems. The focus on agroforestry must filter down to block and village level and forest department must cooperate and support by providing quality planting stock, technical guidance and enabling farmers to freely harvest, transport and sell their produce. The role of wide and effective network of extension services, availability of certified planting stock and buy back arrangements with wood based industries will also be crucial in success of agroforestry in the country.

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Status of Poplar Diseases in India

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Introduction

Poplars and willows are very important tree species for the ecology and economy of countries in temperate and subtropical zones of the world. Poplar species in their natural range occur interspersed throughout the forests of temperate regions of northern hemisphere between the southern limit of around latitude 30^0 N and northern limit of latitude 45^0 N (Tewari, 1993). They are easy to cultivate and form an important component of forestry and agroforestry systems, often for the livelihood of small-scale farmers and native communities (NPC, 2012). Six indigenous and three exotic species of poplars and 32 species of willows are reported in India. *Populus deltoides* has gained considerable importance in agroforestry plantations of Jammu and Kashmir (J. and K.), Punjab, Haryana, Uttarakhand (U.K.) and Uttar Pradesh (western part of U.P.) states of India, mainly due to its deciduous nature, fast growing habit and high industrial demand (Chandra *et al*., 2001). They are also known for their fast growth, easy vegetative propagation, enrichment of the soil with litter and high production (10 to $30 m^3 ha^{-1} yr^{-1}$) on a short rotation of eight to 12 years (Kishwan and Kumar, 2003). So, they occupy a unique and important position in rural economy of India.

In natural forests, a biological balance is normally maintained between the vegetation and its diseases and insects which, generally, remain at an endemic level. Therefore, wherever feasible, natural forests should be maintained within the limits of economics and utility of the crop. The natural stocking may, however, be too slow growing to meet the requirements of intensive management seeking maximum financial gain. Since the latter half of 20^{th} century, there has been a rapid expansion of forest based industries, which is particularly high for pulp and paper. To meet this changing pattern of demand and also to meet the deficit of wood throughout the world, plantations of quick growing species are being raised, particularly in developing countries. Diseases and insects assume considerable significance in plantations (Bakshi, 1976).

Monocultures are widely believed to attract diseases and pests and to be more vulnerable than mixed stands, especially in the long term. Disease problems have, therefore, posed the question regarding the overuse of single clones and use of large monoclonal plantations

Clonal Forestry and Forest Diseases

The importance of vegetative propagation in forestry is well understood, but not so well established particularly in India. The transfer of non-additive characteristic is difficult through seed production approaches but is routinely possible through vegetative propagation (Zobel and Ikemori, 1983). Therefore, it is attractive for achieving gains which have low heritabilities such as growth and cellulose yields. It is especially useful for utilizing hybrids when mass production of hybrids is difficult. Vegetative propagation is an excellent approach for developing clonal forestry programmes. It can eliminate inbreds, provide adapted clones, mass produce valuable genotypes, control genetic diversity and, more importantly, helps in predicting yield in plantation programmes.

Clonal forestry refers to the large scale deployment of relatively few (typically 10-50) known superior clones that have proven their superiority in their clonal test (Bjurden, 1989; Libby and Ahuja, 1993; Talbert *et al.*, 1993). Three main purposes may be mentioned for the use of clones in forestry: to produce a more uniform product, to improve the forest by using a genetically superior planting stock and to offer customer-tailored improved material. Clonal forestry with poplars is common in countries with subtropical and temperate climates like Belgium, France, Italy, Spain, USA and Canada. Poplars are propagated vegetatively through cuttings in order to maintain their genetic purity. Many a times, single clone of poplars have been propagated extensively. Clones of *P. deltoides* have shown a great promise in U.K., U.P., Haryana and Punjab (Sharma, 2009). Several promising clones of G series, D, Sc and St series, L and WSL series have been identified and, subsequently, planted in farm/agroforestry systems throughout Punjab, Haryana, Tarai region of U.K., western part of U.P., some parts of Bihar, West Bengal (W.B.) and Assam (Mishra *et al.*, 2010).

A major concern with respect to clonal plantation forestry is the safeguarding of stand adaptability; i.e., the ability to face a catastrophic biotic or abiotic perturbation. The most widespread use of clonal plantings has been with the willow family (Salicaceae), involving willow (*Salix*) and poplar (*Populus*) species and hybrids (Hall, 2000). Does increased use of clonal planting stock contribute to a decrease in stand viability? Such questions were theoretically explored by considering simplified situations in which susceptibility to the unknown hazard is controlled by one single diallelic locus. Results varied according to: (i) the frequency of susceptible genotypes, and (ii) the level of acceptable stand mortality. If the former is higher than the latter, increasing the number of clones will result in greater susceptibility in the multiclonal variety. If the former is low, increasing clone numbers boosts the probability of success, usually up to 10 genotypes. To cover a wide range of situations, Bishir and Roberds (1999) recommend clonal mixtures of 30 to 40 genotypes.

Presently, around two dozen clones are commercially grown in the country. However, Clone G48 (36.2), WSL22 (18.8 per cent), Udai (11.9 per cent), WSL39 (9.1 per cent), WSL32 (2.9 per cent), Wimco81 (5.3 per cent) and S7C15 (5.8 per cent) together constitute over 90 percent of the total planted poplar in the Punjab, Haryana, U.K. and U.P. states of the country. Whereas, G48, WSL22, WSL39 have widespread acceptability, many others are restricted to a few locations. Similarly, S7C8, WSL A/49 and Bahar are mainly grown in the states of U.P. and U.K. and they are almost non-existent in the states of Punjab and Haryana. G3, once a dominate clone over the greater part of the poplar growing region, is now restricted to only Aligarh and Bulandshahar districts of U.P. and in semi- arid part of Haryana where it does not attract infection of *Bipolaris* sp., may be due to drier weather. Similarly, clone G48, the most preferred clone among the growers over the great part of region of intensive poplar culture (RIPC) (Dhiman, 2012), is not grown towards eastern limits especially eastward Bareilly (U.P.) because of its high susceptibility to sap sucking insects including red mite (Dhiman, 2007). Clone WSL22 is now becoming more acceptable in its place in many locations.

The notion is widely accepted that the exclusive use of a single genotype (clone) over a large area entails an enormous risk: if the clone fails for any reasons, the failure could be total over the entire area, thus, causing almost insurmountable problems for the managemement of the forest and for the industries depending on it. Monocultures are widely believed to attract diseases and pests and to be more vulnerable than mixed stands, especially in the long term. Disease problems have, therefore, posed the question regarding the overuse of single clones and use of large monoclonal plantations (Stelzer and Goldfarb, 1997). It is unlikely that monoclonal cultures and the wide use of some clones are the only explanation to increased disease, but they act as contributing factors. The health hazards come in three forms: first they may constitute a large, undivided risk, and it may be better to spread risks; second, the concentration of a susceptible plants *per se* might increase the disease rate of the individual, while the interaction between neighbours of different susceptibility might reduce those rates; third, monoculture might stimulate the evolution of new, more virulent or aggressive form of the parasite. Because yields typically decline, crop monoculture is commonly considered as not sustainable. The focus has been to develop disease resistance within individual clones, but these clones have proved to be highly susceptible to new varieties of diseases. The diseases keep growing and have caused Germany to more or less abandon poplars. Nevertheless, these incidents have not provided poplar growers with sufficient incitement to focus on more diverse alternatives.

All programmes employing clonal forestry should have an underlying breeding programme of selection, breeding and testing to identify clones of ever-increasing genetic merits. However, when clonal forestry is the deployment option, at least some of the genetic tests must be established identified clones for the purpose of ranking clones and selecting which ones to propagate operationally. Growers that practice crop monoculture generally do so for economic reasons. The selected crop is the most profitable and any profitability loss from yield declines are less than that which occurs from any rotational options available. In these situations, the ability to minimize the losses associated with monoculture can provide the best option to increase productivity and profitability. Multiclonal varieties have been regarded as a means of deploying not-to-resistant clones (Schriner, 1965). Further, mixed stands may have the advantage of offering a more varied scenery and, under certain conditions, of giving a higher production (Heybroke, 1978).

The various annual reports of WIMCO (from mid 80s to early 90s) refer to leaf blight and its presence in few clones, including G3. However, neither quantification of the disease in terms of prevalence/incidence nor its geographical distribution has been specified making the reporting empirical. Though, the repeated references of the blight in the annual reports underlined its seriousness and impact - as a highly productive and popular clone (G3) was withdrawn by the company in due course. For example, in Yamunanagar District of Haryana, G3 was raised as high as 90 per cent of the total poplar plantations during 1985 -1995. After that, G3 clone was completely withdrawn due to its high blight susceptibility. On the other hand, same clone is still grown in Aligarh district of U.P. as blight is absent owing to environmental conditions (moderate rainfall). The specificity of the pathogen (to G3 clone) at one hand and its wider presence on the other hand support the contention of Bishir and Roberds (1999) who recommended clonal mixtures of 30 to 40 genotypes to cover a wide range of situations. In spite of this fungal catastrophy in the recent past, the existing poplar plantations are still heavily dependent on limited number of clones, probably not more than half a dozen in a state (for example, G48, Udai, WSL22, WSL39, S7C8, etc. for Uttarakhand), if political demarcation defies the ecological one (Mishra, 2011).

Poplar Diseases

Distribution and Status

Poplar suffers from a number of diseases as they are being raised as single clone monocultures and are, thus, prone to disease outbreaks. In agroforestry, the situation may further aggravates, where pathogens often diverse their activity from the common host range and cause extensive damage to either of the intercrop species. An account of principal diseases of poplars occurring on indigenous and exotic poplars in India is presented in Table1 to 3. Work on poplar diseases started almost at the same time when exotic poplars were introduced in India; i.e., late 50s. It was pioneered by Dr. K.D. Bagchee who is also known as Father of Forest Pathology in India (Table 2). The surveys on indigenous poplars were confined to two northern states namely, J. and K. and H.P. Other Himalayan states, especially north-eastern ones, where the indigenous poplars have substantial presence were not covered. *P. ciliata* seems to be most susceptible among indigenous poplars as it is affected by maximum numbers of pathogens (11). No disease has been reported on *P. glauca* and *P. rotundifolia*. *M. ciliate* was the only disease that affected all the species of indigenous poplars showing its wide host range.

Among exotic poplars, the surveys were predominantly taken up in nurseries of U.P. especially the western part followed by H.P. Besides, Haryana, Punjab and J. and K. were also surveyed. Further, maximum number of fungal pathogens were recorded on *P. deltoides* (32) followed by *P. x euramicana* (18) and *P. nigra* (10). Whereas, in plantations, highest number of surveys were conducted in U.P. followed by J. and K. and diseases were recorded on three exotics, *P. deltoides*, *P. x euamericana* and *P. nigra*. Out of these hosts, *P. x euramicana* had maximum fungal infections (8) followed by *P. deltoides* (7).

One of the defining facets of the disease is its economic value (Agrios, 1978). However, the assessment of losses in term of economic values is singularly missing in all the studies on poplar diseases, though, it is critical in terms of cost benefit assessment of the poplar culture. Percent mortality of seedlings due to incidence of different diseases in the nursery of WIMCO Research and Development Centre, Rudrapur is shown in Table 4 that ranged from 0.14 to 29.25 per cent. The large scale mortality due to *Alternaria* species was observed in Bazpur nursery and it struck down 29.25 per cent seedlings numbering 24,350 in one season. The cost of these seedlings was Rs. 535,700 (US $10,714 if Rs. 22.0 is considered as cost of one seedling) that being very substantial may discourage the grower to venture into the of poplar cultivation. So, disease management becomes imperative to prove economic viability of poplar cultivation.

Disease is quantified in terms of prevalence, incidence and severity to assess the impact of the pathogen on the host. Limited reports of this nature are available in literature. They primarily measure either incidence or

Table 1. Major diseases in nurseries and plantations of indigenous species of poplars in India

Host	Fungus	Distribution	Reference
		Nursery	
P. alba	*Melampsora populina*	H.P. nursery	Bakshi and Singh, 1967; Singh *et al.*, 1983;
	Uncinula salicis	Srinagar Social Forestry Division, (J. and K.)	Khan, 1988; Rehill *et al.*, 1988
	Uncinula adunca (Wallr)	-	Bakshi *et al.*, 1972
	M. rostrupii; U. salicis (DC)Wint	H.P.	Singh and Singh, 1975
	Cladosporium humile Davis	Kashmir Valley, Kamraj Forest Division, J. and K.	Singh and Khan, 1981; Singh *et al.*, 1983; Singh and Singh, 1986; Rehill *et al.*, 1988; Sharma and Sharma, 2000
	Melampsora ciliata Barclay	Ranikhet, Paharpani, U.P. and Solan and Shimla, H.P.	Singh and Singh, 1986
	M. ciliata	H.P. nursery, Kashmir Valley	Khan, 1988; Rehill *et al.*, 1988 ; Khan, 1999; Sharma and Sharma, 2000
	Venturia populina	-	Kaul *et al.*, 1989
P. ciliata	*M. ciliata*	Kashmir Valley, Palmpur and Bazaura nurseries, H.P.	Bakshi and Singh, 1967; Singh *et al.*, 1983; Rehill *et al.*, 1988; Khan, 1994, 99; Sharma *et al.*, 2005
	Botryodiplodia (Lasiodiplodia) palmarum	H.P. nursery	Bakshi *et al.*, 1972; Singh *et al.*, 1983; Khan, 1988
	M. ciliata	J. and K.	Singh and Singh, 1975
	C. humile	Kashmir Valley	Singh *et al.*,1983; Rehill *et al.*, 1988; Sharma and Sharma, 2000
	M. ciliata	Kehmel Forest Division and Srinagar Social Forestry Division	Rehill *et al.*, 1988
	Rhizotonia solani	Gaja Nursery, U. P. and Jabalpur, Madhya Pradesh	Singh and Singh, 1986; Mehrotra, 1992
	B.(Lasiodiplodia) palmarum	Kurukshetra Forest Division, Haryana and Sanjay Van, Tarai Central Forest Division, U.P.	Singh and Singh, 1986
	Asteroma frondicola; *C. humilie*	H.P. nursery	Khan, 1988
	A. frondicola, *Phyllosticta adjuncta* Bub and Serebrianikow, *U. salicis*	H.P. nursery	Khan, 1988
	Septoria populi (Sacc.)	Kashmir Valley	Rehill *et al.*, 1988
	Pollaccia elegans	Kashmir Valley	Rehill *et al.*, 1988; Kaul *et al.*, 1989
	M. ciliata	H.P. nursery	Khan, 1988
	Alternaria alternata (Fr) Keissler	-	Sharma *et al.*, 1999
	Rosellinia necatrix	H. P. and U.P.	Khan, 1999
	Taphrina aurea	H. P.	Sharma and Sharma, 2000
P. gamblei	*M. ciliata*	North-eastern Himalaya nursery	Viart, 1982
P. suaveolens	*M. ciliata*	-	Singh *et al.*, 1983
		Plantation	
P. ciliata	*P. elegans*	Kashmir Valley	Khan, 1999
P. sauveolens, *P. ciliata*	*Cytospora chrysosperma*	Kashmir Valley	Khan, 1999

severity and that too in nurseries (Singh *et al.*, 1983; Khan and Mishra, 1989; Singh *et al.*, 1991; Sharma *et al.*, 1999; Sharma and Sharma, 2000) with exception of plantations (Singh and Singh, 1986; Rehill *et al.*, 1988). Singh *et al.* (1983) recorded incidence of *M. ciliata* on different poplars in U.P. and H.P. nurseries and natural forest. In nursery, disease incidence ranged from 50 to 100 per cent on different clones while in forest it was 100 per cent on *P. ciliata* in U.P.

Table 2. Major diseases in nurseries of exotic species of poplars in India

Host	Fungus	Distribution	Reference
P. balsemifera	*U. adunca*	J. and K.	Bakshi *et al.*,1972
P. deltoides	*Schizophyllum commune* Fr	Western U.P.	Bagchee, 1960
	Phellinus pachyphleous (Pat.)	Tarai area of U.P.	Bakshi, 1971
	Ganoderma lucidum	Phillaur, Punjab; East Dehradun Forest Division	Bakshi *et al.*,1972; Singh and Khan, 1981; Singh and Singh, 1986
	Cortcium salmonicolor Berk & Br.	U.P.	Bakshi *et al.*,1972
	Phaeoramularia maculicola (Rom. & Sacc.)	Kashmir Valley	Qasba *et al.,* 1981
	B. palmarum	Haryana and U.P.; Lalkua Forest Research Nursery, U.P.; H.P.	Singh *et al.*,1983; Harsh and Kumar, 1997; Singh *et al.*, 1983
	Alternaria stage of *Pleospora infectoria*	Central nursery Anantnag, Forest Division, J. and K.	Singh and Singh, 1986
	C. salmonicolor	Garhwal Hills, U.P.	Singh and Singh, 1986
	Alternaria sp., *M. cilaiata, P. adjunct, B. palmarum, R. necatrix*	H.P. Nursery	Khan, 1988
	Cercospora populina	U.P.	Udit Narain, 1988
	M. ciliata	Kehmel Forest Division and Srinagar Social Forestry Division, H.P., U.P., J. and K.; Nauni, H.P.	Rehill *et al.,* 1988; Singh *et al.*,1983; Khan, 1994
	Dreschlera maydis	India	Jones and Lal, 1989
	V. populina	Kashmir Valley	Koul *et al.*,1989
	Phoma macrostroma	-	Chuahan and Pandey, 1991
	P. adjuncta	-	Singh *et al.*, 1991
	Bipolaris maydis	U.P., Punjab and Haryana	Chauhan and Pandey, 1992
	M. larici-populina Kleb.	Dun Valley	Pandey, 1992
	R. solani	U.P.	Singh and Singh, 1986
	R. nectarix	U.P., H.P.	Khan, 1999
	D. maydis	Payal, Haryana; Central Forest Tarai Division, U.P.	Khan, 1999
	A. alternata	H.P.	Sharma *et al.*, 1999
	Sclerotium rolfsii	-	Khan, 1999
	M. roridum	Dehradun, U.P.	Khan, 1999
	R. necatrix	Shilli nursery Solan, H.P.	Singh and Singh, 1986
	Sun scald canker	Tanda and Pipalparao Ranges of Tarai Central Forest Division, U.P.	Singh and Singh, 1986
	Curvularia lunata	Punjab	Gupta *et al.*, 2001
	Ceratocystis sp.	Doon Valley	Pandey *et al.*, 2002
	Alternaria alternata (Fr.) Keissler (WSL39)	Rudrapur, U.K.	Singh *et al.*, 2011
	B. setariae Shoemaker (1959) (Wimco A/49 x G3)	Rudrapur, U.K.	Mishra, 2011
	B. specifera (Bainier) Subraman. 1971 (G48 x G3)	Rudrapur, U.K.	Mishra, 2011
	Curvularia sp. (WSL22)	Rudrapur, U.K.	Singh *et al.*, 2011
	Daldinia sp. close to *D. eschscholzii* (G48)	Udam Singh Nagar, U.K.	Singh *et al.*, 2011
	Fusarium incarnatum-equiseti complex (WSL39)	Rudrapur, U.K.	Singh *et al.*, 2011

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	Fusarium semitactum Berk. and Rav. (WSL39)	Rudrapur, U.K.	Singh *et al.,* 2011
	Fusarium solani (Mart.) Sacc.(Wimco81)	Rudrapur, U.K.	Singh *et al.,* 2011
	Nigrospora state of *Khuskiya oryzae* H. J. Huds (G48)	Rudrapur, U.K.	Singh *et al.,* 2011
	Rhizoctonia sp. (W22)	Rudrapur, U.K.	Singh *et al.,* 2011
P. nigra	*Cercospora populina*	U.P.	Bakshi *et al,* 1972
	S. populi	J. and K.	Bakshi *et al.,* 1972
	U. adunca	J. and K. Kashmir Valley	Sharma, 1985
	U. populina	Kashmir Valley	Sharma, 1985
	R. necatrix	Gaja Nursery, U.P.	Singh and Singh, 1986; Khan, 1988
	C. humile	H.P.	Khan,1988
	M. ciliata	H.P.	Khan,1988
	P. eleagans	Kashmir Valley	Kaul *et al.*,1989
	P. elegans	J. and K.	Khan and Mishra,1989
	V. populina	Kashmir Valley	Koul *et al.*,1989
	C. humile	J. and K.	Khan *et al.*,1990
P. regenerata	*U. adunca*	Kashmir Valley, J. and K.	Bakshi *et al.,* 1972
P. trichocarpa	*M. cilaiata*	H.P.	Khan, 1988
P. x eumericana	*P. adjuncta*	H.P.; Dehradun, U.P.	Sohi and Nayar, 1969; Rehill and Puri, 1980
	P. pachyphleous (Pat.*)*	Tarai area of U.P.	Bakshi, 1971
	Myrothecium roridum Tode ex Fr.	Dehradun, U.P.	Bakshi *et al.,* 1972; Rehill and Puri, 1980; Singh *et al.,* 1991
	S. populi	Dehradun, U.P.	Bakshi *et al.*,1972; Singh *et al.,* 1991
	B. palmarum	U.P.; Kurukshetra Forest Division, Haryana; Sanjay Van, Tarai Central Forest Division U.P.	Bakshi *et al.*,1972; Singh and Singh, 1986
	Ganoderma lucidum	Phillaur, Punjab; Tarai Cental Forest Division and Dehradun East Forest Division, U.P.	Bakshi *et al.*,1972; Singh and Singh, 1986
	Cortcium salmonicolor Berk and Br.	U.P.; Dehradun East Forest Division, U.P.	Bakshi *et al.*,1972; Rawat, 1981; Singh and Singh, 1986
	Phomopsis sp.	-	Bakshi *et al.*,1972
	Macrophoma bengalensis	Cooch Bihar and Kurseong Forest Division, West Bengal; New Forest , Dehradun	Bakshi *et al.*,1972
	M. roridum	Dehradun, U.P.	Bakshi *et al.*,1972
	G. lucidum	Dehradun, U.P.	Singh and Khan, 1981
	Sphaceloma populi	India	Rehill and Puri, 1980
	B. palmarum	U.P.; H.P.	Singh *et al.,* 1983; Khan,1999

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	Sun scald canker	Tanda and Pipalparao Ranges of Tarai Central Forest Division, U.P.	Singh and Singh, 1986
	M. cilaiata	H.P.	Khan, 1988; Sharma and Sharma, 2000
	P. adjuncta	H.P.	Khan, 1988; Singh *et al.*, 1991
	Cercospora populina	U.P.	Chauhan and Pandey, 1991
P. yunnanensis	*Schizophyllum commune* Fr	Western U.P.	Bagchee, 1960
	Fomes (*Phellinus*) *fomentarius* (L.ex.Fr.)	U.P. Hills	
	B. palmarum	Sanjay Van, Tarai Central Forest Division U.P.	Singh and Singh, 1986
	R. nectarix	Gaja Nursery, U.P.	Singh and Singh, 1986
	M. ciliata	H.P.	Khan, 1988

Table 3. Major fungal diseases in plantations of exotic species of poplars in India

Host	Fungus	Distribution	Reference
P. deltoides	*G. lucidum*	India	Bakshi *et al.*, 1972; Singh and Khan, 1981
	B. palmarum	Peepal Padav and Gangapur Patia plantations, U.P.; Haryana	Rehill and Puri, 1980; Singh *et al*., 1983
	C. salmonicolar	East Dehradun Forest Division, U.P.	Singh and Singh, 1986
	M. ciliata	Kehmel Forest Division and Srinagar Social Forestry Division, J. and K.	Rehill *et al.*,1988
	P. noxius	U.P.	Khan, 1999
	P. elegans, S. populi	Kashmir Valley	Khan, 1999
P. nigra	*P. elegans*	Kamraj and Baramulla Forest Division	Rehill *et al.*,1988
	S. populi	Kamraj, Langate and J.V. Forest Division	Rehill *et al.*,1988
	P. elegans, S. populi	Kashmir Valley	Khan, 1999
P. x eumericana,	*C. salmonicolor*	East Dehradun Forest Division, U.P.;	Singh and Singh, 1986
	B. palmarum, C. populina, Phomopsis sp., *Poria vincta* *Tramotes corrugata* *M. bengalensis*	Pipal Padav, Belachaur and Gangapur Patia plantations, U.P.; Tanda block, Tarai and Bhabar Plantation Division, U.P.	Rehill and Puri, 1980
	P. pachyphloecus	H. P.; U.P.	Khan, 1999

Table 4. Incidence of different diseases in the poplar nursery in WIMCO R. and D. Centre, Rudrapur

S. no.	Disease	Time of incidence	Clone	Total no. of plants	No. of plants died	Mortality (%)
1.	Blister blight	October 2009	Wimco32	17,758	165	0.93
2.	Blister blight	October 2009	Wimco81	5,604	8	0.14
3.	Blister blight	September 2010	Wimco81	980	17	1.73
4.	Blister blight	September 2010	Wimco83	3,920	192	4.90
5.	Sclerotium leaf spot	September 2010	G48	536	6	1.12
6.	Sclerotium leaf spot	September 2010	Wimco81	980	12	1.22
7.	*Alternaria* sp.*	May 2012	G48	83,250	24,350	29.25

*Alternaria appeared during extreme summer in June just after field planting of containerized plantlets in Bajpur nursery in District Udham Singh Nagar, Uttarakhand.

only. Further, the disease severity was light to heavy in both nursery and stand (light = <30 per cent of foliage infected, moderate = 30-50 per cent and heavy = >50 per cent). Singh *et al*. (1991) reported foliar pathogens, *P. adjuncta* and *M. roridum* incidence on clones of *P. deltoides* and *P. x eumericana* in nursery of New Forest, Forest Research Institute, Dehradun. The incidence of the disease was more in old nursery as compared to new nursery site. Sharma and Sharma (2000) conducted a survey on the disease status and distribution of foliar diseases of poplar in 1997-98 in polar growing areas under different agro-climatic zones of Himachal Pradesh. Seven fungal diseases were observed, viz., rust, *M. ciliata*; leaf spot, *C. humile*, *A. alternate, S. populi, Sphaceloma populi*; powdery mildew, *U. salicis* and leaf blister, *T. aures*. The severity of diseases varied with place of survey which may be attributed to varying climatic conditions. Rust had highest mean disease severity of 34.36 per cent, Cladosporium leaf spot 16.60 per cent and powdery mildew with 14.80 per cent. Singh and Singh (1986) reported *C. salmonicolor* attack on various clones of *P. deltoides* and *P. x eumericana* (3.3 to 5.7 per cent) in five - and eleven-yr old plantations in east Dehradun Forest Division of U.P.

Symptomatology

The symptoms of 22 different diseases, (viz., *Botryodiplodia palmarum, Alternaria* sp., *Cladosporium humili, Dreschlera maydis, Macrophoma* sp. *Phomopsis* sp., *Phyllosticta adjucnta, Pollaccia elegans, Septoria populi, Melampsora ciliata, Myreothecium roridum Rhizoctonia solani, Rosellina nectarix, Sclerotium rolfsii, etc.*) have been described on exotics species namely, *P. balsemifera, P. nigra, P. deltoides, P. x eumericana, P. regenerate, P. trichocharpa and P. yunnanensis.* However, these symptoms lack matching photographic back up that becomes a critical limitation under two situations, one, the complex situation of symptoms of mixed infections under field conditions and two, access to discrete symptoms of the same disease on time scale leading to misconception about the complete sympotmatology of a particular disease. The Bipolaris blight has been used as an example to address these issues. The disease usually appears after onset of monsoon in late July. Pink to brown, pin head size spots develop on leaves (Fig. 1.Stage-1). Gradually, these enlarge into dark brown, irregular spots, often surrounded by a chlorotic margin (Fig.1. Stage-2). In rainy or humid weather, the irregular spots coalesce to cover the leaf blade that gave blighted appearance to the entire foliage (Fig. 4.2.1. Stage-3). Sometimes, the chlorotic spots were marginalized through midrib and veins giving a defined pattern of disease spread (Fig.1. Stage-4). Severely infected leaves crumble in dry weather and ultimately fall off prematurely (Fig. 2. Stage-5). Necrotic lesions, sometimes developing into sunken, black spot also appear on green pedicles and shoots (Fig. 4.2.2. Stage-6). Premature defoliation of the seedlings took place in short span of 3-4days. In case of nursery, the susceptible plants collectively provided burning appearance and in case of single plant, it stood conspicuously out of its green neighbours (Fig. 2.A). The symptoms were exclusively noticed on G3 clone of *P. deltoides* or generation having one of the parents as G3 (Fig. 2.B).

The Causal Organism

Practically, all the fungal pathogens belong to higher group of fungi irrespective of the origin of the host. They fall in different categories, for example, most of them infect foliage (*Alternaria* sp., *C. populina, P. adjuncta, M. roridum, S. populi,* etc.) and some heart/root (*G. lucidum*); some cause leaf spot (*A. alternata*), blight (*D. maydis*), canker (*C. salmonicolor*), rust (*M. ciliata*); while some are wood rotter (*F. fomentarius, P. pachyphleous*), etc. Few new pathogens of *P. deltoides* were also reported namely, *B. setariae, B. specifera, Daldinia* sp.*, Fusarium incarnatum*-equiseti complex, *Fusarium semitactum,* Nigrospora state of *Khuskiya oryzae,* etc. (Mishra and Singh, 2011; Singh *et al.*, 2011).

Multiple species of the same genus, Bipolaris have been isolated from the G3 clone and its offsprings from the field. Few of them have been identified while some are still in the process. For example, based on r-DNA sequence analysis, isolate no. B58 and B29 had 99 and 96 per cent similarity with *B. spicifera* and *B. setariae,* respectively. Isolate no. B3 and B12 seem similar to *B. spicifera* while isolate no. B9, B18 and B48 were close to *B. seteriae* on the basis of morphological features namely, colony type and colour, conidiophore, conidum size and germination. Rest of the eight isolates appeared neither close to *B. spicifera* nor to *B. setariae*. It signifies that the initial pathogen, *B. maydis* of poplar has been completely replaced with these new species. Still, this observation needs further confirmation based on more extensive collection of isolates, culturing and identification at both morphological and molecular level (Mishra, 2011).

One more issue of significance is that *B. setariae* and *B. spicifera* has wheat and grasses, respectively as hosts which, otherwise, are also a component of agroforestry systems. This line of observation reaffirms the old belief that *B. maydis* was transferred from maize to poplar as explained by Leonard (1987) that both *P. deltoides* and *Zea mays* have got the same gene centre- North America, regardless of their different botanical descriptions. This suggests that there is a co-evolution of host parasite interaction which are undetectable state under the natural ecosystems. However, when humans interfere the natural systems, epidemic appears due to strong selection pressure on the pathogen populations. In the present case, genetically susceptible male poplar cultivar G3 (Texas provenance) was vegetatively multiplied (uniform cytoplasm) in agroforestry systems in India which imposed strong pressure on the pathogen populations -*B. maydis* race T- which led to the development of devastative epidemics in the country.

The new pathogen-host combinations require fresh explanation, though, physical closeness between the duos, survival option of the pathogen (new hosts), the shrinking distribution base of the susceptible clone, G3 and specificity are some of the issues that may help in explaining the replacement of causal agent of blight with new but related species of *Bipolaris*. For example, as G3 clone was withdrawn from the cultivation during late 90s, it is probable that populations of *B. maydis* may have be replaced with other pathogens including species of *Bipolaris* due to lack of favourable food base (G3) of a pathogen that was already present in epidemic proportions. That is why, the isolations in the present study could not capture the original pathogen of blight, *B. maydis*. It is also important to go for molecular characterization of remaining unidentified isolates, so that, the complete structure of the pathogenic population of *Bipolaris* species can be elucidated as it will be important for resistance screening and development of promising poplar genotypes (Mishra, 2011). .

Besides understanding the diversity of pathogens, it is also important to know the variations among the pathogenic populations from the point of view of breeding disease resistance. To capture this variability of potential pathogens, surveys of poplar nurseries in various states were conducted since 2006 (Singh *et al.*, 2011). Table 5 reveals the status of pathogenic isolates collected from commercial clones of *P. deltoides.* During field trips, it was observed that *A. alternata* and *Curvularia* sp. are commonly present on practically all commercial clones, underlying their wide presence. These fungi are, otherwise, known to be weak pathogens but their universal appearance on all the clones may add to the widely believed fact that the climate change may affect the population structure of the pathogens under field conditions. Chakraborty *et al.* (2008) observed that changes in temperature and other climatic factors may activate some sleeper pathogen species while others may cease to be economically important. This may apply equally to endemic and exotic pathogens. Often minor changes in climatic factors such as temperature can tip the balance in favour of an exotic species for gaining a bridgehead following its inadvertent introduction. Unusual disease outbreaks could also occur from sporadic weather events.

Variations among isolates of the pathogens *(A. alternata, Bipolaris* spp.*, Curvularia* spp.*, Fusarium solani*, *Rhizoctonia* spp., and *Sclerotium rolfsii*) were captured on various cultural and morphological parameters namely, colony type, pigmentation, rate of fungal growth, sporulation, spore size, colour and germination on different growth media (PDA, CDA, MEA, SPA, etc.; Bagwari, 2009; Swati, 2009; Bagwari *et al.*, 2010; Panwar, 2010; Geetanjali, 2010; Geetanjali *et al*., 2011; Gupta, 2011, Gupta *et al.*,2011; Panwar *et al.*,2011, Mishra, 2011; Vadeo, 2012; Upadhyay, 2012). Moreover, fungicidal and biogenic (fungi, bacteria and amongst isolates) sensitivity was also quantified. The growth of different isolates of pathogens showed differential trends over time. The matrix between growth media vis-à-vis cultural and morphological characters help in resolving the differences among the isolates of a pathogen.

The disease development under field condition must be an outcome of various factors- the inherent capacity of the pathogen for causing disease (virulence/aggressiveness, inoculum potential, etc.) besides competition from the other contemporary pathogens, etc. Two experiments were carried out under laboratory conditions to understand the interactions between *Bipolaris* spp. and *A. alternata* (that occupies same time and space (foliage) as pathogen) and within population of *Bipolaris* spp. isolates. These isolates had differential interactions with isolates of another pathogen, *A. alternata* (as antagonist). Minimum efficacy of *A. alternata* had been against isolate no. B29 (-5.8 per cent) and maximum against isolate no. B48 (32.2 per cent). This indicates the presence of mutual antagonism between the two fungi. The interaction among isolates of *Bipolaris* spp. registered different trends with changing isolate in the

Table 5. Isolates of fungal species collected from clones of *P. deltoides* from different states of India

Fungus	Clone	No. of isolate	Place	Year of collection
Bipolaris spp.	G3 and off springs	130	Rudrapur (U.K.)	2006-12
Alternaria alternata	G3, G48, WSL22, WSL39, Udai	>100	Thana Chappar (Haryana), Paniyala and Maheshwari (Roorkee) and Rudrapur (U.K.)	2007-12
Phoma/ Phyllosticta sp.	WSL22, Udai	30	Rudrapur and Paniyala (Roorkee; U.K.)	2008-2009
Curvularia spp.	G48, WSL22, Udai	70	Thana Chappar (Haryana), Paniyala and Maheshwari (Roorkee) and Rudrapur (U.K.), Sharanpur (U.P.)	2008-12
Sclerotium rolfsii	WSL31, WSL39	>100	Jawahar Nagar, Rudrapur and Maheshwari (U.K.)	2008-11
Rhizoctonia sp.	WSL22	20	Rudrapur (U.K.)	2011
Fusarium solani	Wimco81, Wimco83	15	Rudrapur (U.K.)	2011

interaction. For example, isolate no. B29 could suppress isolate no. B40 (38.1 per cent) and isolate no. B48 (38.4 per cent) establishing its better competitiveness (Mishra, 2011).

Pathogen Survival

According to Dickinson and Lucas (1982) whenever pathogens are not sheltered by a host they face problems of survival in a hostile environment. The extent of this problem for any particular pathogens depends on the length of the period between hosts and the relative hostility of the environment. At one extreme, dispersal during epidemic spread may involve only brief periods when spore or other propagules are away from their hosts. On the other, pathogens survive between annual crops planted in successive growing seasons or in rotations when suitable hosts are available only every third, fourth or even fifth year. In the intervening periods, environmental extremes jeopardize the pathogen's chances of survival. Drought, water logging and extremes of temperature can all reduce the viability of dormant pathogen's future inocula; these surviving structures are also subject to microbial antagonism which can severely debilitate or even destroy them. Mishra and Khan (1991) discussed the disease development and pathogen survival of Sclerotium leaf spot of poplars. The source of infection was attributed to sclerotia produced on the infected plants of the previous year and leaf litter. Such information for other pathogens are conspicuously missing in literature.

Management of Diseases

The chemical management of poplar diseases was generally tried in the nurseries. *In vitro* testing of the chemicals has also been attempted. Biological management of the diseases is rare like that of cultural. Similarly, breeding for disease resistance is also an exception than rule. Singh and Singh (1986) recommended several cultural practices to manage Ganoderma root rot, for example, mix planting of deciduous species like semul (*Bombax ceiba*) and kanju (*Pongamia pinnata*) with poplar in order to break the continuity of *Ganoderma* infection in the event of the diseases outbreak in plantations. Further, disease in poplar plantations can be managed by removing roots and stumps of previous crop from the site before raising poplar plantations. Spread of the disease in lines can be checked by increasing spacing in between plants in lines, isolating the disease patches by digging 0.7m deep and 0.3m wide trenches from the healthy plants. They also suggested the management of Rosellinia root rot- the affected plants should be uprooted and destroyed, the infected area of the nursery should not be replanted for one season, the disease from the soil can be eradicated by treatments of the soil with carbon disulphide or 5 per cent solutions of carbolic acid and drenching of soil around affected plants with 0.1 per cent Bavistin was also found effective to check the disease. Sharma and Bhardwaj (1989) suggested pruning out of weak, dead and canker affected branches, and sweeping of the nursery floor and burning of the leaves after leaf fall to manage the canker disease. Khan (1999) also recommended sanitation of planting site, proper spacing and isolation trenches for the management of diseases in poplar plantations.

Experiments were conducted in the nursery (2006-2008) on effect of time of planting and of weeding on the growth and disease status of poplar clone like G-48. Growth as well as disease was quite low in June transplanted G-48 clone of time of planting experiment. However, in 2008 experiment of similar nature, the trends were not so discrete especially with regards to disease. The rains in tarai region of Uttarakhand were started in late June and had a persistent trend over the entire monsoon period. It must have helped the disease initiation at a very early stage of the monsoon. However, due to consistently heavy rains over a long period (June to September 2008), the spread of the disease and its sustenance was affected reflecting a dip in the second stage of observation and, there after, an increase owing to receding rains and high atmospheric moisture (Singh *et al.*, 2011).

Further, impact of the cultural practice, weeding on growth and disease development was also attempted. It can be concluded that moderate weeding to the tune of 15 days may match with the frequent weeding of five days gap both in terms of growth as well as foliar infection. Such information are vital for cutting the cost of nursery operations affecting cost-benefit ratio for a commercial crop like poplar which may be offered as a alternative model of agri-silviculture to agriculture.

Different group of fungicides (systemic and non-systemic) were screened in the laboratory against varied poplar pathogens (*Curvularia* sp., *Drechslera* spp., *F. solani*, *Rhizoctonia* sp., etc.). The systemic fungicides, Benomyl and Propiconazole were found very effective against the isolates of *S. rolfsii* species. The isolate sensitivity to Benomyl was quite apparent at the lower dose of 10 ppm while in case of Propiconazole, no growth was recorded even at the lowest concentration of 5 ppm (Gupta, 2011).

Chemical management of poplar diseases is more attempted for two pathogens; i.e., rust (*M. ciliata*) and set rot (*B. palmarum*; Table 6). The former has wider presence on the indigenous poplars (Table1) leading to more attention for its management. The set is the basic unit for the vegetative

Table 6. Chemical management of poplar diseases

Pathogen	Chemical/ Dose/ Interval	Reference
C. salmonicolor	0.2% Dithane-M-45 + 0.1% Bavistin (spray)	Singh and Singh, 1986
M. ciliata	Copper oxychloride (0.2%)/ fort night; Bavistin (0.1%) or combinations of calixin (0.075%) + Dithane-M-45 (0.15%) /three sprays/20 days intervals; 0.1% Bavistin; Nurseries/ six sprays/ fort night/ Bavistin 0.1% spray at fortnightly interval Cyproconazole(0.03%) or Triadimefon (0.05%) at two weeks intervals; Penconazole best (35.48% disease).	Singh *et al.*, 1983; Khan 1988 & 99; Rehill *et al.*, 1988 Khan,1994; Sharma *et al.*, 2005
R. solani	Blitox, Captan and Thiram @ 20-50g/m^2 (drenching)	Singh and Singh, 1986
C. humile	0.4% Dithane-M-45 (spray); 0.25% Dithane-M-45 + Bavistin	Singh and Singh, 1986; Khan, 1988
B. palmarum	0.5% of mercury fungicide (dip for 15 min.) 0.35% DithaneM-45; 0.03% DithaneM-45; 0.05% Benomyl	Singh and Singh, 1986 ; Rehill *et al.*, 1988; Khan *et al.*, 1990 Sharma and Sharma, 1997
U. salicis	0.2% Dithane-M-45 or any copper oxychloride fortnightly spray	Singh and Singh, 1986
R. necatrix *M. ciliata*,	Dithane-M-45 or Dithane- Z-78(100 g/m^2/drenching)	Khan,1988
S. populi	0.2% DithaneM-45	Rehill *et al.*, 1988
D. maydis	Dithane -M-45 and Bayleton	Khan, 1999

propagation of poplar and any health problem may draw immediate attention for its management.

The biological control of plant pathogens is gaining importance owing to the non- targeted effects of pesticides, environmental pollution due to indiscriminate use of agro chemicals and development of resistance in pathogens to the pesticides, etc. There are few reports regarding use of antagonist (bio-control agent) against poplar pathogens (*Bipolaris* spp., *Curvularia* sp., etc.). In case of *Curvularia* sp., it was observed that only one isolate (no.7) exhibited suppression in the presence of antagonist (12.3) while other isolates of fungi remained unaffected (Pooja, 2010; Pooja *et al.*, 2011). The antagonist (*Pseudomonas* sp.) failed to suppress the pathogen due to presence of haloperoxidase of the pathogen that adversely affected the former. Further, it may also be attributed to the different niche occupied by the fungal isolates (foliage-borne) and antagonist (soil-borne) leading to lack of real life interactions. *Trichoderma* sp was also tested against isolates of *Fusarium* sp., *Rhizoctotia solani*, and *S. rolfsii*. The antagonistic interactions between *Trichoderma* species and *S. rolfsii* revealed one interesting fact that antagonist was able to suppress all the isolates within a close range of 48 to 57 per cent barring isolate no. 2 (79.0 per cent) which had a suppression significantly more than other nine isolates of *Sclerotium* species (Gupta, 2011).

Different studies were conducted to screen poplar genotypes against various diseases (Harsh and Kumar, 1997; Sharma *et al.*, 1999; Mishra, 2011). Nineteen clones of *P. deltoides* were screened against set rot (*B. palmarum*). The study revealed that S7C8 clone was most resistant followed by TRI- T-19, S7C15, PDA/1945, S7C20 and L188:89. On the other hand, most susceptible clone was L-52/88 followed by PD-3201 (Harsh and Kumar, 1997). An experiment was conducted to assess resistance of poplar germplasm against *A. alternata* in Nauni nursery, H.P. and reported 5 per cent incidence of disease on three clones (Delcnat-4, Narkanda and Chamba) and two hybrids (165M2 and 2M2) of *P. ciliata*. Also, five clones of UHF selections (P2/92, P6/92, P9/92, 96-1, 2PC); four clones of Lalkuan selections (1L-3B, 1L-4B, 1L- 8, 3L-2B) and two hybrids (HybB and Hyb3) showed disease symptoms (Sharma *et al.*, 1999). Mishra (2011) screened seven commercial clones of *P. deltoides*, namely, G3, WSL 22, WSL39, G48, Udai, S7C8 and S7C15 against *B. spicifera*. Barring WSL-39, all the clones exhibited symptoms of blight.

Besides screening of genotypes, the crude toxin of *Bipolaris* species were tested against shoot juveniles and root cuttings of G3 clone of *P. deltoides* (Fig. 3). It was observed that out of the sixty isolates tested, six isolates (B2, B4, B19, B31, B32, and B34) were more aggressive in comparison to others as they initiated blight symptoms earliest after 3hrs on shoot juveniles. While, isolate B16 and B18 could produce blight after 6h. Most of the aggressive isolates (B2, B19, B31 and B32) exhibited 100 per cent foliage blight. While, isolates like B18 and B45 exhibited wilting symptom within 3h. Blighted symptom was also expressed

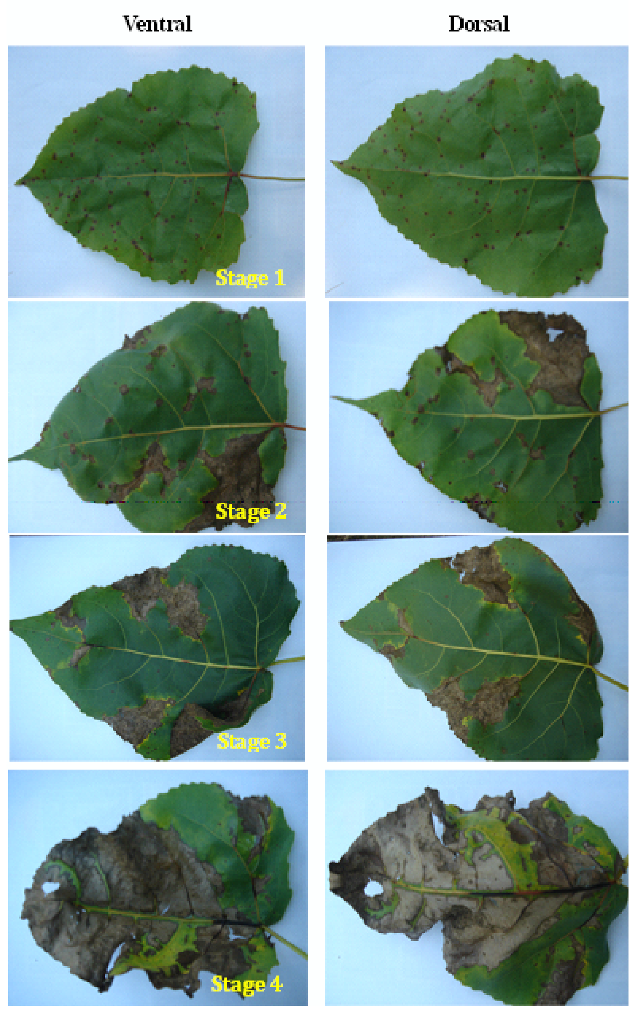

Fig.1. Various stages of blight development on the poplar foliage in nursery.

Fig. 2. Various stages of blight development on the poplar foliage (Stage 5) and shoot (Stage 6) in nursery.

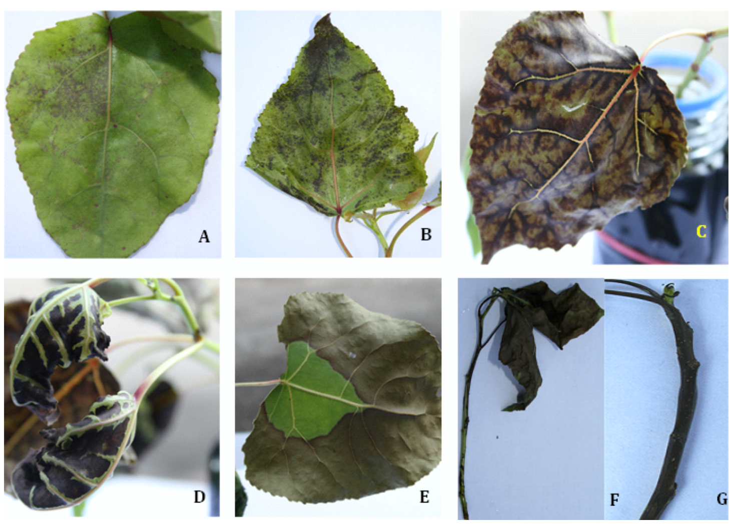

Fig. 3. Stage I: Symptoms produced by crude toxin on shoot juveniles of G-3 clone. A-B) Initial to mild flecking on leaf, C) blightening of leaf blade with prominent blackening of veins, D) inter-veinal blight, E) blightening of leaf from margin in wards, F) completely blighted shoot juvenile and G) shoot blight.

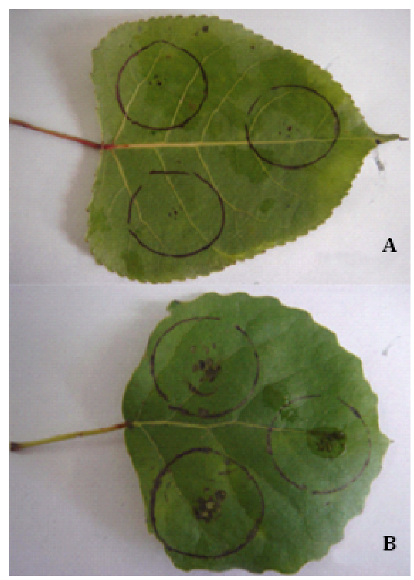

Fig. 4. Steps of *in-vitro* testing of the fungal toxin. A. Leaf of G-3 control (with drop of sterilized distilled water) and B. Toxin treated leaf (with drop of toxin at the centre.

within the same observation period by isolates like B43 and B50. Similar symptoms were observed with leaf bioassay of pure toxin (Fig. 4). Similarly, Chauhan and Pandey in 1995 carried out physiological identification of *B. maydis* race T pathogenic to *P. deltoides*. Toxin metabolites were isolated by chloroform extraction. Presence of toxin in the solution was detected by using a leaf disc bioassay leaf discs floated 500 to 1,000 ppm concentrations exhibited about cent per cent necrosis within 12 to 15 hour of incubation. At 100 ppm, necrosis was very slow but at 10 ppm only flacking was recorded. Toxin is known to be produced by race T but not by race O. In this study, only P isolate produced the toxin in the culture medium which was detected by host sensitivity test in which susceptible poplar cultivars-G3 and 111101 exibited necrosis.

All the isolates of *Bipolaris* spp. could initiate pathogenic reaction in G3 clone but to varying degrees. Pathogenic reactions were more prominent and swift in shoot juvenile in comparison to stem cutting probably due to direct sucking of the cultural filtrate in the vascular tissues in the former. While in case of stem cutting, the uptake of the filtrate was through roots that took longer route to reach the leaves. Moreover, the hardening of the tissue in cuttings may be another impediment of early expression of the severity of the symptoms. During night, the appearance of pathogenic reaction was quite slow as transpiration rate is less due to low night temperature. In absence of a strong pull the uptake of liquid (water and filtrate) through vascular tissues is also slow that, in turn, may slow down the distribution of the toxin in the foliar part and accordingly its effect in symptom expression like wilting and blightening.

Poplars occupy a unique and important position in the rural economy of India. Users including farmers have fully appreciated the benefits of poplar cultivation and consider poplar tree as assets for the future needs. It is only possible when they get constant supply of the healthy planting material through assured quality control including disease free seedlings. High cost and even impossibility of direct chemical control and the uncertainty of biological management indicate the necessity for developing pest resistant forest trees. It is possible only through the screening of the promising germplasm for disease resistance. The field evaluation of important diseases, understanding of the biology of the pathogens especially their disease cycle, development of quick methods for the resistance screening (toxin bioassay, etc.) are some of the approaches that will contribute towards the culture of poplar.

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Fungal Decay in Poplar Trees and Wood

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Introduction

Poplar (*Populus deltoides*) is an ideal tree for agroforestry and farm forestry in North India. Indigenous poplars grow in the Himalayas whereas *P. deltoides* have been introduced on the farm land in the plains of Punjab, Haryana, Uttarakhand and Uttar Pradesh. The tree has become an integral part of the agri-ecosystem and play an important role in local, state and national economy. Initially, poplar farming was introduced to meet the demand of match industry but now poplar wood is extensively used in making plywood and many other products. Presently, the plywood industry is the main consumer of poplar wood. Yamunanagar in Haryana is the main poplar wood trading and processing centre in the country, where demand of about 300 plywood industrial units exceeds the supply. Farmers are the main growers of poplar to meet this demand. Poplars have changed the landscape of this region and also contributed in tree cover of the country.

Besides plywood, poplar wood has uses in making packing cases, matchsticks, ice cream spoons, etc. Poplar wood is not used for making furniture and doors and windows because of the mindset that it is soft and not durable. However, studies have revealed that the poplar wood has varying durability and natural decay resistance and therefore, can be safely used for furniture and doors and windows making (Harsh *et al.*, 2009). Poplar trees and wood are attacked by wood decaying fungi in field and during storage. An account of fungal decay in poplar (*P. deltoides*) and natural decay resistance is being given below.

The poplar wood has varying durability and natural decay resistance, however, poplar trees and wood are attacked by wood decaying fungi in field and during storage

Fungal Decay in Living Trees

Root Rot

Root rot in poplar trees is caused by *Ganoderma lucidum* (Curtis:Fr.) P. Karst. (Fig. 1a) The affected trees exhibit drying of branch tips when the root system is decayed by the fungus. Young trees of 2-3 years die fast from top downwards. The older trees may uproot during storms and heavy rains due to rotting of anchoring roots. The fruiting bodies develop during the rainy season at the base of the trees which are with a dark brown shiny stipe and reddish brown laccate cap. *G. lucidum* has been reported to cause 100 per cent mortality in poplar plantations in Phillaur, Punjab.

Heart Rot and Canker Rot

Phellinus pachyphloeus (Pat.) Pat. (=*Fomes pachyphloeus* (Pat.) Bres.) causes heart rot in older poplar trees (Fig. 1b). The trees become hollow within and the decay extends into sapwood making the trees vulnerable to wind breakage. The fungus enters the trees through wounds caused due to tractor movement and sunscald injuries on the stem. The heartwood development seldom takes place in young poplar which is harvested early. However, when poplars are retained longer especially in avenues and for breeding programmes, *P. pachyphloeus* infection may take place. Singh and Singh (1986) have reported this infection in Tarai region of Uttarakhand (in erstwhile Uttar Pradesh).

Fomes fomentarius (L.: Fr.) Fr. causes heart rot of *P. nigra* trees on roadside in Kashmir (personal observation during 2012 visit; Fig. 1c). The heart rotted trees snap during storms. Singh and Singh (1986) have reported *F. fomentarius* in *Populus yunnanensis* and *P. ciliata* trees in Kumaun Hills of Uttarakhand.

Singh and Singh (1986) reported *Earliella scabrosa* (Pers.) Gilb. & Ryv. (=*Trametes corrugata* (Pers.) Bres.) causing heart rot in 10-yr old trees of *P. x euramericana* in Tarai region of Uttarakhand. Harsh (2008) reported it from Lalkua (Nainital), Uttarakhand in *P. deltoides* (L-series; Fig. 1d).

Wood Decay in Storage

Poplar wood decays fast by wood decaying fungi while in storage. Mostly it is attacked by white rot fungi. The common white rot fungi reported by Harsh (2008) on stored poplar wood are: *Daldinia concentrica* (Bolt.) Ces. & De Not. (Fig. 1e), *Lenzites acuta* Berk., *Pycnoporus sanguineus* (L.: Fr.) Murr. (Fig. 1f) and *Pleurotus* spp. Singh and Singh (1986) have reported *Oxyporus populinus* (Fr.) Donk (=*Fomes connatus* (Weinm.) Gill. on stumps and roots of *Populus* spp. in Chakrata and Mussoorie in erstwhile Uttar Pradesh (now in Uttarakhand) and *Polyporus squamosus* Fr. on dead stem of *Populus* spp. in Manali, Himachal Pradesh.

Natural Decay Resistance of Poplar Wood

The information regarding the natural decay resistance in commercially grown poplar clones was first time brought out in India by Harsh (2008). It is a misconception that poplar wood is not durable, however, the study conducted at Forest Research Institute, Dehradun revealed otherwise. The study revealed that there is definite variation among the clones/ source material of poplar for decay resistance; even within same clone of different locations and some clone exhibited natural decay resistance.

Thirty-nine samples of 16 clones of *P. deltoides* were collected from the states of Haryana, Punjab, Uttar Pradesh and Uttarakhand and subjected to accelerated laboratory tests (Bakshi *et al.*, 1967) to assess natural decay resistance in them using one white rot test fungus *Pycnoporus sanguineus* and one brown rot test fungus *Gloeophyllum striatum*. The wood blocks were categorized on the basis of weight loss in four resistant classes; i.e., highly resistant (0-10 per cent wt. loss), resistant (11- 25 per cent wt. loss), moderately resistant (26-44 per cent wt. loss) and non-resistant (above 45 per cent wt. loss; Table 1). Most of the tested poplar clones showed resistance against brown rot fungus. Brown rot fungi are more confined to higher altitude temperate regions and from the findings, it can be suggested that poplar (*P. deltoides*) wood can be safely used for construction and furniture making at high altitudes. It was also revealed that unlike most traditional timber species, heartwood of poplar is more susceptible to decay fungi than sapwood. This quality can be used while peelings are made for plywood manufacturing. Leaving a central core of inner-wood would give a decay resistant material.

The materials assessed for natural decay resistance were obtained from trees of different age groups starting from 4.5 years to 16 years, but age of trees was not found to show any relation to decay resistance as the wood from 4.5 years of tree was found in the same resistant class as from the tree of 16 years of age. Similarly, wood samples from the trees of 5-7 yrs of age showed wide variation in decay resistance from Class I (highly-resistant) to Class IV (non-resistant).

Study showed that there were clear cut variations in natural decay resistance among different clones as well between the same clones. While G-48 clone from Pind Khakli, Hoshiarpur (Punjab) showed Class I (highly resistant) resistance, G-48 clone from Haryana Bungha, Hoshiarpur and Tajowal Mand, Kathgarh, Hoshiarpur were in Class IV (non-resistant). Similarly, G-3 clone from Brahman Majra, Jagadhri Tehsil, Yamunanagar (Haryana) showed Class II resistance against decay but G-3 from Haryana Bungha, Hoshiarpur and Pind Khakli, Hoshiarpu showed Class IV resistance (Table 1).

Clone G-48 from Pind Khakli, Hoshiarpur and S7C15 from WIMCO, Rudrapur were found to be highly resistant

a. ***Ganoderma lucidum***

b. ***Phellinus pachyphloeus***

c. ***Fomes fomentarius***

d. Heart rot in poplar

e. ***Daldinia concentrica***

f. ***Pycnoporus sanguineus***

g. Accelerated laboratory test for natural decay resistance in poplar wood

Fig. 1. Fungal decay in poplar trees and wood, a.-d. decay fungi of tree, e.-f. wood decay fungi of storage and g. test for natural decay resistance in poplar wood.

Table 1. Per cent weight loss in wood blocks of different clones of poplar

S. no.	Clone/ material	Locality	Age (yrs)	Percent weight loss (Resistance class)			
				Sapwood (outer)		Inner-wood (heartwood)	
				White rot	Brown rot	White rot	Brown rot
1.	S7C4	Sitapur, U.P.		39.09±1.89 (III)	7.61±1.89 (I)	23.69±1.69 (II)	8.29±0.67 (I)
2.	S7C15	Bahraich, U.P.		29.41±3.29 (III)	2.82±0.55 (I)	32.03±2.99 (III)	1.75±0.52 (I)
3.	G-48	Mohali, Punjab		31.22±4.80 (III)	2.52±0.40 (I)	25.59±3.86 (III)	2.44±0.15 (I)
4.	WSL-39	Wimco Seedlings, Rudrapur	6-7	16.99±3.08 (II)	4.13±0.97 (I)	41.39±5.25 (III)	2.82±0.19 (I)
5.	L-34 (TC)	- do -	6-7	19.57±1.31 (II)	3.37±0.43 (I)	25.88±2.82 (III)	3.33±0.27 (I)
6.	G-3 (Female)	- do -	6-7	22.84±2.99 (II)	3.82±0.96 (I)	21.75±6.32 (II)	3.26±0.36 (I)
7.	Uday	- do -	6-7	12.17±0.30 (II)	8.18±0.33 (I)	39.03±4.99 (III)	10.47±0.52 (I)
8.	WSL-42	- do -	6-7	21.46±1.40 (II)	10.59±0.70 (II)	34.25±3.14 (III)	9.82±0.39 (I)
9.	S7C8	- do -	6-7	45.16±1.59 (IV)	9.74±0.40 (I)	NA	NA
10.	WSL A-26	- do -	6-7	26.72±1.53 (III)	3.77±0.91 (I)	34.05±7.95 (III)	6.13±2.61 (I)
11.	G-48	- do -	6-7	24.93±1.51 (II)	2.29±0.30 (I)	37.05±6.47 (III)	3.44±0.46 (I)
12.	S7C4	- do -	6-7	31.80±2.72 (III)	14.66±1.05 (II)	36.65±5.11 (III)	1.99±0.70 (I)
13.	L-49	- do -	6-7	38.34±7.92 (III)	2.80±0.33 (I)	59.01±4.98 (IV)	2.67±0.24 (I)
14.	WIMCO-81	- do -	6-7	27.68±3.49 (III)	3.99±0.94 (I)	43.33±4.80 (III)	3.66±0.95 (I)
15.	G-48	Pavan Poplar Ltd., Rudrapur		35.40±2.26 (III)	9.87±1.71 (I)	22.71±14.95 (II)	2.49±3.15 (I)
16.	S7C5	- do -		27.70±3.36 (III)	10.02±2.07 (I)	18.80±2.90 (II)	13.40±2.42 (II)
17.	Uday	- do -		19.39±2.40 (II)	7.16±1.67 (I)	27.55±2.90 (III)	14.80±1.10 (II)
18.	S7C15	- do -		7.36±0.33 (I)	3.32±0.88 (I)	24.62±2.20 (II)	7.71±0.90 (I)
19.	L	Pandori Mindomind, Punjab	16	41.63± 3.80(III)	4.01±1.29 (I)	41.86±3.56 (III)	3.58±0.45 (I)
20.	PD-124	- do -	16	44.12±1.95 (IV)	3.57±1.51 (I)	41.75±4.51 (III)	3.73±0.98 (I)
21.	G-48	- do -	16	34.80±1.06 (III)	7.60±0.44 (I)	43.23±2.09 (III)	2.83±0.62 (I)
22.	G-3	Pind Khakli, Punjab	5-6	45.06±3.36 (IV)	5.61±1.09 (I)	43.93±3.26 (III)	3.83±0.36 (I)
23.	G-48	- do -	5-6	5.35±0.14 (I)	3.04±0.49 (I)	43.85±3.65 (III)	2.81±0.55 (I)
24.	G-48	Garhdewal, Punjab	5-6	27.97±2.20 (III)	4.50±0.19 (I)	49.36±2.15 (IV)	4.13±0.28 (I)
25.	G-3	Hariana, Punjab	5-6	31.84±2.21 (III)	6.09±1.23 (I)	23.14±3.18 (II)	2.62±0.65 (I)
26.	G-3	Hariana Bungha, Punjab	5-6	48.28±6.74 (IV)	6.51±0.21 (I)	44.74±3.14 (IV)	4.84±0.79 (I)
27.	G-48	- do -	5-6	50.09±1.13 (IV)	4.82±1.09 (I)	38.97±2.12 (III)	3.17±0.43 (I)
28.	G-48	Bela Tajowal, Kathgarh, Hoshiyarpur	5-6	42.69±4.10 (III)	3.44±0.79 (I)	39.75±4.69 (III)	2.55±1.01 (I)
29.	G-48	Tajowal Mand, Kathgarh, Hoshiyarpur	5	45.66±1.18 (IV)	4.41±0.96 (I)	55.19±4.58 (IV)	3.30±0.70 (I)
30.	G-48	Santemajra, Hoshiyarpur	7	36.74±1.89 (III)	2.92±0.77 (I)	41.43±3.77 (III)	3.74±2.29
31.	G-48	Khadri Village, Jagadhri Tehsil, Yamunanagar	7	25.66±2.92 (III)	5.50±0.98 (I)	-	5.68±0.91 (I)
32.	G-48	- do -	4.5	43.21±3.17 (III)	6.23±1.03 (I)	41.80±4.33 (III)	10.06±0.57 (I)
33.	G-48	Brahman Majra, Jagadhri Tehsil, Yamunanagar	6	23.04±3.38 (II)	5.22±0.41 (I)	16.61±0.28 (II)	4.16±0.36 (I)
34.	G-3	- do -	8	16.37±0.84 (II)	5.18±0.58 (I)	18.38±1.09 (II)	2.33±0.41 (I)
35.	G-48	Dakwala Village, Near Darpur, Yamunanagar	7	35.78±3.53 (III)	4.72±0.67 (I)	37.93±2.38 (III)	4.39±0.49 (I)
36.	G-48	Panjeto Village, near Chacharauli, Yamunanagar	7	39.02±1.68 (III)	4.16±0.34 (I)	40.74±5.13 (III)	3.90±0.60 (I)
37.	G-3	Aligarh, U.P.		23.18±2.83 (II)	3.06±0.32 (I)	32.60±2.18 (III)	2.85±0.28 (I)
38.	WIMCO-22	WIMCO Seedlings Ltd., Rudrapur, U.K.		29.95±5.89 (III)	3.36±0.36 (I)	15.25±1.26 (II)	3.54±1.56 (I)
39.	G-48	- do -		27.66±1.86 (III)	1.32±0.66 (I)	44.71±5.11 (III)	2.38±0.35
		CD at 5%		**4.28**	**1.07**	**4.13**	**1.21**

clones against decay. These materials can be used for making decay resistant plywood as well as for construction and furniture making. Decay resistance was found to vary within a tree from base to top, maximum resistance was observed at 2.5 m height, above and below, it decreased considerably (Table 2). Resistance was more at the base than at the top of the tree. This quality can be used for selecting logs one meter above and below 2.5 meter from the base for selecting material for manufacturing decay resistant plywood and panels. Clones/source material showing resistance against decay will have potential for other uses, such as furniture making, construction, panelling, and will fetch good price to the growers.

Management interventions could help poplar culture in delaying the decay of the wood. The field observations recorded over the poplar growing region indicates that the slow growing poplar especially planted on forest land gets more decay than that actively growing on farm fields. The decay further appears to be accelerated with termite infected fields when some trees may be totally hollow from bottom to top, though they may show some foliage on the crown. Wood decay in storage accelerates when logs get alternate wetting and drying during rains which causes conducive environmental condition for fungus to multiply and infestation. Poplar has largely developed a mechanism of fresh wood usage where it on harvest and conversion, is quickly transported to the marketing/processing sites and immediately used. The problem of wood decay in storage is more common in government harvest and supplies which take a lot of time in harvesting, storage in depots before the logs are auctioned and, finally, used.

Table 2. Natural decay resistance pattern within a tree (clone G-3, WSL-22 and G-48) at different heights

Height	Per cent weight loss			
	Sapwood (outer)		Inner-wood (heartwood)	
	White rot	Brown rot	White rot	Brown rot
G-3				
Base	38.27±4.41	4.60±0.96	51.77±5.49	8.27±1.06
1.25 m	30.26±1.08	6.05±0.81	37.46±2.64	6.73±0.77
2.50 m	23.18±2.83	3.06±0.32	32.60±2.18	2.85±0.28
3.75 m	41.31±1.61	12.50±1.29	33.87±2.65	7.38±0.80
5.00 m	42.65±5.69	10.85±0.35	NM	NM
6.25 m	48.74±4.09	11.90±0.43	NM	NM
Top	49.28±1.15	12.77±1.03	NM	NM
WSL-22				
Base	16.07±2.65	1.78±0.44	45.73±2.99	3.14±0.81
1.25 m	9.46±2.70	2.07±0.22	29.79±11.00	3.11±0.57
2.50 m	3.48±0.48	1.02±0.28	3.02±1.06	3.31±0.74
3.75 m	4.49±1.11	2.31±0.42	14.05±2.08	2.07±0.67
5.00 m	29.95±5.89	3.36±0.36	15.25±1.26	3.54±1.56
6.25 m	31.06±3.59	4.99±0.94	31.93±2.27	5.61±0.53
Top	31.34±1.62	5.18±0.36	NM	NM
G-48				
Base	33.72±4.42	1.31±0.29	41.73±5.78	2.47±0.17
1.25 m	29.11±6.89	1.28±0.17	40.96±6.46	3.07±0.20
2.50 m	28.18±1.85	1.19±0.41	42.33±3.48	2.38±0.35
3.75 m	34.75±6.77	1.57±0.25	47.09±4.12	2.74±0.20
5.00 m	35.47±2.77	2.77±0.19	NM	NM
6.25 m	38.17±1.85	4.49±0.22	NM	NM
Top	39.22±1.33	4.75±0.17	NM	NM

*Not measurable (heartwood).

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Status of Insect Pests of Poplar in India with Special Reference to *Clostera* spp.

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Introduction

Most of the exotic poplars, especially *Populus deltoides* have been suffering multiple insect injuries since their introduction in India. Infestation by different insect species to poplar has been reported from time to time by many workers, including Pruthi and Batra (1960); Chatterjee and Thapa (1964); Seth (1969); Lohani (1976); Chatterjee and Chaturvedi (1981); Singh *et al*. (1983); Singh and Prasad (1985); Singh and Singh (1986); Sohi (1989), etc. Such reports provide specific information of insect incidences. Large scale defoliation of *P. deltoides* trial plantations (Clones G-3 and G-48, IC-100, 3-4 yrs of age) by *Clostera cupreta* (Butler) and *C. fulgurita* (Walker) was reported from time to time from the Central Tarai region of Uttar Pradesh (Seth, 1969; Lohani, 1976; Chaturvedi, 1981; Singh *et al.,* 1983) . By 1980s, the defoliation outbreak spread over an area of 1,100 ha and became alarming. It had to be supressed by aerial spraying of carbaryl (Sevin) insecticide (Singh *et al.,* 1983; Singh, 1998). This defoliator has now spread through out the region of *P. deltoides* growing. Large scale defoliation by *Clostera* spp. is known to significantly decrease the growth increment of poplar trees (Gao *et al*., 1985). Severe and repeated defoliation in young plants results in mortality (Singh and Singh, 1986).

Severe attack by *Apriona cinerea* Chevrolat (poplar stem borer) was reported in 2-3 yrs old *P. deltoides* plantations, from Paonta Valley in Himachal Pradesh (Verma and Khurana, 1985); Jammu region (Sharma and Bhatia, 1996) and also from other parts of Uttar Pradesh and Haryana (Singh *et al*., 1987). Attack by this borer into the tree bole renders its timber unsuitable for any commercial use, as the entry of fungus and pathogens in the bored galleries also causes discolouration of its wood. It becomes weak, offering little resistance to wind and gets broken by a modest gust. Repeated attacks result in forking of the bole or mortality of tree (Singh and Prasad, 1985).

As many as 133 insect species so far have been recorded by different workers at various locations infesting different poplar species in India

In view of involvement of large number of insect species in different incidences on poplar trees, there was a need to have complete information of various insect species involved in causing multiple injuries to poplars. Few attempts were made in the past to glean information on poplar insects. Mathur and Singh (1960) were the first to list 42 insect species mostly indigenous to India and adjacent countries that caused damage to poplar and its timber in India. Later, Singh and

Singh (1975) listed 17 species as important pests of poplars. Sen-Sarma and Gupta (1979) have reported 33 poplar pests and highlighted the importance of *Apriona cinerea* Chevrolat, *C. cupreta* and *C. fulguritia* in causing major problems. Rishi (1979) identified 32 insect pests from Kashmir Valley pointing out that *Lymantria obfuscate* (Indian gypsy moth) and *Aeolesthes sarta* (Quetta borer – a xylophagous insect) as serious pests of hill poplars. Verma *et al*. (1983) reported 55 insects feeding on poplars in Himachal Pradesh along with information on their nature, extent of damage and control measures. Verma *et al*. (1983) considered 16 species as major or minor pests in various parts of India based on earlier reports Rawat, 1979; Rishi, 1979; Sen-Sarma and Gupta,1979; Singh and Singh,1986, identified 16 insects as important poplar pests from economic point of view in nurseries, plantation and natural stands.

From Punjab, Sohi and Mann (1986) reported a species of leaf hopper, *Kusala salicis* (Cicadelidae) as a new pest of poplars. Sohi *et al*. (1987) had also identified poplar hairy caterpillar, *Clostera restitura* as a major defoliator of poplar in Punjab. Later, Sohi (1989) had listed 26 insects feeding on poplars from northwestern India. Singh (1991) had reported a polyphagous defoliator, *Orgyia postica* as new species defoliating *P. deltoides* in Uttarakhand. Recently, Ahmad and Faisal (2004) have reported caterpilars of *Eupterote undata* (Blanchard) causing defoliation to *P. deltoides* in nursery and plantation in parts of Uttarakhand. Most of such reports are based on limited information involving incidences of attack on poplar of particular location or region or state. In the present report a systematic account of infestation of all insect species on different poplar species reported so far in India is presented.

Insect Pest Spectrum on Poplar

As many as 133 insect species so far have been recorded by different workers at various locations infesting different poplar species in India. Although indigenous poplars are relatively safe from insect attack, exotic species have become soft target for insect infestation. These insects are represented by 42 families belonging to nine orders (Table 1). It includes all categories of pests including stem and shoot borers, defoliators, sap suckers, pests of felled trees and converted timber and termites, etc. Various insect species infesting poplars are systematically arranged order wise to which they belong with the record of infestation on different poplar species. Information is updated with recent findings so as to make a ready reckoner for the use of researchers and field workers.

Coleoptera

Coleoptera forms a potential group of poplar pests as 36 insect species belonging to 8 families including Anthribidae, Buprestidae, Cerambycidae Chrysomelidae, Curculionidae, Lyctidae, Platypodidae and Scarabaeidae, etc. are reported to cause multiple injuries to different poplar species. Most of the species are borers but some are defoliators and also nursery pests.

Anthribidae

Family Anthribidae is represented by *Tropiderinus muneeri* (Bedel) whose larvae bore into the dead wood of *P. euphratica* (Beeson, 1941) causing infestation of moderate intensity.

Buprestidae

There are five buprestid borers recorded infesting poplar especially *P. euphratica*. Among these *Capnodis kashmirensis* Fairmaire and *Chrysobothris femorata* Oliv. are capable of causing considerable injury. Larvae mostly attack poplar which are damaged by wind, sun scaled or by breakage of branches. Larvae cause maximum infestation between the bark and wood, cutting off the flow of sap which results in girdling of the tree (Rishi, 1981). *Capnodis miliaris* klug was first recorded by Mathur and Singh (1960) on *P. euphratica*. It has also been observed infesting *P. alba* and *P. nigra* (Browne, 1968). It is a large black beetle 30 to 40 mm long with a covering of white, powdery deposit. Mathur and Singh (1960) reported infestation on dead wood of poplar by the larvae of unidentified species of *Chrysobothris* sp. Another buprestid beetle *Melanophila picta indica* infests dead wood of *P. euphratica* especially in the month of June (Beeson, 1941).

Cerambycidae

Eleven insect species belonging to family Cerambycidae have so far been found infesting on different species of poplar. While two species are defoliators, remaining nine cause infestation into growing shoots.

***Aeolesthes sarta* Solsky:** It is popularly known as ‘Quetta borer’ is a serious pest. Larvae feed on bark and sapwood and bore in to the stem and branches and make deep tunnels leaving packed dust. Its attack was first recorded by Mathur and Singh (1960) on *P. alba*, *P. euphratica* and *P. nigra*. Attack by this borer recurs for several years in successions, often killing the host by girdling (Browne, 1968). Heavily infested trees dry up in 3-4 yrs. Grub is difficult to control. Poisoning of tunnel gives protection only upto 40 per cent as the tunnel are kept packed with wood dust. Trees weakened either by defoliators’ attack or by repeated lopping of

Table 1. Insect pests of poplar infesting different parts of the tree

Order	Family	Species	Status
Coleoptera	Anthribidae	1. *Tropiderinus muneeri*	Borer of Dead wood
	Buprestidae	2. *Capnodis kashmirensis*	Wood borer
		3. *Chrysobothris femorata*	Wood borer
		4. *Chrysobothris sp.*	Dead wood borer
		5. *Capnodis miliaris*	Wood borer
		6. *Melanophila picta indica*	Dead wood borer
	Cerambycidae	7. *Aeolesthes sarta*	Bark and Sap wood borer
		8. *Apriona cineria*	Stem and root borer
		9. *Batocera rubus*	Stem borer
		10. *B. rufomaculata*	Wood borer
		11. *Glenea maculata*	Defoliator
		12. *G. spilota*	Defoliator
		13. *Purpuricenus indus*	Dead wood borer
		14. *P. wachanrui*	Wood borer
		15. *Saperda calcerata*	Wood borer
		16. *Stromatium barbatum*	Wood borer
		17. *Macrotoma crenata*	Stem borer
	Chrysomelidae	18. *Crysomela populi*	Defoliator
		19. *Plagiodera versicolora*	Defoliator
		20. *Phyllodecta abdominalis*	Defoliator
		21. *Nodostoma watehousei*	Defoliator
	Curculionidae	22. *Myllocerus cardoni*	Defoliator
		23. *M. Pastulatus*	Defoliator
		24. *M. discolor*	Defoliator
		25. *M. discolor uniformis*	Defoliator
	Lyctiidae	26. *Lyctus africanus*	Sap wood borer
	Platypodidae	27. *Crossatarsus wilmot*	Sap wood borer
	Scarabaeidae	28. *Cotinus nitida*	Defoliator
		29. *Hilyotugus holosericeus*	Defoliator
		30. *Melolontha melolontha*	Defoliator
		31. *Oryctus nasicornis*	Defoliator
		32. *Protaetia impavida*	Defoliator
		33. *Oxycetonia versicolor*	Defoliator
		34. *Granida albosparsa*	Defoliator
		35. *Holotrichia longispennis*	Defoliator
		36. *Melolontha furicauda*	Defoliator
Diptera	Agromizidae	37. *Phtomyza sp.*	Leap minor
Heteroptera	Scutelleriadae	38. *Chrysocoris purpurpeus*	Sap sucker
	Pentatomidae	39. *Agnoscelis nubila*	Sap sucker
	Cicadellidae	40. *Kusala salicis*	Sap sucker
Homoptera	Aphidae	41. *Aphis populi*	Defoliator
		42. *Chaitophorus populi*	Defoliator
		43. *C. kapuri*	Defoliator
	Coccidae	44. *Doraphis populi*	Forms black galls
		45. *Pemphigus immunis*	Forms twig galls
		46. *P. bursarius*	Forms twig galls
		47. *P. imaicus*	Forms leaf galls
		48. *Epipemphigus imaicus*	Forms twig galls
		49. *Thecobius sp.*	Defoliator
		50. *Pterocomma sp.*	Defoliator
		51. *Chaitophorus dorocola*	Defoliator
		52. *C. indica*	Defoliator
		53. *C. populeti*	Defoliator
		54. *Eriosoma lanuginosum*	Defoliator

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		55. *Pemphigus kashmiricus*	Forms woody galls on twigs and branches
		56. *P. mordwilkoi*	Forms woody galls on twigs and branches
		57. *P. nainitalensis*	Forms woody galls on twigs and branches
		58. *P. napaeus*	Forms globose unilocular galls on the twigs
		59. *P. spirothecae*	Sap feeder, forms red, yellow or green spiral gall
		60. *Doraphis populi*	Infests arial portion of host
		61. *Pterocomma populifoliae*	Forms black galls
		62. *P. populeum*	
		63. *Tuberolachnus salignus*	Sap sucker
		64. *Tuberolachnus sp.*	Sap sucker
		65. *Pseudococucus sp.*	Sap sucker on stem, branches and twigs
		66. *Pulvinaria vitis*	
		67. *Quadraspidiotus perniciosus*	
	Margarodidae	68. *Drosicha stebbingi*	Sap sucker
		69. *Perisopneumon tamarinda*	
	Psyllidae	70. *Megatrioza hirsuta*	Sap sucker
		71. *Pauracephala speciosa*	Forms open pit galls on leafs
		72. *Phylloplecta sp.*	
		73. *Phylloplecta gardeneri*	Forms flattened, unicellular galls on leafs
		74. *Trioza gardneri*	Sap sucker on leaf causing galls
		75. *Phyllocnistis populella*	Leaf miner
		76. *Tetraneara sp.*	
		77. *Pterocomma populeum*	
		78. *P. populifoliae*	
Hymenoptera	Tenthredinidae	79. *Messa populifiella*	Leaf miner
	Xylocopidae	80. *Xylocopa sp.*	Borer of felled trees
Isoptera	Rhinotermitidae	81. *Coptotermes heimi*	
		82 .*C. kishori*	
		83. *Heterotermes indicola*	
		84. *Odontotermes distans*	
	Termitidae	85. *O. obesus*	
		86. *Microtermes unicolor*	
Lepidoptera	Nymphalidae	87. *Phalanta (Atella) phalanta*	Defoliator
	Cossidae	88. *Zeuzera coffeae*	Stem borer
		89. *Z. oescelli*	Stem borer
	Eupterotidae	90. *Eupterote undata*	Defoliator
	Gelechiidae	91. *Stenolechia sp.*	Skeletoniser and defoliator
	Geometridae	92. *Ascotis selenaria*	Defoliator
		93. *A. infixaria*	Defoliator
		94. *A. selena ria reciprocaria*	Defoliator
	Lasiocampidae	95. *Malacosoma indica*	Defoliator
		96. *M. kashmirica*	Defoliator
	Limacodidae	97. *Cheromettia apicata*	Defoliator
		98. *Thosea cana*	Defoliator
	Lymantriidae	99. *Lymantria dispar*	Defoliator
		100. *L. obfuscata*	Defoliator
		101. *Dasychira dalbergiae*	Defoliator
		102. *Euproctis signata*	Defoliator
		103. *Orgyia postica*	Defoliator

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	Metarbelidae	104. *Indarbela quardinotata*	Defoliator
	Noctuidae	105. *Agrotis sp.*	Defoliator
		106. *Helicoverpa armigera*	Defoliator
		107. *Nycteola reuayana*	Defoliator
		108. *Spodoptera litura*	Defoliator
	Notodontidae	109. *Clostera cupreata*	Defoliator
		110. *C. fulgurita*	Defoliator
		111. *C. retitura*	Defoliator
		112. *Pygaera restitura*	Defoliator
		113. *Neocerura liturata*	Defoliator
	Psychidae	114.*Cryptothelia crameri*	Defoliator
	Pyralidae	115. *Pyralis pictalis*	Defoliator
		116. *Pyrausta dinasalis*	Defoliator
		117. *Sylepta sp.*	Defoliator
	Sesiidae	118. *Aegeria ommatiaeformis*	Wood borer
		119. *Paranthrene tabaniformis*	Wood borer
		120. *P. tabaniformis var. rhingaeformis*	Wood borer
	Sphingidae	121. *Clanidopsis exusta*	Defoliator
		122. *Hyloisus luscitiosa*	Defoliator
		123. *Laothoe (Amorpha) populi*	Defoliator
		124. *Smerinthus ocellatus*	Defoliator
		125. *Pachysphinx modesta*	Defoliator
	Tortricidae	126. *Eucosma glaciata*	Shoot borer
		127. *E. xerophloea*	Defoliator
		128. *Gypsonoma hapalosarca*	Defoliator
		129. *G. riparia*	Defoliator
		130. *Gypsonoma sp.*	Shoot borer
	Arctiidae	131. *Diacrisia indica*	
Orthoptera	Acrididae	132. *Schistocera gregaria*	Defoliator
Thysanoptera	Thirpidae	133. *Scirtothrips dorsalis*	Sap sucker

branches by local people fall an easy prey to this pest (Bhatt and Qadri, 1981) while, healthy trees have been found free from the attack by this pest (Stebbing, 1914). Dark brown or black beetle measures 2.5 to 4 cm in length while full grown larva measures up to 7.5 cm (Bhatt and Qadri, 1981).

***Apriona cineria*:** The stem and root borer is the most common and important species amongst xylophagous insects of poplar specially in north-west India. It attacks wide range of poplar clones and hybrids including *Populus* 'Casale', *P*. 'Robusta', *P. nigra*, *P. x-euramericana*, *P.* 'regenerata' and *P. yunnanensis* (Sen-Sarma and Gupta, 1979). Beetles feed on bark and young shoots while young larva after hatching enters the central pith region of stem and starts tunneling downwards, periodically ejecting the frass outside which is accumulated at the base of the stem. Larva continues tunneling from the stem in to the root and finally adult emerges from a circular hole above the ground level. Life cycle is completed in two years (Chatterjee and Sen-Sarma, 1968). Young plants up to the age of 3 years are more susceptible for its attack while large trees are almost free from *Apriona* attack. Up to 5 per cent young trees were reported severely attacked by this beetle in poplar plantations in sub montane track in Punjab (Sohi, 1990). Attacked trees become weak and are prone to breaking off by wind. Beetle has collateral host plants which include apple, mulberry, fig and willow (Chatterjee *et al*., 1969).

***Batocera rubus* Linnaeus:** It is commonly known as mango stem borer. It is a polyphagous pest infesting mango, jack fruit, rubber and fig trees. Larvae of *B. rubus* have been reported causing considerable damage to *P. x-euramericana* (Choudhary *et al*., 1970). Female lays eggs under the loose or wounded bark of stem or branches. Newly hatched grub with its strong mandibles immediately starts boring into sapwood. Later the developing grubs make galleries in the stem as well as in thinner branches. Beetle emerge through the wide flattened holes in the bark (Choudhary *et al*., 1970).

Although wood dust and excrement are ejected out from the entrance hole, symptoms of the attack are not always very clear. Attacked trees start shedding of the leaves and suddenly collapse due to severe hollowing.

***Batocera rufomaculata* De Geer:** It is a polyphagous pest widely distributed in the Oriental and Madagascar region, the Near East and in Caribbean islands. In Indian subcontinent it has been reported from wide range of dicotyledonous host trees including *Acacia* spp., *Adina cordifolia*, *Albizia lebbek*, *Artocarpus hirsuta*, *A. integra*, *Bombax malabaricum*, *Dalbergia sissoo*, *Ficus* spp., *Morus alba, Shorea robusta,* etc. Its infestation to *P. x- euramericana* was documented in a review on poplar insects (Thakur, 1999).

Glenea maculata* and *G. spilota: These are two cerambycid defoliators of poplars. While *G. maculata* defoliates new flush of poplars in March, *G. spilota* feeds on the foliage of *Populus* '*casale*', *P. deltoides*, *P. nigra* and *P*. 'Robusta' (Sen-Sarma and Gupta, 1979).

***Purpuricenus indus* Semenov:** It is a pest of dead wood. Larvae are reported to bore into heartwood of *P. ciliata* (Mathur and Singh, 1960). Another species *Purpuricenus wachanrui* Levrat (syn. *P. haussknechti* Witte) is reported to breed in *P. ciliata* in Pakistan and is considered to be an important pest. The long horn borer is also distributed in the Near East including Cyprus and eastward to India (Browne, 1968). *Saperda calcerata* (Col.: Cerambycidae) is reported to infest old trees of *P. deltoides* in certain areas of Kashmir Valley (Rishi, 1981). Sapoozing and frass at the base of the tree are indications of the attack.

***Stromatium barbatum* Fab.:** It is a polyphagous pest of timber especially in furniture, wood work in houses, packing cases, doors and windows, etc. About 350 different kinds of wood are attacked by this species (Beeson and Bhatia, 1939). Its infestation to the wood of *P. ciliata* and *P*. *tremula* has been reported by Mathur and Singh (1960). In majority of cases, its damage is manifested after a long time of its infestation due to long larval life.

Macrotoma crenata: It is a polyphagous species infesting *Populus* spp. in India upto 2,000 m in the Himalaya (Singh and Singh, 1986). The beetle is dark brown measuring 28 to 58 mm in length and has rough pitted surface. The grubs bore into the stem and sometimes to trunk, making zigzag tunnels, which are packed with compact mass of fibres and excreta. Emergences of adults take place in July.

Chrysomelidae

There are four species of chrysomelid beetles reported infesting various species of poplar. All the four species are defoliators.

***Chrysomela populi*:** It is one of the major defoliator of poplar and *Salix* in the valley of Kashmir. Its infestation on *P. ciliata* was first reported in India by Beeson (1919). The beetle is prevalent in the forest nurseries in Kashmir where it attacks *Populus* '*Casale*', *P. deltoides*, *P. ciliata*, *P*. *nigra* 'Italica', *P*. 'Robusta', *P*. Reinebeck', *P*. 'Regenerta' and *P*. *alba* (Ahmad and Ashraf, 1981). It defoliates *P*. *yunnanensis* in Kumaon region. Severe defoliation causes die-back in shoots and serious loss in increment.

Plagiodera versicolora: It is commonly called as willow leaf beetle infests foliage of poplars and willows from April to June. A brilliant, bluish green beetle spends winter in adult stage under the bark or in debris near the base of trees. The beetles swarm on the trees in April or May and feed for a short period, skeletonizing the leaves. Female lays irregular masses of eggs on leaves, which hatch in about a week. Larvae feed gregariously on both the surfaces of the leaf. There are at least two generations in a year. Heavily infested trees become entirely brown by September end (Singh and Singh, 1986). *Phyllodecta abdominalis* Baly is reported to cause defoliation to *P*. *ciliata* and *P*. *nigra* (Sen-Sarma and Gupta, 1979). Defoliation to *P. ciliata, P. casale, P. deltoides, P. nigra* and *P.* 'Robusta' by *Nodostoma watehousei* was reported by Mathur and Singh (1960).

Curculionidae

Four curculionid weevils have so far been reported to cause infestation to poplars by way of defoliation. *Myllocerus cardoni* and *M. pastulatus* were observed feeding on the foliage of various clones of *P*. *deltoides* with light to moderate intensity in poplar nurseries in Mala and Campiergang, (U.P.) (Thakur, 1981). *Myllocerus discolor* Boheman, a polyphagous defoliator was reported feeding on poplar leaves by Beeson (1941). Defoliation by its sub species *M*. *discolor uniformis* Marshall, was reported by Mathur and Singh (1960).

Lyctiidae and platypodidae

Lyctus africanus Lense, and *Crossatarsus Wilmot* are the only members of Lyctiidae and Platypodidae, respectively infesting poplars. Beetle and larvae of *L. africanus* bore in the sapwood and (Table 1) damage wood of *P. euphratica* while adults and larvae make small numerous tunnels into the wood of *P. ciliata* (Mathur and Singh, 1960).

Scarabaeidae

Scarabaeidae beetles are polyphagous and form a strong group of nursery pests. While adult beetles defoliate the plants, the larvae which are commonly called chafer grubs, live inside the soil and feed on the roots and its bark. So far, nine species of scarabaeid beetles have been reported infesting different species of poplar in the nurseries. *Cotinus nitida*, *Hilyotrugus holosericeus* Redtenbacher, *Melolontha melolontha* L., *Oryctus nasicornis* Linnaeus and *Protaetia impavida* have been reported infesting poplar nurseries in Kashmir Valley (Rishi, 1981). *Oxycetonia versicolor* Fab. has been reported by Mathur and Singh (1960) as the pest of poplar nurseries. Remaining three species including *Granida albosparsa* Moser, *Holotrichia longipennis* Blanchard and *Melolontha furicauda* Ancey have been reported as the pest of poplar nurseries by Singh and Singh (1986). The chaffer grubs of late have also been recorded attacking young nursery plants during March-April and damage of around 10 per cent plants have been recorded in some nurseries in Uttar Pradesh and Uttarakahnd.

Diptera

Agromizidae

The order Diptera is represented by only one species of leaf miner, *Phytomyza* sp. larvae mines into the upper surface of the leaf. Its infestation was first recorded on different clones of poplar in Dhubri and Calcutta (Vijay Veer and Chandra, 1984). Infestation results in deformation, curling and premature leaf fall.

Heteroptera

Order Heteroptera is represented by its three members including *Chrysocoris purpurpeus* Westwood (Scutelleridae), *Agnoscelis nubila* Fabr. (Pentatomidae) and *Kusala salicis* (Ahmed) (Cicadellidae) (Sohi and Mann, 1986; Tewari, 1993; Roychoudhury *et al*., 1994).

Chrycosocoris purpurpeus: It is a sap sucking bug which has been recorded infesting poplar in a nursery at Jabalpur (M.P.) *Agonoscelis nubila* is widely distributed in many countries including China, Japan, Myanmar, Sri Lanka, etc. Its infestation to poplar has been reported in Karnataka, Kashmir, Arunachal Pradesh, Maharashtra, Tamil Nadu and West Bengal (Tewari, 1993). It passes five generations in a year. Insects suck the sap from foliage and green tender shoots which is harmful especially during dry period in summer. Affected plants show light defoliation and stunting growth of shoots.

Homoptera

About 40 homopteran species so far have been recorded infesting on different poplar plants. Majority of them are aphids while others include membracids, coccids and margarodids.

***Aphis populi* (Aphidae):** *Aphis populi* along with *Chaitophorus populi* was recorded infesting *P. alba* in nurseries and plantation in Kashmir (Rishi, 1981) although *A. populi* was first reported on *P. alba* by Mathur and Singh (1960). Other aphid species *C. kapuri* and *Tetraneara* spp. were reported infesting the stem of *P. ciliata* in Kashmir (Rishi, 1981) while Maity and Chakrabarti (1981) reported *C. kapuri* infesting in cluster on lower and upper surface of poplar leaves in Shimla (H.P.). This species is known from north-west Himalayas. Cocccid type aphid *Doraphis populi* forms coccid black galls on *P. aurea* (Rishi, 1981). At high elevations *Pemphigus immunis* Buckton, *P. bursarius* Linnaeus and *Epipemphigus imaicus* Cholodovsky were reported forming twig galls on *P. nigra* var. Italica, *P. ciliata* and *P. caspica* (Rishi, 1981). Formation of leaf gall by *Pemphigus imaicus* Buckton on *Populus ciliata* and on *P. tremula*, *P. nigra, P.* 'Italica' and *P. caspica* by *Pemphigus immunis* was first reported by Mani (1955) and Mathur and Singh (1960). Infestation of *Thecobius* sp. and *Pterocomma* sp. have also been recorded on poplar at high elevations of Kashmir (Rishi, 1981). *Chaitophorus dorocola* Matsumura was collected from north-east India on poplar (Maity and Chakrabarti, 1981). This species is known to infest *P. maximowiezii* and *P. sieboldi* in Japan (Higuchi, 1972). *Chaitophorus indica* Ghosh has been reported from north-east Himalaya (Maity and Chakrabarti, 1981). It is found in cluster on the undersurface of both young and mature leaves. It has been collected from Darjeeling, Kalimpong, Tashing Durbin and Kamsi (West Bengal) (Chakrabarti, 1977). *Chaitophorus populeti* (Panzer) (syn. *Aphis populeti*) is reported to infest *P. alba* in Kashmir (Maity and Chakrabarti, 1981).

***Eriosoma (Schizoneura) lanuginosum* (Hartig) (syn. *Eriosoma taskhiri*):** This is another aphid reported to infest poplar in Kashmir (Maity and Chakrabarti, 1981). It is distributed in India (Kashmir), Pakistan and Afghanistan (Mani, 1973).

***Pemphigus kashmiricus* Rishi:** It was reported infesting poplar in Kashmir (Rishi, 1979). *Pemphigus mordwilkoi* Cholodovsky and *P. nainitalensis* Cholodovsky are common aphids in Himalayan zone, where they form woody galls on the twigs and branches of *P. ciliata* (Beeson, 1941; Mani, 1955).

***Pemphigus napaeus* Buckton:** This forms globose, unilocular galls on the twigs of *P. ciliata* and *P. euphratica* in Himalayas upto an altitude of 3,000 m or more (Mani, 1955).

***Pemphigus spirothecae* Passerini:** It is a spiral gall aphid, widely distributed in northern India and also in Britain. It feeds on the sap of leaf petioles of *P. nigra* and *P. nigra* var. italica. Its feeding causes the formation of red, yellow or green spiral gall on the infected petiole during the summer months. Infestation of this aphid on *P. nigra* was first recorded by Mathur and Singh (1960). Infestation by *Doraphis populi* (Maskell) to poplar was reported by David *et al.* (1971), (Rishi, 1979) and Maity and Chakrabarti (1981). *Pterocomma populifoliae* (Fitch) has been reported to infest *Populus* sp. in north-east India and also from north-west (Maity and Chakrabarti, 1981). Richards (1967) reported that the species usually infest the aerial portions of its hosts. *Pterocomma populeum* (Kaltenbach) was reported from Kumaon Himalaya (van der Goot, 1916).

***Tuberolachnus salignus* Gmelin (syns: *Cinara saligna, Pteroclorus salignus, Tuberolachnus viminalis*):** It is commonly called as gaint willow aphid; widely distributed in temperate regions of Africa, America, Asia and Europe. A large brown aphid, easily recognized by the presence of a prominent, dark mid-dorsal abdominal tubercle and by a rich pink stain, which is yielded when crushed. It occurs in large colonies, feeding on the sap of stems, branches and twigs. It has been recorded infesting on *P. maximowiezii* and *P. nigra* and some species of *Salix*. Vijay Veer and Chandra (1984) recorded another species of *Tuberolachnus* infesting on some clones *P. deltoides* in Dhubri (Assam). Aphids were found sucking the sap from tender shoots of saplings and plants, which results in die-back of twigs. Aphids infested twigs or shoots become black due to the growth of fungus on honeydew of aphids.

***Pseudococcus* spp. (Coccidae):** This was reported sucking the sap of foliage and branches of *P. euphratica* (Mathur and Singh, 1960). Another coccid *Pulvinaria vitis* (L.) was recorded to infest *P. ciliata* (Sharma and Sharma, 1993) *Quadraspidiotus perniciosus* Comstock is one of the most important polyphagous pests widely distributed throughout India especially in Kashmir infesting poplars and other fruit trees (Singh, 1963; Browne, 1968; Rishi, 1981). Shoots, stem and twigs of young trees are attacked resulting in withering and death of the tree. Its host range encompass about 2,000 hosts plant (Rishi, 1977). *Drosicha stebbingi* Green (Homoptera : Margarodidae) a large scale insect, which is principally a pest of *Magnifera indica* and *Shorea robusta,* but also infests numerous other dicotyledons and occasionally conifers. Its infestation to poplar has been noticed in nurseries (Tewari, 1993).

***Perisopneumon tamarinda* Green (Margarodidae) (syn: Drosichiella tamarinda):** It is a polyphagous mealy bug which feeds on the sap of various dicotyledonous trees including *Populus* sp. Female lays eggs in silken egg-sacs in September, at a depth of about 5 to 15 cm in soil, and hatch following April only. Young nymphs climb on to the host plant to feed. Life cycle is annual (Browne, 1968).

***Megatrioza hirsuta* (Crawford) (Homoptera: Psyllidae):** It is a jumping plant louse which is widely distributed in India. It feeds on the sap of *Terminalia tomentosa* causing distortion to the leaves (Browne, 1968). Tewari (1993) has reported its infestation to poplar. There are two generations in a year. Females of one generation lay eggs in the bark cavities in November which over winter. They hatch in April and nymphs move to young leaves where they feed gregariously and complete the development in June. The adults lay eggs on shoots and leaves and nymphs of this generation feed on the sap of the foliage, becoming adults in November. Feeding causes leaf margins to roll upwards and inwards until they meet at the mid rib and the rolled part become swollen. Incidence of attack on young plants is relatively higher.

***Pauracephala speciosa* (Homoptera: Psyllidae):** It is reported to attack *P. ciliata* in Shimla (H.P.). It forms open pit galls on the leaves which results in curling in case of heavy infestation (Kaul and Sharma, 1982).

***Phylloplecta gardeneri* (Laing) (Homoptera: Psyllidae):** It makes flattened, unicellular galls on the leaves of *P. euphratica,* which are usually separate, yellowish to dark green , smooth and about 5x4 mm in size. A leaf may carry up to 18 galls on both the surfaces. The adults appear with the advent of new foliage in January-February and gall formation starts immediately. One nymph inhabits each gall. Last moulting takes place inside the gall (Beeson, 1941). Another species of *Phylloplecta* makes large globular galls on the twigs of *P. euphratica,* which vary in size up to 12 mm and are formed on the youngest shoot and remain for several years (Beeson, 1941). *Trioza gardneri* Laing is a jumping plant louse which occurs as the minor pest of *P. euphratica*. The adults get active early in the year when new foliage is unfolding (Browne, 1968). Nymphs feed on the sap of leaf causing formation of galls. Family Lithocolletidae is represented by only one insect, *Phyllocnistis populella*

Chambers. It mines the under surface of the poplar leaves causing browning (Rishi, 1981).

Hymenoptera

The order is represented by only two insects. *Messa populifiella* (Tenthredinidae) mine the under surface of poplar leaves causing browning and finally drying while *Xylocopa* sp.(Xylocopidae) bore into the felled trees of poplar (Rishi, 1981).

Isoptera

Six species of termites, five belonging to family Rhinotermitidae and one to family Termitidae represent Isoptera.

***Coptotermes heimi* (Rhinotermitidae):** It is one of the most serious pest, largely responsible for die-back and mortality in some clones of *P. deltoides,* especially 65/27 which was ultimately discarded for planting in Tarai region of Uttar Pradesh (Thakur, 1981). Other rhinotermitid species implicated with the damage in poplars include *Heterotermes indicola, Odontotermes distans* and *O. obesus* (Thakur, 1981). Termites gain entry either through the roots or injured portion of the stem near the ground level. After gaining entry, they start infesting upward and radially in the main bole resulting in hollowing of the tree. Another rhinotermitid, *Coptotermes kishori* Roonwal and Chhotani was recorded infesting poplars in Assam (Berivara) (Vijay Veer and Chandra, 1984). Main root of over 10 per cent plants was found damaged by this species.

***Microtermes unicolor* Snyder (Termitidae):** It was observed to cause extensive damage to IC clone of *P. deltoides* plantation at Bahalpur (Assam) (Vijay Veer and Chandra, 1984).

Lepidoptera

Lepidopterans make an important group of poplar pests. So far 45 lepidopteran insect species have been recorded infesting different species of poplars. Most of them are defoliators, while some are borers, sapsuckers, skeletonisers and nursery pests.

Nymphalidae

Phalanta (Atella) phalanta: It is the common butterfly occurring in fast growing species of poplar especially in Tarai region of Uttarakhand although its infestation was first reported by Rawat (1981). Larvae feed on poplar leaves along with other defoliators.

Cossidae

Family Cossidae is represented by two species including *Zeuzera coffeae* Nietner and *Z. oescelli.* Both the species are borers of poplar trees. The larvae bore into the stem and branches of saplings. The portion of branches above the point of entrance gets dry.

Eupterotidae

Family Eupterotidae is represented by *Eupterote undata.* Larvae are reported infesting the foliage of *P. deltoides* in nursery and plantations (Ahmad and Faisal, 2004)

Gelechiidae

Family Gelechiidae is represented by *Stenolechia* sp. Young larvae are reported to skeletonise and later defoliate *P. euphratica* (Mathur and Singh, 1960).

Geometridae

Family Geometridae is represented by two species and one subspecies. *Ascotis selenaria* Deris and Seliff and *A. infixaria* were reported to cause defoliation to *P. deltoides, P.* 'Casale' and *P.* 'Robusta'. Subspecies, *A. selena ria reciprocaria* Walker was also reported defoliating same species of poplar (Tewari, 1993).

Lasiocampidae

Two species of family Lasiocampidae were reported infesting some species of poplar. *Malacosoma indica* Walker defoliates *P. ciliata* in hilly areas of Uttarakhand and Himachal Pradesh (Singh and Singh, 1986). It is highly polyphagous. Besides poplar, larvae frequently attack *Quercus dilatata, Q. leucotrichophora, Pyrus pashia, Prunus padam,* apple, almond, apricot, cherry, gooseberry, peach, pear, walnut, etc. The caterpillars web a tent like nest at the forking of twigs and hide in the nest while resting. The young larvae- feed on expanding buds while advanced stage larvae congregate on the leaf lamina and feed voraciously. Another species of *Malacosoma*; i.e., *M. kashmirica* was recorded on poplars in the hilly region of Kashmir valley (Rishi, 1981). The larvae are voracious feeders on the foliage leaving behind only mid rib. Its damage on poplar was more pronounced in nursery. Main infestation period was April to June.

Limacodidae

Two defoliating species including *Cheromettia apicata* Moore and *Thosea cana* Walker attack poplars. Caterpillars of these two moths were reported defoliating *Populus* 'Casale', *P. deltoides* and *P.* 'Robusta' (Mathur and Singh, 1960).

Lymantriidae

Larvae of five species belonging to family Lymantriidae were reported to defoliate different species of poplar in India. *Lymantria dispar* Linnaeus (syn. *Protheria dispar)* is commonly known as Gypsy moth. The larvae are polyphagous on the foliage of many broad-leaved plants and also to some extent to conifers. Larvae have been recorded causing defoliation to *P. tremuloides* and *Salix* spp. among other tree species (Browne, 1968). Larvae of *Lymantria obfuscata* Walker have been reported as defoliators of the poplar (Mathur and Singh, 1960). The clusters of larvae of this pest could be seen during daytime on the trunk of poplar during June-July in Kashmir (Rishi, 1981).

Maximum consumption of the foliage by the larvae was observed during dawn and dusk. *Dasychira dalbergiae* was reported as an important defoliator of *Populus* 'Casale', *P. deltoides, P. nigra, P. trichocarpa* and *P.* 'Robusta' (Sen-Sarma and Gupta, 1979). *Euproctis signata,* commonly called as brown tail moth, has been recorded on poplars as a minor pest in Kashmir Valley (Rishi, 1981) although it is primarily a pest of the fruit trees. Larvae feed on tender foliage and buds in May and , continue to skeletonize leaves until late summer. Caterpillars of another lymantriid, *Orgyia postica* were found defoliating poplar specially *P. deltoides* in poplar growing areas in Uttar Pradesh and Uttarakhand (Singh, 1991).

Metarbelidae

Two species belonging to family Metarbelidae were reported to infest poplar. These cause substantial damage to poplars. *Indarbela quardinotata* Walker, a polyphagous species, has been reported attacking branches and shoots of many clones of *P. deltoides* in Dhubri (Assam) and Calcutta (Vijay Veer and Chandra, 1984). Larvae get entry into the branches through snags. Attack reduces the plant vigour. Rawat (1981) reported defoliation to certain clones of *P. deltoides* by *Inderbela* spp. in Tarai region of Uttarakhand.

Noctuidae

Family Noctuidae is represented by four species which are mostly defoliators, however, large scale damage by any noctuid has not so far been reported. *Agrotis* sp. has been reported as minor pest of poplar especially at nursery stage (Rishi, 1981). Mathur and Singh (1960) have reported defoliation of *P. euphratica* and *P. ciliata* by the larvae of *Helicoverpa armigera* and *Nycteola reuayana* Scopuli, respectively. Larvae of *Spodoptera litura* have also been reported defoliating poplar.

Notodontidae

Family Notodontidae is represented by five species. Some representatives are potential pests causing considerable damage to poplar.

Clostera cupreata* (syn. *Pygaera cupreata)* and *C. fulgurita: These are the major defoliators of poplars. Although epidemic defoliation in poplar has been regularly reported in Tarai region of Uttarakhand since 1966 (Seth, 1969), but involvement of *C. cupreata* in large scale infestation was first reported. It defoliates many species of poplars. *P. deltoides* is the most attacked species, which experiences epidemic defoliation almost every year in some locations. It defoliates *P. ciliata* in Jammu and Kashmir (Singh and Singh, 1986). Its attack starts in the month of March-April. The eggs are laid on the leaf surface in-groups of 200-300. It completes its life cycle within 19-20 days. There are 8-9 generations in a year in plains.

C. fulgurita: It attacks several species of poplars including *P. ciliata, P. deltoides, P. nigra* and *P. alba* and some species of willows; i.e., *S. alba, S. babylonica* and *S. tetrasperma. C. cupreata* along with *C. fulgurita* have caused epidemic defoliation to poplar in Tarai region of Uttarakhand, several times since 1966 (Seth, 1969; Lohani, 1976; Singh *et al.,* 1983). Moth starts laying eggs in the month of March - April on the under surface of the leaf. One female deposits 500-700 eggs. There are about 10-12 generations in a year in the plains of North India.

***C.* (syn. *Pygaera) restitura* Walker:** It was reported as the pest of *S. babylonica* (Mathur and Singh, 1960). It has also been reported as the pest of *Populus* sp. and *Salix* sp. in Pakistan (Browne, 1968). Mann (1981) had reported *P. restitura* as the pest of poplar in India. Another two notodontid species including *Neocerura liturata* Walker and *N. wisei* Swinhoe were reported to cause defoliation of *P. ciliata*.

Psychidae

Only one species *Cryptothelia crameri* was reported to defoliate *P. deltoides* and *P.* 'Robusta' (Kaul and Sharma, 1982).

Pyralidae

Three species belonging to this family have been reported as defoliators of poplars. *Pyralis pictalis* Curtis was found defoliating *P. alba* (Mathur and Singh, 1960) while *Pyrausta dinasalis* Walk. defoliates *P. ciliata* and *P. deltoides* (Beeson, 1941; Vijay Veer and Chandra,1984). Another pyralid *Sylepta* sp. has been reported as the defoliator of *P. deltoides* and *P.* 'Robusta' (Kaul and Sharma, 1982).

Sesiidae

Family Sesiidae is represented by three species. All of them are borers to poplar. *Aegeria ommatiaeformis* Moore bores *P. euphratica* and some other species of poplar (Mathur and Singh, 1960).

***Paranthrene tabaniformis* Rottenburg:** It is a pest of some poplar and *Salix* species. Recorded hosts include *P. alba, P. deltoides, P. nigra* and *P. tremula* (Browne, 1968). The adults emerge during mid summer. Eggs are laid singly in the cracks in bark of the tree. The larvae make tunnel in the bark and wood. Heavily infested trees are weakened and rendered liable to wind break. Subspecies, *Paranthrene tabaniformis* var. *rhingaeformis* Hubner has been reported as borer of *P. alba* (Mathur and Singh, 1960).

Sphingidae

It is represented by five insect species including *Clanidopsis exusta* Butler, *Hyloisus luscitiosa* Clemens, *Laothoe (Amorpha) populi* Linn; *Smerinthus ocellatus* Linn. and *Pachysphinx modesta* Harris. Larvae of these species were reported to defoliate poplar species (Mathur and Singh, 1960). Larvae of *L. populi* are solitary feeders, attain a length of about 6.5 cm and become yellowish green when fully grown. The adults usually have a wingspan of about 10 cm (Browne, 1968).

Tortricidae

Five insect species belonging to this family have been recorded infesting poplars. *Eucosma glaciata* Meyrick is commonly called as poplar shoot borer. Mathur and Singh (1960) first recorded its infestation to poplar. It is one of the destructive insects of young poplars particularly in nurseries. Larvae feeding on terminal tissues prevent normal growth and may kill the growing tip, which results in forking. Another species of *Eucosma;* i.e., *E. xerophloea* Meyrick was reported to be the pest of *P. euphratica*. Larvae skeletonise the foliage (Mathur and Singh, 1960). Defoliation of *P. euphratica* by *Gypsonoma* (=Eucosma) *hapalosarca* Meyrick in Punjab was reported by Beeson (1941). Larva of *Gypsonoma riparia* skeletonises and webs together the leaves of *P. euphratica* during July to September (Beeson, 1941). An unidentified species of *Gypsonoma* sp. was reported to make tunnel in shoots and branches of *P. deltoides* (Rishi, 1981). The larvae tunnel in the pith of terminal buds, stunting and distorting the growth and often kill them. Terminal growth is slowed and the trees become forked with heavy branching.

Arctiidae

Larvae of *Diacrisia indica* were reported to defoliate *Populus* 'Casale', *P. deltoides* and *P.* 'Robusta' (Sen-Sarma and Gupta, 1979).

Orthoptera

Nymphs and adult grass hoppers of *Schistocera gregaria* Forskal (Acrididae) feed on the foliage of lower portion of the plants. Its infestation has been recorded on *P. nigra* (Mathur and Singh, 1960).

Thysanoptera

***Scirtothrips dorsalis* Hood (Thirpidae):** It sucks sap resulting in curling and deformation of leaves. It is a minute, yellow colour thrip which attacks young leaves or half-open buds (Vijay Veer and Chandra, 1984).

Management of Poplar Defoliators, *Clostera* spp.

Although over 133 insect species of varying nature of damage have so far been recorded causing infestation to the poplar of different dimensions (Batra, 1960; Chatterji and Thapa, 1964; Singh and Prasad, 1985; Singh and Singh, 1986; Sohi and Mann, 1986; Pruthi and Sohi, 1989; Tewari, 1993). Poplar defoliators, *C. cupreata* and C. *fulgurita* are the two major pests which have often caused severe defoliation to the poplar in main planting areas of northern India (Seth, 1969; Lohani, 1976). Such defoliation in large areas on regular basis adversely affect the growth increment and also reduce the quality of the timber. On few occasions, epidemic defoliation by these insects was suppressed by aerial spraying of insecticides (Singh *et al.,* 1983). Keeping in view the exorbitant expenditure involved in aerial spraying and the quantity of environmental dis-harmony caused by large scale application of chemical insecticides, it was mandatory to explore the avenues other than pesticides' application for effective management of the primary defoliators, *C. cupreata* and *C. fulgurita.*

Realizing the gravity of problem, many workers have attempted to evolve alternate environment friendly methods to contain the problem of defoliation. During present attempt, efforts are made to review all such trials to formulate an integrated approach to contain the problem of insect defoliation in poplar nurseries and plantation.

Surveillance of the Pest Problem

The importance of understanding the extent of insect activity in an area to make decisions in insect pest management cannot be overstated. Indeed, this knowledge is indispensable to the paramount principle of pest management: to take no action against a pest unless that pest is known to be present and posing an actual or potential threat. Such insect activities as forest invasion, long-range migration, local movement, feeding and reproduction are detected and documented through pest surveillance. Pest surveillance is the watch, kept on a pest for the purpose of decision making. Depending on the kind of pest (native, newly introduced, potential invader), surveillance programmes attempt to estimate the numbers in a population and their distribution, and to assess how these factors change over time. More succinctly stated, the major objectives of surveillance are detection of species presence and determination of population density, dispersion, and dynamics.

Besides institutes of ICFRE, forest departments, farmers raising poplar plantations, NGOs involved in research on poplars and other institutions/companies promoting poplar planting are the agencies conducting surveillance of such nature. An insect pest survey is a detailed collection of insect population information at a particular time in a given area. The survey programme may be carried out for an entire growing season or at certain critical period in the insect life cycle. Surveys may be classified as 'qualitative' or 'quantitative'. Qualitative surveys are the least complex and are generally aimed at pest detection. Usually, qualitative surveys yield lists of pests species discovered, along with a subjective reference to density, for example, abundant, common, rare, etc. Quantitative surveys are the most common type employed in insect pest management. The quantitative survey attempts to define numerically the abundance of an insect population in time and space. Such information is used to predict future population trends and to assess potentialities of the pest population. To collect information in the quantitative survey, a count of insects or a measure of their presence is required. Because of the great number and/or secretive nature of many insects, it is not feasible or even desirable to take a census to count every individual in the population. Instead, it is usually more efficient to estimate population density by sampling.

Success of any pest management programme is largely dependent upon proper and regular surveillance and monitoring the pest situation. It is necessary to monitor the pest problem and record the population trends of pest as well as its natural enemies. Changes in pest distribution and its abundance and the influence of biotic and abiotic factors on pest population would greatly help in adopting proper control strategy. Regular surveillance of the pest situation would further help to evaluate the pest and parasitoid composition in the field which in turn provides suitable data for forecasting the future level of pest population besides marking the appropriate time for field release, etc.

Utilisation of Relative Natural Insect Resistance in Poplar

Host plant resistance refers to the heritable qualities of a cultivar to counteract the activities of insects so as to cause minimum per cent reduction in yield as compared to other cultivars of same species under similar conditions (Dhaliwal *et al.*, 1993). Snelling (1941) defined plant resistance as those characters that enable a plant to avoid, tolerate or recover from attacks of insects under conditions that would cause greater injury to other plants of the same species. Resistance to insect is the inheritable property as perceived by Kogan (1982) that enables a plant to inhibit the growth of insect populations. 'Relative insect resistance' can be assessed by the following characters:

1. It is heritable and controlled by one or more major genes.
2. It is relative and can be measured by comparing with other cultivars of the same species.
3. It is measurable quantitatively as well as qualitatively.
4. It is variable and can be modified by abiotic and biotic factors.

Ahmad (1993) had tested 109 clones of *P. deltoides* belonging to Europe, America, Australia, United Kingdom and Turkey for determining the presence of relative resistance to the primary defoliator of poplar, *C. cupreata.* Critical difference in mean leaf area of different clones consumed by the larvae was made the basis for evaluation. Resistant clones were grouped as 'most resistant' (R1) 'resistant' (R2), and 'moderately resistant' (R3), while susceptible clones as Sl, S2 and S3 on the basis of weightage percentage of resistance/ susceptibility. Clone 67 of USA/Alabama (33^{o} N lat.) was found to be most resistant clone with weightage percentage of resistance as 100 followed by A 37 T 100 of FGR / Alabama (USA) and S1'92 of USA (Stoneville). 109 clones were placed into six homogenous groups of 13, 26, 19, 24, 14, and 13 in different categories as R1, R2, R3, Sl, S2 and S3, respectively. Clone 100 of USA (34^{o}N lat.) was judged as most susceptible followed by 2498 of Netherlands/Illinois and S7C20 Stoneville, USA.

Plant resistance has many advantages as a primary tactic in insect pest management strategies. Among all the important parameters or factors are effectiveness, selectivity against the pest, relatively long stability, compatibility with other tactics, and human and environmental safety. In addition, resistant varieties can be adopted into tree protection schemes easily and economically, resulting in both short-term and long-term gains. Although, the gains of developing and using resistant plants far outweigh the disadvantages, the most important limitations of the approach include time required for development and problems with biotypes. Biotypes are sure to develop over a period of time. To avoid/cope with this, vertical resistance should be avoided and polygenic resistance must be encouraged. Regular testing is therefore necessary to introduce/replace the resistant variety with the latest highest resistant variety at an appropriate time.

Resistance or susceptibility of plants to the insect is the result of a series of interactions between plants and insects which influence the ultimate degree of establishment of insect populations on plants (Saxena and Pathak, 1979; Saxena, 1986). The factors which determine insect establishment on plants can be categorised into two groups: (1) Insect responses to plants, and (2) Plant characters influencing insect responses. The insect responses include orientations, feeding, metabolic utilisation of ingested food, growth of larvae to adult stage, adult longevity, egg production, oviposition and hatching of eggs. Unfavourable biophysical or biochemical plant characters may interrupt one or more of these insect respnoses inhibiting establishment of an insect population on a plant and rendering it resistant to infestation and injury. This is a field which may be worked out separately for each plant species to ascertain the definite factors responsible for relative insect resistance.

Use of Biopesticides/Antifeedants

Much before the advent of synthetic organic insecticides various botanical pesticides including neem, bakain, pyrethrum, rotenone, nicotine, etc. were being used to suppress the pests of agriculture in different parts of the world. It is estimated that there are about 500,000 different plant species present globally. Most of these plants contain bioactive organic chemicals. However, only 10 per cent of these plants have so far been examined for their pesticidal property (Benner, 1993).

Since the realization of remarkable insecticidal properties of plant species like *Chrysanthemum* sp. (Family: Compositae), a new era was opened and Pyrethrum was used extensively for the control of various insect pests in different parts of the world (Russell and Knipe, 1941; Senior White, 1945; Muirhead-Thomson, 1948). Other prominent plant species and their products which were in use include *Tephrosia* sp. (Barnes and Freyre, 1966), *Derris* sp., *Nicotiana* sp., Citronella oil, *Eucalyptus* oil, etc. (Curtis, 1990).

Insecticidal properties of root and bark extracts of *Dalbergia stipulacea* in acetone and in alcohol and n- butanol soluble portion of alcohol extract of *Adina cordifolia* leaves were tested against poplar defoliator, *C. cupreata.* N-butanol soluble fraction of leaves extracts of *A. cordifolia* was found to be most effective against the larvae as it gave 19.99, 18.56 and 10.60 average mortality out of 20 larvae at 2.0, 1.0 and 0.5 per cent concentrations, respectively. It is closely followed by bark and root extracts of *D. stipulacea* in acetone proved to be least effective among the five extractives tested. Alcohol seems to be better solvent in extracting active ingredient from root and bark of *D. stipulacea* as in both cases alcohol extract was remarkably more effective than that of acetone extractives (Ahmad *et al.,* 1996a).

A number of plant species have also been evaluated for their antifeedant properties against poplar defoliators. Acetone and alcohol extracts of bark and roots of *D. stipulacea,* leaves of *Eucalyptus* hybrid and *Adina cordifolia* along with ursolic acid and bryonolic acid were evaluated for their antifeedant potential against *C. cuperata.* Ursolic acid (separated from *Eucalyptus* hybrid leaves extract) has shown maximum antifeedant activity and gave over ninety two per cent protection of poplar leaves from its pests (Ahmad *et al.,* 1997b).

Bhandari *et al.* (1988) tested neem seed extractives on poplar defoliator, *C.cupreata* in laboratory. Neem seed extraction in various solvents such as acetone, chloroform, ethanol and methanol was attempted and the crude extracts thus obtained, were tried against larvae of poplar defoliator, *C. cupreata* Butler. Of all the extractives, the one obtained in methanol was found to exhibit a very high degree of antifeedant property at 0.125 and 0.025 per cent dilution, respectively. Seed extractives of bhekal *(Prinsepia utilis)* were also tested against poplar defoliator, *C. cupreata* for antifeedant properties. The extractive showed good biological activity at 0.25 per cent dilution against the third instar larvae of *C. cupreata.*

Use of botanical pesticides is flourishing rapidly but with certain limitations. Limited commercial availability, comparatively higher cost and fast deactivation under field conditions are some of the constraints for their large scale use on long term basis.

Biological Control

Biological control of an insect pest is the device to suppress its population by employing its own natural enemies which may be parasitoides, predators or disease causing organisms, including bacteria, viruses, fungal pathogens or nematodes.

Parasitoids

Use of parasitoids is gaining immense importance in biological control programme. They provide cost effective, environment friendly and biodiversity promotive way of controlling pests on sustainable basis. In a biocontrol programme of defoliators, a strategy can be formulated to explore the possibility of utilization of some exotic parasitoid species as well as to find out if natural enemy complex indigenously associated with the poplar defoliators are compatible to tackle the massive defoliation problem.

In an effort to evaluate the efficiency of exotic parasitoids, seven species of egg parasitoids, *Trichogramma,* viz., *T. achaeae, T. confusum, T. chilonis, T. exiguun, T. japonicum, T. perkensi* and *T. pretiosum* were evaluated for parasitization against the eggs of poplar defoliator, *Clostera cupreata.* All *Trichogramma* species except *T. confusum* and *T. japonicum* were found to cause appreciable degree of parasitization to the eggs of *C. cupreata.* Higher parasitisation of 64.80 and 64.40 per cent was produced by *T. perkensi* and *T. achaeae* respectively, closely followed by *T. chilonis, T. pretiosum* and *T. exiguum* with 58.40, 54.20 and 52.40 per cent parasitization, respectively. However, *T. japonicum* did not accept the eggs of poplar defoliators even after repeated efforts with many pairs of parasitoids. Biology of the parasitoids was also studied in their new host. Effect of varying temperatures was seen on their life cycle and parasitization capability. The studies showed that all the six species of *Trichogramma* successfully completed their life cycle in the eggs of *C. cupreata* taking a period of 8 to 10 days. *T. achaeae* took comparatively less time (8.2 days) followed by 8.40, 8.60, 8.80 and 9.20 days taken by *T. exiguum, T. chilonis, T. pretiosum, and T. perkensi,* respectively. Low temperature conditions considerably extended the time period of parasitoids' development but does not affect their reproductive potential. Fresh eggs of the host were found most suitable for the acceptance by the parasitoids (Ahmad, 1992).

Efforts have been made to explore the natural enemy complex indigenously associated with the poplar defoliators. Extensive regular surveys were conducted over the years to the main poplar growing area in northern India including Tarai region of Uttarakhand, Uttar Pradesh and Haryana to collect regular monthly samples. These surveys yielded rich parasitoids and predator fauna associated with the defoliators. Four egg parasitoids; i.e., *Telenomus colemani, Trichogramma chilonis, Ooencyrtus Iucina* and *Pediobius* sp.; three larval parasitoids, *AIeiodes percurrens, EupIemus* sp. and one unidentified Ichmeumonid and two pupal parasitoids; i.e., *Brachymeria euploeae* and *Brachymeria* sp. were recorded parasitising on *C. cupreata.* Six parasitoid species including *Teienomus colemani, Trichogramma chilonis, Pediobius* sp., *Aleiodes percurrens, Eupelmus* sp. and *Brachymeria* sp. were recorded for the first time (Ahmad *et al.,* 1997a). While parasitising capability of *Pediobius* is yet to be confirmed, *T. colemani* seems to be a promising parasitoid species. Presence of *T. colemani* in the field was relatively common and has also been reared in the laboratory on its natural host.

Among three larval parasitoids, *A. percurrens* was common on both defoliating species; i.e., *C. cupreata* and *C. fulgurita* although in low percentage ranging 2-9 per cent. The species was successfully reared in the laboratory on both the host larvae. *A. percurrens* presents sufficient scope for its exploitation as a biocontrol agent for the control of poplar defoliators. Other two larval parasitoid species were very scanty and require detail study before arriving at any conclusion regarding their status as the biocontrol agents.

Two chalcidid species, *Brachymeria euploeae* and *Brachymeria* sp. were recorded as pupal parasitoids. Their presence in the field was very rare and insufficient for conducting laboratory experiments. The parasitoids might prove promising for exploitation as biocontrol agents in view of their capability of parasitizing last stage of the larva and also pupa. The parasitized pupae are easy to handle and also to transport.

The above findings indicate sufficient scope for detail study in respect of a number of parasitoids as promising bio-control agents which later can be attempted for mass rearing.

Predators

Canthecona furcellata, although a polyphagous species, has frequently been observed in poplar nurseries and plantations throughout growing season along with the presence of defoliator's larvae. Although population of the bug is much lower than the *Clostera* larvae, but it is higher than other predators including some species of preying mantids present in the poplar nurseries and plantation. Bug has often been observed preying on the *Clostera* larvae in the field despite the presence of other defoliating larvae including pyralids, geometrids, lymantrids, etc. This indicates its predatory preference towards *Clostera* larvae.

Detailed study was conducted on preying potential of different nymphal instars, as well as adult, against the larvae of *C. cupreata.* Except first instar nymphs all remaining nymphal instars and adult are predaceous on *C. cupreata* larvae. A bug during its whole development and adult period consume on an average number of 159.98 second instar larvae or 115.74, 89.68 or 86.535 larvae belonging to third, fourth or fifth instar, respectively (Ahmad *et al.,* 1996b). Bug can easily be reared in the laboratory on the larvae of *Clostera* spp. as well as on other insects. *Sycanus collaris* Fabr. (Hemi: Reduviidae) was also recorded preying on *Clostera* spp. (Singh, 1998).

Pathogenic Micro-Organisms

Use of micro-organisms for the suppression of pest problem is gaining prominence in view of adverse impact of pesticides to the environment. Natural epizootic occurs among the immature stages of *C. fulgurita* and the pathogen has also been isolated from the diseased larvae (Sen Sarma and Ahmad, 1984). Disease pathogen was found to be NPV of sub group A of the genus *Baculovirus* which is claimed to be host specific. The disease was characterised by colour change and rapid disintegration of the infected larvae. The number of polyhedral inclusion bodies (PIBs) per larva ranged from 0.37 x 109 to 2.92 x 109. Artificial infection of the disease to the healthy larvae could be achieved by feeding them with poplar leaves sprayed with crude suspension of NPV. Cross infectivity tests confirmed the host specificity of the pathogen. The natural incidence of the disease among the laboratory breed larvae was 42.7 ± 7.7 per cent (Ahmad and Sen Sarma, 1983). NPV has also been observed infecting the larvae of prime defoliator of poplar, *C. cupreata* in the field as well as in the laboratory culture of the insect (Ahmad *et al.,* 1998). It indicates variable infecting behaviour of the virus causing concern to its host specificity. Studies on various aspects of NPV from its infectivity to host range, intensity of infection and variability of conditioning are important areas which need further investigations to confirm its host range and to develop techniques for culture preservation and field application.

Integrated Insect Pest Management

IPM programme is a comprehensive system that utilises all suitable techniques and methods of pest prevention and suppression to maintain pest population below economic injury level. Thus, an IPM programme must be planned along with the establishment of the plantation and to continue till the felling. Mathur (1977) had emphasised the integrated approach of various control methods to contain the insect problems in various tree species and summarised a few examples including management of sal heart wood borer, *Hoplocerambyx spinicornis,* teak skeletoniser, *Eutectona machaeralis,* teak defoliator, *Hyblaea puera* and deodar defoliator, *Ectropis deodare.* His main emphasis was to integrate mechanical approach with the use of pesticides. He also advocated the introduction of parasitoids and predator species. Epidemics of the major insect species of important tree species are still occurring periodically. Such incidences are suggestive of some gap in the adoption of integrated approach and necessitate alternate methods and combination of devices. In spite of our knowledge of various effective approaches of pest control, epidemic insect outbreak is dependently controlled by the large scale application of insecticides in the name of modern fourth generation pesticides. Epidemics of teak and deodar defoliators were controlled by aerial spraying of insecticides (Singh, 1980; Singh *et al.,* 1989). Sal heartwood borer has caused phenomenal epidemic in recent past in Madhya Pradesh contributing to a national loss which runs in millions of rupees.

Such instances might not be interpreted as failure of IPM programme. In fact, it should be attributed to the negligence, ignorance, poor planning and lack of perception. Non toxic approaches as has been detailed above are of sufficient potentiality to contain any pest outbreak. IPM is required to be perceived in its true sense. It emphasizes the need to have complete knowledge of the pests' bio-ecology as has been lettered with surveillance, and the complexity of the situation which warrant adoption of specific measure. Such strategy, if followed on sustainable basis, would not allow the pest to rise beyond the economic threshold level.

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Studies on Wood Quality of Poplar

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Introduction

Poplar (*Populus deltoides*) is an extensively planted agroforestry tree species in northern India. Its wood for industrial and domestic use is available from Jammu and Kashmir, Himachal Pradesh, Punjab, Haryana, Uttarakhand and Uttar Pradesh. After eucalypts, poplar is the major source of woody raw material from plantations. Research organisations in India have been working on its utilisation aspects and have generated voluminous data, ranging from strength properties to seasoning behaviour, preservation, ammonia fumigation, wood working and finishing qualities in addition to peeling characteristics and manufacture of panel products. The species is the main source of raw material from trees outside forests in northern India. *P. ciliata* is found and mainly grown in hilly tracts of Jammu and Kashmir, Himachal Pradesh and Uttarakhand.

Physical and Mechanical Properties

Poplar has been explored for its material characteristics and utilisation aspects for various end use suitability

The first ever article on strength properties of three *Populus* species was published by Shukla and Sangal (1986). Preliminary strength data generated on three logs of *P. deltoides;* 2 logs each of *P. casale* and *P. heidmij* were reported in this paper. Shukla *et al*. (1989) reported physical and mechanical properties of *P. ciliata* timber obtained from Theog Division, Himachal Pradesh. Later on, as more and more material became available for commercial exploitation, a need was felt to generate more information on its properties and end utilization. Timber testing work started on a larger scale to assess the wood quality of material from various sources including clones. Series of research articles were published by various researchers on *P. deltoides*: Shukla *et al.* (1990) on strength properties of 16-yr old IC clone; density and strength properties variation from pith to periphery in 15-yr old by Shukla *et al.* (1991); bottom to top variation of strength properties in 10-yr old G3 clones by Shukla *et al.* (1995-96); Shukla and Singh (1995) tested 10-yr and 15-yr old *P. deltoides* from Dehradun and Haryana. Shukla *et al.* (1996) studied the effect of different preservative formulations/retention on strength properties of *P. deltoides*. Rajput (1996) brought out a comprehensive review on the work carried out on the utilisation aspects of *P. deltoides* timber till 1996. Dubey *et al*.

(1997) utilised non-destructive vibration test method for estimating modulus of elasticity of *P. deltoides* timber.

Tree improvement by way of clone development and assessing their quality for utilization was seriously taken up at FRI laboratory. Era after 1997 was marked with the studies devoted to characterisation of poplar clones. In this series Rajput *et al.* (1997) published on specific gravity and compressive strength variation in $7^{1/2}$-yr old 20 clones developed by M/s Wimco Seedling Ltd., Rudrapur and Shukla *et al.* (2000) published strength data on the same clones; Jain and Khanduri (2003) reported strength data on six clones of 10-yr old and subsequently Kothiyal *et al.* (2005) reported strength data on 10-yr old 12 clones.

As on today strength data on 20 clones (two tree each) of $7^{1/2}$ -yr old (G-48, G-3, S7C13, St-63, St-240, S7C3, 111412, St-121, 3650, St-288, St-153, St-100, St-71, 110610, 111234, 112107, St-163, 6238, 110412); five logs of 16-yr old IC clone; six clones (two tree each) of 10-yr old (D121, G3, G48, S7 C4, S7 C15, S7 C20); 12 clones (one tree each) of 10-yr age (L12/82, L13/82, L34/82, L49/82, L52/82, L62/84, L71/84, L75/84, L188/84, L200/84, L247/84, L290/84) have been generated. Clones G3 and G48 have been studied in two age groups; i.e., 7 and 10 years, Table 1 depicts the range (maximum and minimum) of values of strength properties obtained for all the material studies in India both in green and air-dry conditions. It is quite evident that there is wide variation in strength properties, which can be gainfully utilized. Physical and mechanical properties of some of the best performing and worst performing clones (in terms of strength properties) in green condition is also given in Table 1. From the strength data, it is evident that strength properties of material grown at Rudrapur are better than the one from Haldwani (e.g. Clone G3 and G48). Overall, at Haldwani, S7C4 has performed better followed by G48 and L 290/84 whereas L75/84 and IC are worst performing in terms of strength properties. Overall taking poplar from both the locations together, it is clear that clone S7C3 from Rudrapur has given the best properties, highest specific gravity and low FSP. This is followed by S7C4, which is having low specific gravity but higher strength. These two clones are followed by St-63, G3 and G48. L75/84 and IC are poorest in strength. Among the clones studied, further multiplication trials of S7C3, S7C4, St-63, G3 and G 48 along with assessment of wood quality need to be done.

Table 1. Physical and mechanical properties of *P. deltoides*

Property	Green condition	Air-dry condition	S7C3	St 63	G3		G48		S7C4	L290/84	L71/84	L13/82	St-240	L75/84	IC
Place			R	R	R	H	R	H	H	H	H	H	R	H	H
Age (Yr)			7	7	7	10	7	10	10	10	10	10	7	10	16
No of logs/tree			2	2	2	2	2	2	2	1	1	1	2	1	5
Specific gravity	0.355-0.511	0.381-0.528	0.511	0.448	0.433	0.362	0.442	0.405	0.410	0.422	0.392	0.397	0.408	0.355	0.398
Weight (kg/mm^3)	697-976	427-605	929	955	952	853	914	814	828	834	766	940	829	848	976
Shrinkage (%)															
Radial	3.4-5.9		5.3	4.7	3.6		4.8		-				4.2		5.0
Tangential	7.3-10.3		9.1	9.8	8.6		10.3		-				9.7		7.8
End	11.9-12.9								-						
FS Point (% mc)	24.3-33.4		26.8		29.9		30.0						32.3		26.8
Static bending															
FS at EL (kg/cm^2)	132-346	162-439	315	296	260	132	268	219	295	249	198	181	228	140	220
MOR (kg/cm^2)	249-636	257-859	636	537	448	297	460	389	406	437	370	331	386	249	341
MOE (10^3kg/cm^2)	17.1-98.9	44.0-112.8	98.3	71.7	59.9	54.1	67.1	62.9	90.7	63.5	30.0	33.6	49.7	17.1	46.0
Impact bending:															
FS at EL (kg/cm^2)	287-701	295-932	744	636	557	484	596	596	701	464	447	445	503	349	390
MOE (10^3kg/cm^2)	26.9-111.4	39.6-138	98.5	74.1	58.2	47.4	74.1	71.7	73.0	37.2	51.2	32	61.8	26.9	34.4
Compression// to grain															
CS at EL (kg/cm^2)	38-214	94-219	201	145	113	84	140	131	155	55	153	81	153	38	
MCS (kg/cm^2)	62-297	164-458	297	251	179	134	205	198	219	94	189	120	193	62	171
Compression ⊥ to grain															
CS at EL (kg/cm^2)	15-48	28-79	37	48	38	20	41	31	35	29	25	32	28	20	15
Hardness, kg															
Radial	195-372	150-460	310	372	302	214	286	274	259	203	242	228	260	199	195
Tangential	183-382	172-524	325	382	341	221	323	280	277	199	253	217	264	207	183
End	175-393	182-552	351	393	299	238	299	280	284	231	251	175	270	203	182
Shear // to grain															
Radial, (kg/cm^2)	25.1-74.4	39.9-110.3	74.4	65.7	57.5	44.5	63.5	62.6	64.5	29.4	48.8	28	50.1	25.1	52.5
Tangential, (kg/cm^2)	25-1.8.06	52.0-99.0	84.8	68.5	60.1	44.7	67.3	70.8	66.9	32.0	60.5	28.1	59.8	25.1	54.8
Tension // to grain															
TS at EL (kg/cm^2)	179-411	679	-												282
MTS (kg/cm^2)	512-685	730	-												512
MOE (kg/cm^2)	45.3-57	80.1	-												55.3
Tension ⊥ to grain															
Radial (kg/cm^2)	13.0-36-9	16.7-45.8	26.1	27.5	25.1	18.0	36.9	20.8	20.8	19.2	15.6	13.5	15.2	14.1	16.3
Tangential(kg/cm^2)	13.3-42.1	20.4-55.7	34.3	32.4	32.8	20.7	42.1	23.1	23.1	19.5	19.2	17.5	15.9	18.0	15.4
Cleavage															
Radial (kg/cm)	25.5-48	43.6-72.5	49.9	48	46.0	44.4	41.8	46.2	46.2	37.9	40.6	37.8	39.5	27.8	
Tangential (kg/cm)	29.4-43	42.9-87.0	52.8	43	43.5	46.2	46.2	42.6	42.6	40.6	41.8	41.7	45.0	35.7	

FSP- Fibre saturation point; H- Haldwani, R- Rudrapur.

Wood Working and Carving Quality of Poplar

Working and carving qualities play a vital role in the judicious utilisation of timbers which vary in anatomical features, physical and mechanical properties, durability, seasoning behaviour and other characteristics for furniture, joinery, turning, handicraft, etc. FRI has evaluated the working and carving qualities (Table 2 and 3) for *P. deltoides* and *P. ciliata* (Shukla *et al*., 1991). The working qualities are reviewed under six major wood working operations namely planning, boring, mortising, shaping, turning and sanding. Carving behaviour of wood is evaluated under punching, chiselling, fret saw work and scooping.

Staining Poplar (*P. deltoides*) Using Ammonia Fumigation and Bark Extract

Work has been carried out on wood staining trials conducted on pre-finished surface of plain looking *P. deltoides* timber using aqueous bark extract of *Terminalia alata* as staining material (Badoni *et al.*, 1990). It was observed that dip treatments (0.5 to 120 hr) stain the pre-finished surface of *P. deltoides* in reddish brown shades in varying degree with prominent surface figure. Ammonia fuming of stained specimens further darkens the wood to blackish brown shades.

Out of the various combinations tried, pre-ammonia fuming (12 hr) followed by swabbing/spraying/short interval dipping in the bark extract was found very effective in achieving golden brown shades and prominent surface figure near to the natural look of teak (*Tectona grandis*). Gupta *et al.* (2007) conducted some experiments on gloss and ammonia fumigation film forming and penetrating types of finishes on poplar surface.

Timber Drying

One of the major problems encountered in utilization of plantation grown poplar is that during sawing, with release of stresses a large proportion of this material is prone to severe distortion coupled with warping during seasoning due to low resistance of planks to drying stresses. When logs are sawn by conventional Cant method to get the desired size of planks, growth stresses cause crook to occur at the headrig. Further, additional crook develops in drying because of non-uniform longitudinal shrinkage and the inherent low resistance of planks to the drying stresses. Studies on air and kiln drying behaviour of *P. deltoides* revealed that though it is not difficult to dry the material, and is prone to severe distortion. The major defects observed in all seasoning are bow, crook, honeycombing. In conventional kiln seasoning also, as per the usual schedule, the species has shown severe bow, spring and twist. Hardly any plank was free from warping degrade of one kind or the other. In addition, several planks developed moderate to severe collapse. Planks free from collapse or having slight collapse belonged to outer positions in the log. However, a reconditioning treatment for 6 hr showed appreciable recovery in the collapse. The values of degrade observed in one of the kiln drying experiments were recorded and are presented here in Table 4 along with permissible values to demonstrate the ineffectiveness of conventional seasoning method for this species (Pandey and Kambo, 1991).

The study was undertaken to estimate the distortion due to growth strains in logs of this species based on diametric slabs sawn out of the log. The maximum values of peripheral tension and compression strains recorded on diametric slabs (Sharma *et al.*, 1990) taken from three consecutive bolts of a single log of *P. deltoides* are given in Table 5. Corresponding values recorded for eucalypts hybrid in the earlier study are also detailed for comparison.

The strains are larger in magnitude both in tension and compression than in eucalypts hybrid. The wood is much weaker than eucalypts hybrid and a given stress in it is expected to be associated with larger strains. There is no indication

Table 2. Working qualities of some Indian timbers

Species	Specific gravity	Best cutting angle in planning (°)	Overall performance (CRF)	Ease of working (ease factor)	Working quality index	Grouping based on overall performance	Comparative performance (turning)
Tectona grandis	0.57	25	100	100	100	I	100
P. deltoides	0.55	20	39	119	94	II	10
P. ciliata	0.40	15	42	117	92	III	52

Table 3. Data on carving quality of some timbers taking teak as hundred

Species	Specific gravity	Overall comparative performance under combined wood working operations	Overall comparative performance under carving operations	Carving quality index
T. grandis	0.556	100	100	100
P. deltoides	0.550	39	39	52
P. ciliata	0.400	42	39	52

Table 4. Observed vs permissible degrade of different kinds over length of 215 cm *during kiln drying

Type of degrade	Extent of degrade and (No. of planks)		Permissible
	In sawing	After kiln drying	
Bow	7-8 mm (2) 3-5 mm (5) Nil (5)	16 mm (2) 8-11 mm (6) 3 mm and below (4)	8 mm
Spring	Not recorded	15-18 mm (3) 10-11 mm (4) 3 mm and below (5)	10 mm
Twist	Nil (12)	20 mm (1) 10-12 mm (5) 4-6 mm (2) 4 mm and below (4)	63 mm
Cup	Nil (12)	4-5 mm (3) 2-5 mm (2) Nil (7)	2.54 mm

* Estimated on proportional basis from permissible norms for 300 cm length

Table 5. Maximum peripheral tensile strains and interior compressive strains (μE) in diametral slabs cut out of 3 consecutive bolts from a log of *P. deltoides*

Bolt no.	Mode of sawing of strips	Max. strains ($\mu E = 10^{-6}$ m/m)	
		Peripheral tensile	Interior compressive
1.	Serially cut		
	First radial half of slab	388	610
	Second radial half of slab	290	312
2.	Serially cut		
	First radial half of slab	-	-
	Second radial half of slab	406	810
3	Balanced tangentially sawn		
	First radial half of slab	260	652
	Second radial half of slab	432	652
	Eucalyptus hybrid		
	Serially cut		
	First radial half of 3 slab	100-296	272-316
	Balanced tangentially cut	298-328	116-186

from this preliminary test that balanced tangential sawing would reduce the level of strains in compression or in tension compared to the strains obtained in serial cutting of strips. This is at variance with the observations made on eucalypts hybrid in which balanced tangential sawing appreciably reduced compressive strains compared to serial cutting. This preliminary investigation suggests that radial or balanced tangential sawing as adopted for eucalypts hybrid can not be of utility in case of *P. deltoides* and modified sawing and drying techniques need to be evolved for this species to minimize growth stress induced warping problems. To overcome this problem, the Forest Research Institute, Dehradun has now developed a system of sawn wood manufacturing process known as saw dry rip (SDR).

The saw-dry-rip (SDR) system for sawn wood manufacture was developed at Forest Products Laboratory, USA in 1978, for use with hardwoods, which generally have longitudinal growth stress problems. The technique aimed to control excessive warping in sawn timbers, which had to a great extent restricted low and medium density hardwoods from being used in the manufacture of structural lumber on commercial scale. In India saw-dry-rip technique was successfully applied to *Eucalyptus* logs and the same was used in *P. deltoides* (Pandey and Kambo, 1993). In this study comparison of four sawing and drying treatments were made by evaluating warp (crook, bow and twist) based on the permissible limit at 12 per cent moisture content. The combination of SDR high temperature drying treatment produced the best result as the per cent of rejects of scantlings was found to be 5-8 per cent in comparison to other treatments where rejection ranged from 20-57 per cent. In this method first the logs are sawn in thick section slabs keeping the thickness of slabs equal to the width of desired ultimate planks. These slabs are then rough edged and are dried under high temperature as per schedule given below (Table 6). The slabs thus dried are ripped into planks of desired width (Pandey and Kambo, 1993). Pandey (1995) carried out studies on bulk flow and diffusion of moisture in *Eucalyptus tereticornis* and *P. deltoides* for predicting drying rate. Kishan Kumar *et al.* (2008) conducted vacuum press drying studies on *P. deltoides* and concluded that the timber can be successfully dried with considerable reduction in drying time.

When the material is dried at high temperature, it is theorised that the lignin, which naturally bonds fibers together is plasticized and the stressed fibers slip to a neutral or unstressed position. The lignin then rehardens and wood is stress free. Table 7 gives the comparison of different drying schedule.

The SDR and high temperature combination is much better suited for the processing of *P. deltoides* as the percentages of rejects were minimum due to warping. The possible reasons could be:

1. Stress balanced by slab sawing.
2. Wide planks restrain warp.
3. Drying stresses offset growth stresses.
4. Lignin plasticized at high temperature.

Table 6. High temperature drying schedule

Initial moisture content	More than 50%
Dry bulb temperature	102ºC
Wet bulb temperature	90ºC
Duration	96 hr
Followed by reconditioning	
Dry bulb temperature	90ºC
Wet bulb temperature	86ºC
Duration	6 hr
Final moisture content	12-15%

Table 7. The comparative performance of drying by different methods

Air seasoning	Kiln seasoning	High temperature drying
25 mm thick planks, 40-45 days	25 mm thick planks, 6-7 days	100 mm thick slabs, 4 days
Prone to severe distortion	28-57% rejection due to warp and honeycombing	5-8% rejection due to warp

Storage of Poplar Logs

One of the major problems faced during storage of logs of poplar in the timber yard is discolouration and decay in wood due to fungal attack. Staining fungi cause mostly discolouration of the sapwood. The progress of staining fungi is very rapid and the entire poplar sapwood may become stained in course of one to a few weeks. Though strength properties of stained wood mostly remain unaffected, such wood is not liked because of its appearance. To avoid this problem, prophylactic treatment of the logs should be undertaken as soon as they reach the storage yard or at the felling site itself when transportation of logs from felling site to storage yard is not done immediately.

The bark must first be removed completely for protective treatment before spraying thoroughly the entire surface with a 2.5 per cent water solution of sodium pentachlorophenate, boric acid and borax mixed in the ratio of 0.5: 1.1. The logs are, then, stacked on the ground under hygienic conditions. It must be remembered that this treatment is effective only if it is undertaken immediately after felling and cross cutting into logs. Once infection occurs, it is difficult to control it through prophylactic treatment. Beri *et al.* (1979) studied effect of preservatives on chemical constituents and pulping quality of *P. deltoides* logs during open storage.

Natural Durability and Preservative Treatment

For rational utilization of any wood species, its natural durability and treatability should be known in advance. Experiments at FRI have been conducted to determine natural durability of poplar heartwood in Indian condition and treatability of the timber (Dev and Kainth, 1989; Kumar and Dobriyal, 1993, 1995; Dobriyal and Kumar, 1999: Dobriyal *et al.,* 2001). Page and Gnanaharan (1999) studied the influence of wood moisture on the preservative treatment of New Zealand grown poplar. *P. deltoides* has been classified as non durable timber and is easily treatable and falls under treatability class 'a'. Field experiments at FRI test yard have been conducted on treated samples with coal tar creosote- fuel oil mixture (50:50) at three levels of absorptions and Ascu/CCA/As_2O_3, $2H_2O$: $CuSO_4$, $5H_2O$; $Na_2Cr_2O_7$, $2H_2O$ (in the ratio of 1:3:4) at three retention levels. No uniform trend has been observed on the effect of different preservative formulations/retentions on strength properties although at lowest retention of 4 kg/m^3 has given maximum values of strength properties (Shukla *et al.,* 1996).

End Utilization of Poplar Wood

A number of studies have been conducted at FRI for finding various end uses of *P. deltoides* e.g pencil making (Rao *et al.*, 1994; Rao, 1996), wood poles (Jain *et al.,* 1990), packing cases (Shukla 1979). The study on lateral bearing strength in double and quardruple shear joints has also been conducted (Pruthi and Mamgain, 1994). Poplar has been recommended for doors and window shutters (Shukla, 1997), light furniture, packing cases, crates, sports goods, artificial limbs, pencil making and poles.

Reconstituted Wood Products from Poplar

A brief review of the research carried by FRI, Dehradun has been compiled by Singh and Negi (2001) and the same is reproduced here in addition to work carried out by Indian Plywood Industry Research and Training Institute (IPIRTI), Bangalore. The current research is focused on combining plywood with other plantation species such as *Eucalyptus* and *Paulownia* and utilising lops and tops of poplar.

Veneer, Plywood and Blockboard

Optimum conditions for peeling: Uniformity of thickness in veneer is of great importance for its subsequent use in plywood, laminated wood,etc. Lack of uniformity in thickness of veneer may result in poor bonding with adhesives. Keeping in view the above, optimum conditions for peeling poplar into veneer having uniformity in thickness, tightness and strength were studied (Shukla *et al.*, 1992). IPIRTI, Bangalore also studied the peeling drying and drying characteristics of poplar (Indian Plywood Industry Research and Training Institute, [n.d.]). Considering the results obtained during peeling of two species *viz., P. deltoides* and *P. ciliata* the optimum conditions of peeling are given in Table 8.

Table 8. Optimum conditions of peeling

	P. ciliata	*P. deltoides*
Veneer thickness (mm)	1.61	1.61
Temperature of log conditioning (^oC)	55	55
Speed of peeling (m/min)	39.62	45.72
Knife angle	91.2^o	90^o

Plywood and allied products: *P. deltoides* obtained from Lalkuan, Haldwani (Uttaranchal) and *P. ciliata* from Kothani Range, Shimla (H.P.) were studied for its suitability for making various grades of plywood and blockboards. Both the species did not offer any gluing problem and satisfactory glue bond could be obtained with common commercial adhesives like, PF and UF for making plywood. Experiments on 3 and 5 ply indicated that the species is easy to treat with water borne preservatives and fire retardant chemicals and adequate loading of the chemicals can be obtained. Treatment with preservative (copper-chrome-arstenate) and fire retardant-cum antiseptic chemical (ammonium phosphate, copper sulphate and sodium dichromate) did not adversely affect the glue bond. The species is suitable for making, (a) plywood for general purposes, (b) marine plywood, (c) plywood for concrete shuttering work, (d) preservative treated plywood, (e) fire retardant plywood and also for (f) blockboards (Shukla *et al.,* 1986; Rajawat *et al.,* 1989; Dimri *et al.,*1990, 1993).

The service life of plywood from *P. deltoides* can be increased by adopting glue line poisoning using arsenic tri-oxide mixed in PF glue. The glue shear strength of treated as well as untreated plywood with three different thickness of veneers; i.e., 0.8 mm, 1.6 mm and 3.2 mm was studied. Statistical analysis showed that the glue line treatment does not adversely affect the glue bond in plywood, while resists the termite attack considerably (Dimri *et al.*, 1995). Khali *et al*. (2005) found in his study that combination of ply comprising of *P. deltoides,* eucalypts hybrid and *Paulownia fortunei* can be successfully made for overcoming the material shortage and inferior quality of plywood made from individual species.

Laminated Veneer Lumber (LVL)

Laminated veneer lumber (LVL), a high strength engineered material can be used as a substitute for solid wood as they retain structural properties of wood. Veneers and strips obtained from small diameter logs are glued in parallel laminates or laminated veneer lumber (LVL) which has all the properties of thick wooden planks.

LVL can be manufactured in varying sizes and thicknesses, being dimensionally stable and having more uniform strength properties, it is more versatile than sawn timber. Suitability of plantation grown *P. deltoides* was evaluated for laminated veneer lumber (LVL) and suitability for door/window shutters (Shukla and Negi, 1998). Specific gravity of LVL is affected by pressure, pressing period and also the thickness of the veneer used. With decrease in veneer thickness, specific gravity in general increases (Shukla *et al.,* 1996).

Compressed Wood

Compressed wood has improved strength and elastic properties and high resistance to wear. These properties make it suitable for use in textile industry/auxiliaries, door handles, bearing, rollers, etc. Suitability of *P. deltoides* and *P. ciliata* was evaluated for compressed wood shuttle blocks. The density of poplars after compression varied within the range of 1.05 to 1.20 g/cm^3. The strength properties of the compressed wood from these two species meet the requirements specified for shuttle blocks and were comparable with imported *Cornus* spp., *Carpinus* used for making shuttle blocks (Shukla and Bhatnagar, 1989)

Reconstituted Wood

Reconstituted wood product developed from lignocellulosic material has highly directional properties suitable for structural purposes (Coleman, 1981).

Reconstituted wood developed from lops and tops of poplar have the strength properties comparable with teak (Shukla, 1992) as reflected in Table 9. Thickness swelling somewhat higher than teak could be reduced by incorporating suitable sizing agents as in case of particle board. The product has solid edge and can be bored, shaped, moulded, nailed and screwed with machine and hand tools. It can be painted and polished with case as in case of solid wood.

Table 9. Physical and mechanical properties of structural wood from poplar and compared with solid wood of poplar and teak

Property	Structural wood	Solid wood	
	Poplar	Poplar	Teak
Specific gravity	0.68	0.465	0.59
Volumetric shrinkage AD to OD (%)	4.95	11.9	4.05
Modulus of rupture (kg/cm^2)	1147	780	959
Compressive strength (kg/cm^2)	445	381	532
Shear strength (kg/cm^2)	101	90	102

Laminated Doors and Windows

In solid wood the growth defects like knots are often localized and form the weakest part of the structure. The problem with poplar for its utilization for doors and windows is that it is a light timber and the presence of knots in the whole length of wood.

The physical and mechanical properties of short rotation poplar wood could be considerably improved by applying the technique of laminations and simultaneous compression (Shukla, 1997; Shukla and Negi, 1998). The construction of laminated wood may be either all veneer construction or solid wood core laminated with veneer. Since poplar is not a durable timber, finished panels may be given pressure treatment with CCA preservative and dried before polishing. Plywood manufacturing units in the country using poplars can easily undertake the manufacture of laminated doors without any additional investment.

Plywood Using Lignin Adhesives

For reducing the cost of synthetic resin, black liquor lignin based phenolic adhesives for plywood have been developed in which the phenol is replaced with black liquor for making adhesives. An attempt was made to develop exterior grade plywood from *P. deltoides* using lignin based phenolic adhesives. The result showed that 30 per cent replacement of phenol with black liquor from pine needles, the plywood meet the BWP grade and up to 50 per cent for BWR grade requirements (Singh and Singh, 1994).

Fibre Board

Suitability of 1 and 2-yr old *P. deltoides* (G3 clone) without debarking was evaluated for hardboard manufacture (Shukla *et al.*, 1986), with a view to utilize whole tree stem. Bark/wood ratio worked out on oven dry basis for some selected stem is given in Table 10 below. The hardboards were prepared from 1 and 2-yr old plants containing 30 and 21 per cent bark respectively. One per cent emulsion was used to reduce the water absorption of the boards. Both 1 and 2-yr old *P. deltoides* were found suitable for hardwood manufacture. However, 2-yr old plant gave better board properties than 1-yr old. This may be due to higher percentage of bark in 1-yr old plants. The effect of mixing *P. deltoides,* bark and wood on the physical and mechanical properties of hardboards was also studied (Shukla, 1997). It was observed that individually poplar wood is suitable for hardboard but not the bark. However, certain quantities of bark could be mixed with wood producing satisfactory board. Bark to the extent of 20 per cent (OD) helps in improving the physical and mechanical properties of the board as compared to the boards prepared from wood alone. In standard hardboards, the bark content can be safely increased up to 50 per cent. *P. ciliata* without bark was evaluated for making hardboards (Shukla *et al.,* 1985, 1986; Shukla, 1987). It was found to be a very suitable species for the purpose. Suitability of *P. ciliata* for hard boards was also studied by Shukla *et al.* (1985).

Table 10. Moisture content and wood/bark ratio in 1 and 2 years old *P. deltoides* stems

Plant age (yr)	Middle dia (mm)	Moisture			Wood (%)	Bark (%)
		Overall	Wood	Bark		
1	7.26	12.5	13.8	9.5	70	30
2	8.30	11.0	11.2	10.2	79	21

Utilization of Bark

A large quantity of bark constituting 10 to 20 per cent of total timber is accumulated at mill site, which is not properly utilized. The investigations carried out on utilization of bark from *P. deltoides* show that satisfactory plain and veneered particleboard meeting the requirements of specification are obtained (Singh *et al*., 1995-96).

Utilization for Particleboard

Suitability of lops and tops of *P. deltoides* with and without bark as a raw material for particleboard manufacture was evaluated. The data indicated that *P. deltoides* wood alone and with bark (about 19 per cent) is suitable for making particleboard. Satisfactory boards meeting the requirements are made using 10 per cent phenol formaldehyde resin and 1 per cent was emulsion as sizing agent in both the cases. However, the strength properties of the board without bark are slightly better than the board with bark (Singh *et al*., 1995).

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Status of Anatomy and Physical Properties of Wood in Poplars

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Introduction

Poplars are among the world's fastest growing industrial wood, which is grown in pure or mixed plantations as well as in association with agricultural crops. Poplars are also widely cultivated on the field boundaries, roads, canals, riverbanks as multipurpose tree species. Their wood is in much demand for pulp, plywood, match wood, packing cases and light constructional timber (Mathur and Sharma, 1983).

In India, many species of *Populus* were introduced among which *P. deltoides* did very well and has now occupied large chunk of forests, farmland, road and canal-sides in Haryana, Jammu and Kashmir, North Bengal, Punjab, Uttarakhand and Uttar Pradesh (Chaturvedi, 1982; Dalal and Trigotra, 1983; Jha and Gupta, 1991).

Wood is highly variable material and the aim of tree improvement program is to reduce these variations to obtain quality wood for the products. The variation of wood elements within a species/clone is also affected by climate and the system under which they are grown. Studies made on mature-juvenile wood characteristics have indicated that parent with high or low wood density produce progeny with juvenile wood similar to that of the parent (Zobel, 1964, 1973; Nicholls, 1967). Wood properties of mature age tree can also be predicted on the basis of wood properties evaluated at younger age (Zobel, 1965).

> **The variability in anatomical characteristics has profound influence on properties of wood and features of interest in this connection include cell size, proportion and arrangements of different elements and specific gravity**

The variability in anatomical characteristics has profound influence on properties of wood (Dadswell, 1957; Burley and Palmer, 1979). Features of interest, in this connection, include cell size, proportion and arrangements of different elements and specific gravity. The general pattern of variation in wood element dimensions is found not only within a species but also observed within a tree (Dinowoodie, 1961; Zobel, 1965; Rao and Rao, 1978; Pande *et al.,* 1995). The important endogenous species of *Populus* are *P. alba, P. ciliata, P. euphratica* and *P. nigra*. They all are medium density wood. Specific gravity of these species ranges from 0. 37 (*P. alba*) – 0.54 (*P. euphratica*) (Raturi *et al*., 2001).

Wood quality has become a major concern in the forest product industry only very recently due to the steady increase in intensively managed plantations and the move in forest management towards short rotations (Vargas-Hernandez and Adams, 1991; Zhang, 1995). Tree breeders have realized that wood quantity (volume growth) and quality cannot be treated as independent traits and that wood quality improvement should form an integral part of tree breeding programs (Keith and Kellog, 1986; Van Buijtenen, 1986; Magnussen and Keith, 1990). A good quantum of the work was carried out world over on wood properties of poplars. Some of the studies on the different aspects of wood anatomy and physical properties of poplar's wood were also carried out in India (Gamble, 1922; Pearson and Brown, 1932; Metcalf and Chalk, 1950; Chauhan *et al*., 1999, 2001; Raturi *et al*., 2001; Venkiah *et al*., 2007; Aziz and Pande, 2008, 2009, 2010; Gautam and Pande, 2008, 2009, 2010, 2011; Gautam, 2010; Pande and Dhiman, 2010, 2011; 2012; Pande, 2011, 2011a; Pande *et al*., 2012).

Wood anatomical studies can be classified into two categories; first, structure related qualitative and second, wood variation related quantitative studies. The paper presents a detailed account of both of the dimension of the research on anatomical and physical aspects of the wood of *Populus* and an attempt was also made to compare it with other species.

Structure Related Studies

In India, anatomical studies were conducted in different Indian species of *Populus* by Gamble (1922), Pearson and Brown (1932), Metcalf and Chalk (1950), Raturi *et al.* (2001), Gautam (2010). Gamble (1922) described a small account of wood structure *of P. ciliata, P. euphratica* and *P. alba* in his classical work 'A manual of Indian timbers'. The common features of the wood of all three species were: wood was soft, even grained, annual rings marked by smaller and fewer pores, pores small, very numerous often subdivided or in short radial multiples, rays fine to very fine, numerous and regular. The colour differentiation in wood was: grey or brownish grey in *P. ciliata;*, sapwood white and heartwood red coloured and black near the pith in *P. euphratica* whereas wood white often with red or yellowish tinge in *P. alba.* Metcalf and Chalk (1950) describe rays as uniseriate sometimes biseriate with less than 1 mm in height and homogeneous. Pearson and Brown (1932) and, thereafter, Raturi *et al.* (2001) made a complete anatomical description of these species. There not much difference was observed in wood structure of these three species. However, the colour of wood of *P. euphratica* was red to reddish brown with dark lines forming tortoise shell figure in flat sown board. Gautam (2010) described the structure of micro- and macro-propagated wood of L34 clone of *P. deltoides* as per IAWA feature list of microscopic features (IAWA, 1989) (Fig. 1).

Coded Description on the Basis of IAWA List Microscopic Features of *P. deltoides*

1. Growth ring boundaries distinct; 4. Wood semi-ring-porous; 5. Wood diffuse-porous; 7. Vessels in diagonal and/ or radial pattern; 13. Simple perforation plates; 22. Intervessel pits alternate; 23. Shape of alternate pits polygonal; 24. Minute-d" 4 µm; 31. Vessel-ray pits with much reduced borders to apparently simple: pits rounded or angular; 35. Vessel-ray pits restricted to marginal rows; Mean tangential diameter of vessel lumina, 40. d" 50 µm; 61. Fibers with simple to minutely bordered pits; 66. Non-septate fibres present; 68. Fibres very thin-walled; 75. Axial parenchyma absent or extremely rare; 89. Axial parenchyma in marginal or in seemingly marginal bands; 92. Four (3-4) cells per parenchyma strand; 93. Eight (5-8) cells per parenchyma strand; 96. Rays exclusively uniseriate; 104. All ray cells procumbent; Rays per millimeter, 115. 4-12/mm (Table 1).

Table 1. Coded description on the basis of IAWA List microscopic features of L-34 clone of *P. deltoides*

Species	Clone	IAWA List of microscopic coded features
P. deltoides	L34 (macro)	1, 4, 5, 7, 13, 22, 23, 24, 31, 35, 40, 61, 66, 68, 75, 89, 92, 93, 96, 104, 115.
P. deltoides	L34 (micro)	1, 4, 5, 7, 13, 22, 23, 24, 31, 35, 40, 61, 66, 68, 75, 89, 92, 93, 96, 104, 115.

Wood Variations

Of the various wood quality parameters, specific gravity is the most widely studied. This easily assessable wood property is of key importance in forest product manufacture because it has a major effect on both yield and quality of fibrous and solid wood products (Davis, 1961; Barefoot *et al*., 1970; Lewark, 1979) and because it can be changed by silvicultural (Williams and Hamilton, 1961) and genetic manipulations (Zobel, 1961; Van Buijtenen, 1962). Variation in wood parameters offers possibility for selection of breeding stock with desirable wood quality. Length of cells also has a marked effect on product quality. It is generally the cell dimension next in importance to wall thickness in determining the final product value (McGraw, 1985). Although all characteristics of the cell have some effect on the quality of a manufactured product, most are minor in comparison to cell length (Zobel and Buijtenen, 1989). These include cell wall thickness, width of cell, ray characteristics, cell dimension ratios and grain characteristics, microfibril angle, etc. Other wood properties such as juvenile wood content, fiber quality, compressed wood, heartwood content, chemical properties, etc. should also be considered in future tree improvement programs (Zhang and Chui, 1996).

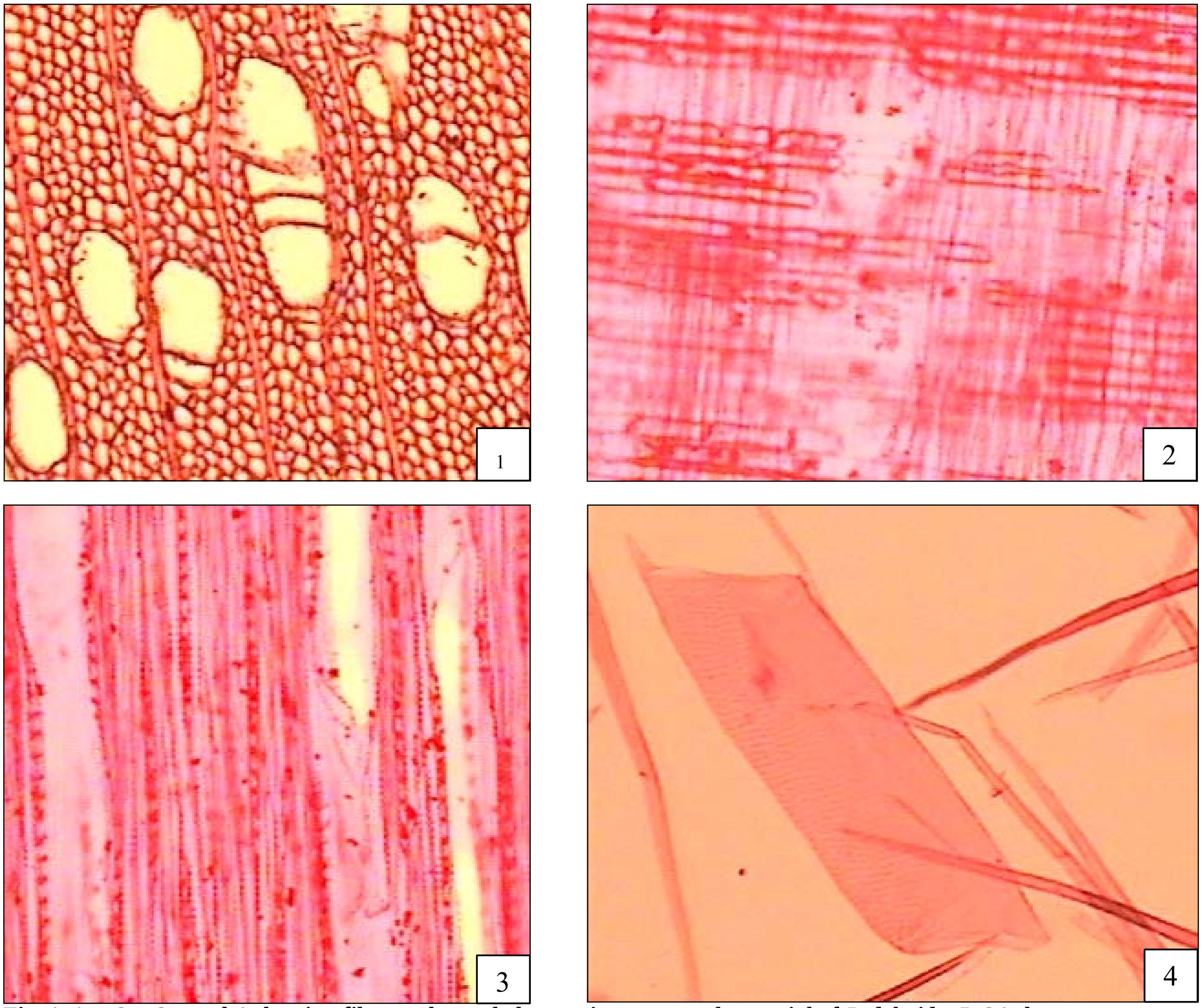

Fig. 1. 1-x, 2-r, 3-t and 4-showing fiber and vessel element in macerated material of *P. deltoides* L-34 clone.

Within Tree Variation in Poplars

Radial variation

Fiber dimensions: Kaeiser (1956) reported average fiber length increased successively with the number of rings from the pith to outwards. Kaubaa *et al.* (1998) found similar results in the hybrids of poplars. Anatomical variations in *P. deltoides* were examined in 8-yr old trees of six different clones by Chauhan *et al*. (1999). The variation in fiber length was significant and showed an increase with the age. Radial variation with an increase from pith to outwards was reported by Chauhan *et al.* (2001). Variation of fiber length and fiber width for seven poplar clones was reported by Yang and Zuo (2003). The pattern of increase in fiber length and width from pith to bark was noticed. Radial variation in fiber morphology of five different poplar clones grown in Tiancchang, Anhui Provenance, China, were studied for fiber length, fiber width, lumen diameter, double cell wall thickness, the ratio of fiber length to width. Result showed that from pith to outward, the fiber length, width and the ratio of fiber length to fiber width of five poplar clones all increase with the increase of growth rings; reach a maximum in a certain year and then decrease or level off (Zha *et al*., 2005). The radial variation in fiber length was significant for parents, individual female and male hybrid clones except Udai. Variations were also significant for fiber lumen diameter and fiber wall thickness differently in different F1 hybrids. Both significant and non-significant variations were observed for fiber length from pith to periphery with the different patterns of variations in different parents and F1 hybrid clones of *P. deltoides*. Further, the trend from pith to outwards was more or less increasing (Pande, 2011). Cheng and Bensend (1979) reported fiber length increased uniformly throughout the successive growth rings from the pith in six *Populus* clones, they also concluded that the variation in fiber length was mainly a result of physiological and environmental factors rather than a genetic factor. Yanchuk *et al.* (1983) reported radial variation of fiber length in 15 genetically distinct clones of trembling aspen (*P. tremuloides*) from natural stands in central Alberta, Canada. Fiber length patterns of change across the radius were all very similar foremost of the clones. The increasing trend for fiber length from pith to outwards in some clones were also reported by Pande and Dhiman (2010, 2011); Pande (2011, 2011a), Pande and Dhiman (2012) and Pande *et al.* (2012).

Comparison with other species: The studies on radial variation in different species/clones of *Populus* were more or less similar with the studies conducted in other tree species by different workers. Significant differences in the fiber length were observed between the core and outer wood of *Paraserianthes falcatraria* trees planted in Indonesia (Ishiguri *et al*., 2007). In radial variation of wood elements of major Korean ash species, fiber length increased from pith for 10 to 15 years and, then, stabilized (Joong and Joong, 2002). Pith to periphery variation in fiber length was reported by Purkayastha *et al*. (1979-80) in woods of 8-10 yrs old seedling seed raised *Eucalyptus tereticornis* plantations at different localities. In the same way, significant pith to periphery variations in fiber length was reported by Jorge *et al*. (2000) in *E. globulus.* Carvallo (1962), Tomazello and Variacano (1987) and Bhat (1990) in seedling seed raised progenies of different species of *Eucalyptus*. Fiber length increased 63 per cent from the pith to the bark in the branches of European black alder as reported by Vurdu and Bensend (1979). There was no significant difference in fiber length between lower and upper sides of branches. Anatomical characters were investigated in stems of rotan semambu (*Calamus scipionum*), 6-12 yrs old, from a plantation in Sarawak, Malaysia. Fiber outer- and lumen-diameter slightly increased from the centre to periphery (Roszaini, 2000). Most reports on radial pattern of variation in hardwoods and species; *Acacia* in particular deal with fiber length and most agree that fibres near the centre of the tree are shorter. Radial variation in the morphology of axial elements of *Acacia mangium* was studied by Honjo *et al*. (2002); radial variation in fiber length by Wu and Wang (1988), Sining (1989), Lim and Gan (2000), Susilawati *et al*.(2002) and by Rao and Sujatha (2004). They reported varying patterns of change in fiber length in this species. Fiber length ranged from 958 to 1,200 µm and tended to increase from the centre to the intermediate regions before decreasing slightly towards the outer regions in most cases in 14-yr old *Acacia mangium* (Lim and Gan, 2000). Within-tree radial variation in fiber morphology was studied by Pande *et al*. (2008) in 12-yr old tree of *Leucanea leucocephala*. They observed that the variations were non-significant except for fiber-diameter, increased from pith to outwards. Pith to periphery variation in anatomical properties such as fiber outer diameter, fiber lumen diameter, fiber wall-thickness were studied in tropical broad leaved species such as *Broussonetia papyrifera*, *Poinciana regia*, *Pittosporum tetraspermu*, *Grevillea robusta* and *Tamarindus indicus* by Rao *et al.* (1996). Fiber length increased radially from pith to bark in natural and plantation trees of the species of *Hyeronima* and *Vochysia*; ranging from 1.92 to 2.98 mm (natural) and 1.45 to 2.71 mm (plantation) for *Hyeronima*; and from 0.63 to 1.75 mm (natural) and 0.69 to 1.47 mm (plantation) for *Vochysia*. Neither species had a clearly defined juvenile wood zone. Fiber length continued to increase with distance from pith (Butterfield *et al*., 1993). Knigge and Koltzenburg (1965) found a rapid increase in cell length during the first 10-20 yrs in hardwoods, followed by a leveling off. This pattern was also present in poplars (Jayme *et al.,* 1943; Scaramuzzi, 1955; Boyce and Kaiser, 1961).

In contrary, Veenin *et al*. (2005) reported non-significant radial variations in fiber length in *Eucalyptus camaldulensis;* in *Dalbergia sissoo* by Pande and Singh (2005) and in *Eucalyptus tereticornis* by Pande and Singh (2009). The cambial age does not influenced the fiber dimension in case of clonal plantation wood of these species resulted less formation of juvenile wood as shown by non-significant radial variation in fiber dimensions.

Vessel element's dimensions: The increasing trend from pith to outward was reported on different clones of *P. deltoides* by Chauhan *et al*. (1999, 2001). Within-ramet radial variations in vessel element length and diameter were significant for female parent and F1 hybrids of both the sexes differently in different clones, however, non-significant for male parents. It showed differential trend of radial variation for male and female parents and F1 hybrid clones of *P. deltoides* for vessel element dimensions (Pande, 2011). Within-ramet radial variation in vessel element length in micro-propagated wood was significant in L-34 clone of *P. deltoides,* however, these variation was non-significant for macro-propagated wood (Gautam, 2010). Non-significant radial variations in vessel element dimensions were noticed in micro- and macro-propagated plantation wood of the age of 6 years with no definite trend (Pande and Dhiman, 2010). Significant variation in vessel element diameter with pith to outwards increasing trend and non-significant variation of vessel element length was reported by Pande and Dhiman (2011) in some *P. deltoides* clones. Female (G48) clone also showed significant variation in vessel element dimensions with increasing trend from pith to outwards while male (G3) clone showed non-significant difference (Pande *et al.,* 2012). Further, radial variations between micro- and macro-propagated plantation wood were also significant for vessel element length in *P. deltoides* clones (Pande and Dhiman, 2010). Anatomical variations in *Populus deltoides* were examined in 8-yr old trees of six different clones by Chauhan *et al*. (1999). Significant intra-clonal variation in vessel element length, vessel element diameter and vessel frequency was observed. In general, the trend from pith to outwards was increasing for vessel dimensions as in fiber dimensions in different clones of *P. deltoides*.

Comparison with other species: Pith to periphery variation in vessel element length was investigated in *Artocarpus heterophyllus*, *Albizia lebbek*, *Casuarina equisetifolia*, *Glericidia* spp. and *Syzgium gardnerii*. Results indicated that trends vary from pith to periphery depending upon the species and anatomical features (Rao *et al*., 2003). The length of vessel elements increased from pith outwards following a second degree curve. This dependence is the least distinct for vessel elements. In mature zone, anatomical elements are on average, 10 to 20 per cent longer than juvenile wood. With deteriorating conditions of tree growth, the length of the anatomical elements tends to increase. The most of the studies discussed above, shows increasing trend from pith to outwards for vessel element dimensions.

Non-significant variations were also reported by Veenin *et al*. (2005) in *E. camaldulensis;* by Purkayastha *et al*. (1974) *in E. tereticornis*; Mamit (1986) in *A. mangium*; Pande and Singh (2005) in *Dalbergia sissoo* and Pande and Singh (2009) in *E. tereticornis* for vessel element dimensions. These studies mostly pertain to clonal plantations so shown less impact of juvenile wood on the wood properties.

Specific gravity*:* Within-ramet radial variation in specific gravity were significant for female parents and non-significant for male parents and in most of the F1 female and male hybrids. It showed that this trait was stable in most of the hybrid clones and male parents (Pande, 2011). Non-significant radial variation in specific gravity was reported by Pande and Dhiman (2011) in parent and F1 and F2 generation clones of *P. deltoides*. Pande (2011a) reported significant radial variation in specific gravity of *P. deltoides* clones. Significant pith to periphery variations for this trait was reported by Gautam (2010) in L34 clone of *P. deltoides*. In general, the pith to outwards trend was increasing for specific gravity.

Comparison with other species: All possible patterns of wood density variations were reported in hardwoods. Medium density diffuse porous hardwoods such as the *Acacia* follow the general pattern of low density near the pith and then an increase, followed by a slower increase or leveling off toward the bark (Zobel and van Buijtenen, 1989). Ani and Lim (1993) studied wood density of four trees of 5-yr old *A. mangium* trees and also found an increase in this property in the radial direction from the centre to the outer region near the bark. Such an increasing pattern was observed in *A. auriculiformis* also by Kholik and Marsoem (2002). Mamit (1986) however, did not find any significant variation in wood density from pith outwards in this species while different pattern of variation in *A. mangium* was reported by Lim and Gan (2000) wherein density tended to increase from pith to the intermediate region before decreasing towards the bark.

Within-tree, variation in the specific gravity due to direction (N, SE and SW) and pith to periphery locations were non-significant while significant due to height and its component like main bole, $twig_1$ and $twig_2$ in *Leucanea leucocephala* by Pande *et al.* (2008). Further, non-significant radial and vertical variations in clones of *D. sissoo* by Pande and Singh (2005); in *E. tereticornis* by Pande and Singh (2009); in *E. camaldulensis* by Veenin *et al.* (2005) and some of the hybrid clones of *P. deltoides* by Pande (2011).

Vertical variations

Fiber dimensions*:* Venkaiah *et al.* (2007) reported an increase in fiber length from base to top. Fiber length was low at the bottom and higher in mid of the tree (Kauubaa *et al.,* 1998). Fiber length in young *Populus* stems, relation to clone, age, growth rate and pruning was studied by Debell *et al*. (2002) and reported that averaged over all disks at 1.5 m, clones differed significantly in ring width, and fiber length in contrary to the study conducted by Pande (2011) where vertical variations were non-significant for fiber length in most of the F1 male hybrids. Within-clone correlations between ring width and fiber length or between wood properties were low and generally non-significant. This pattern was also present in poplars (Jayme *et al*., 1943; Scaramuzzi, 1955; Boyce and Kaiser, 1961). Murphy *et al*. (1979) studied the selected wood properties of young *Populus* hybrids. Within clones, fiber length increased each year for all three clones and hybrid NE-388 had significantly greater fiber length among clones for each of the 2, 3, 4 yr. Variation of fiber length and fiber width for seven poplar clones was reported by Yang and Zuo (2003). They observed a pattern of increased fiber length from base to top. The investigation carried out by Gautam (2010) had shown the same pattern particularly for micro-propagated ramets of L-34 clone of *P. deltoides* and is in agreement with the studies carried by Yang and Zuo (2003). This pattern was also present in other poplars (Jayme *et al.,* 1943; Scaramuzzi, 1955; Boyce and Kaiser, 1961).

Within-ramet vertical variations in female parent (G48) were significant for fiber outer diameter, fiber lumen diameter and fiber wall thickness differently in different clones. The variation in male parent (G3) was significant for fiber length and fiber wall thickness and the pooled data was significant for all the wood traits except fiber wall thickness. Fiber length gradually increased from base to certain height and finally decreased at the top (Pande and Dhiman, 2012). The increasing trend in fiber length from bottom to top was also reported. Within-ramet vertical variations in female parent (G48) were only significant for fiber outer diameter, fiber lumen diameter and fiber wall thickness. The fiber wall thickness follow a definite trend as thick walled cells were present at the base of female parent which gradually decreased from bottom to top. The significant variations were also observed in female hybrids differently in different cases (Pande, 2011).

In contrary, Inokuma *et al*. (1956) reported that fiber length showed a constant decrease in upward direction of *Populus japanogigas*. Non-significant within-ramet vertical variation in macro-propagated ramet of L-34 clone of *P. deltoides* for all the wood traits were reported by Gautam (2010). Further, she reported non-significant variation due to the interaction of height*direction*position. Non-significant within-ramet vertical variation was observed in G48, G3, and other F1 hybrid clones for most of the wood traits. Moreover, variations in parents and offspring for pooled data were non-significant for all wood traits except fiber wall thickness (Pande, 2011). Both the studies indicated that the homogeneous wood properties could be achieved at a particular height and also from the bole of individual ramet.

Comparison with other species: Tajima (1967) reported that variation within a tree is often greater than that of between the trees of the same species grown under the same conditions. As stated by Larson (1967), more variability in wood characteristics exists within a single tree than among trees growing on the same site or between trees growing on different sites. McGraw (1985) for loblolly pine and Koch (1985) for hardwoods clearly illustrated some of the many within-tree patterns of wood variations. Wood varies tree to tree but also within a tree from pith outward and from the base of the tree to its top. The magnitude of within-tree differences can be very large and are important. Non-significant vertical variation in fiber length while significant variation in fiber diameter and lumen diameter in 28-yr old *Daniellia oliveria* was reported by Idu and Ijomah (2000). Yang and Zuo (2003) reported a pattern of increased fiber length from base to top.

In contrary, non-significant vertical variation in fiber dimensions in clones of *D. sissoo* by Pande and Singh (2005); in *E. tereticornis* Pande and Singh (2009); in *E. camaldulensis* by Veenin *et al.* (2005); in 12-yr old tree of *L. leucocephala* by Pande *et al.* (2008) and some of the hybrid clones of *P. deltoides* by Pande (2011).

Vessel element dimensions*:* Significant axial differences in vessel element length of some clones of *P. deltoides* was reported by Chauhan *et al.* (2001) with irregularly increasing trend. Gautam (2010) reported significant axial variation in vessel element length while non-significant variation for vessel element diameter in L-34 clone of *P. deltoides* with irregular trend for vessel element length while increasing bottom to top trend for vessel element diameter. Non-significant axial variation was reported in most of the F1 hybrids and parents of *Populus deltoides* with irregular trend by Pande (2011). The more or less similar results were also obtained in micro- and macro-propagated plantation wood of *Populus deltoides* (Pande and Dhiman, 2010). Significant variations in vessel element length in G48 clone whereas non-significant variations in vessel element dimensions in G48 and G3 (vessel element diameter) of *P. deltoides* with increasing trend from bottom to top were reported by Pande *et al.* (2012). The above studies indicated that pattern in axial variations in vessel element length is variable from clone to clone in *P. deltoids*, however, general bottom to top trend was increasing.

Comparison with other species: Dimensional variation was investigated in vessel characters along vertical and horizontal axes of a 40-yr old tree of *Afzelia africana* in Gerei forest, Nigeria. Mean dimensional values were: vessel element diameter 233.46 µm and F/V length ratio 2.25. Other traits analyzed showed considerable variation but were not significantly related to distance along either axis (Idu and Ijomah, 1996). Variation in dimensions from stem base to the top in trees of 'aroeira' *Myracrodruon urundeuva* was reported (Florsheim *et al*., 1999). Discs were removed from each tree at the base, breast height and 50 per cent and 100 per cent of commercial height. Samples were taken from each disc at 0 per cent, 50 per cent and 100 per cent of the radius. In the longitudinal direction, the lowest value of vessel element length and diameter were found at the base, while the highest were found at 50 per cent of commercial height. The pattern of axial variation of vessel dimensions in *Populus* is more or less similar as in the other tree species.

In contrary, non-significant vertical variations in vessel element dimensions in clones of *D. sissoo* by Pande and Singh (2005); in *E. tereticornis* by Pande and Singh (2009); in *E. camaldulensis* by Veenin *et al.* (2005); in 12-yr old tree of *L. leucocephala* by Pande *et al*. (2008) and some of the hybrid clones of *P. deltoides* by Pande (2011).

Specific gravity*:* Significant differences with decreasing trend bottom to top in specific gravity of some clones of *P. deltoides* was reported by Chauhan *et al*. (2001). Gautam (2010) also reported significant axial variations in specific gravity in L-34 clone of *P. deltoides* with increasing trend from bottom to top. Significant axial variation was reported in most of the hybrids of *P. deltoides* by Pande (2011). Non-significant axial variation in specific gravity was obtained in micro- and macro-propagated plantation wood of *P. deltoides* (Pande and Dhiman, 2010) while significant variation in specific gravity in G48 and G3 clones of *P. deltoides* with increasing trend from bottom to top was reported by Pande *et al.* (2012). Radial and inter-progeny variations in the dimensions of the wood elements and specific gravity of 21 half sib progenies of *P. deltoides* was reported by Pande and Dhiman (2012). Significant radial variation was reported for specific gravity. In general, it was concluded that axial variations in specific gravity in different clones was shown different patterns however the trend from bottom to top was increasing.

Intra and Inter-Clonal Variations

Intra- and inter-clonal variations in wood traits in the genus *Populus* were studied by many a worker (Phelps *et al*., 1982; Kauba *et al*., 1998; Chauhan *et al*., 1999; Chauhan *et al*., 2001; Aziz and Pande, 2008, 2009, 2010; Gautam and Pande, 2008, 2009, 2010;; Gautam, 2010; Pande, 2011, 2011a; Pande and Dhiman, 2011, 2012).

Fiber dimensions: Fiber length in young *Populus* stems, relation to clone, age, growth rate and pruning was studied by Debell *et al*. (2002). They found variations among the clones. Murphy *et al*. (1979) studied the selected wood properties of young *Populus* hybrids and observed inter-clonal variation. Variation of fiber length and fiber width for seven poplar clones was reported by Yang and Zuo (2003) and found significant variations among the clones for fiber length. Clone to clone variations in some parent and hybrid clones for wood traits were also reported by (Pande 2011, 2011a; Pande and Dhiman, 2011). Further, inter-clonal variations were also recorded in the hybrids of the different parental combinations (Pande, 2011). Anatomical properties of selected *Populus* clones under intensive culture were studied (Cheng and Bensend, 1979). The within-tree and among-clone variations were evaluated for anatomical properties and fiber quality, particularly the amount of tension wood. Significant intra- and inter-clonal differences in fiber dimensions of some clones of *P. deltoides* was reported by Chauhan *et al.* (1999, 2001). Inter-clonal variation was reported by Venkaiah *et al*. (2007). The longest fibers were found in the clone 'IC' (1.236 mm), closely followed by 'A-238' (1.222 mm) and shortest fibers in '6-17' (0.952 mm). Gautam (2010) also reported significant intra-clonal variations and variations due to different sites in fiber dimensions in L-34 clone of *P. deltoides*. Significant intra- and inter-clonal variations were reported in most of the hybrids of *P. deltoides* by Pande (2011). Significant intra- and inter-clonal variations in fiber dimensions were obtained in micro- and macro-propagated plantation wood of *Populus deltoides* (Pande and Dhiman, 2010) and also in G3 and G48 clones of *P. deltoides* by Pande *et al.* (2012). Inter-progeny variation in 21 half sib families of *P. deltoides* was reported by Pande and Dhiman (2012).

Vessel element dimensions*:* Anatomical properties of selected *Populus* clones under intensive culture were studied and inter-clonal variation was reported (Cheng and Bensend, 1979). Significant intra- and inter-clonal differences in vessel element dimensions of some clones of *P. deltoides* were reported by Chauhan *et al*. (1999, 2001). Gautam (2010) also reported significant intra-clonal variations and variations due to different sites in vessel element dimensions in L-34 clone of *P. deltoides*. Significant intra- and inter-clonal variations were reported in most of the F1 hybrid clones of *P. deltoides* by Pande (2011). Significant intra- and inter-clonal variations in vessel element dimensions were obtained in micro- and macro-propagated plantation wood of *P. deltoides* (Pande and Dhiman, 2010) and also in G48 and G3 clones of *P. deltoides* were reported (Pande *et al.*, 2012).

Specific gravity*:* Wood density in 9-yr old *Populus* clones were studied in relation to clone age, growth rate and pruning and inter-clonal variation was noticed (Debell *et al*., 2002). Song *et al*. (1997) noticed significant difference in wood density of trembling aspen among four locations in China. Clone × environment interaction was significant. Natural variation in *P. tremuloides* was reported. The variation within clone was environmentally caused. The variation between clones is caused by differences in environment as well as in genetic constitution. Diameter, volume and specific gravity showed wide differences in one and the same clone as compared to between-clone differences, whereas fiber length showed less pronounced within-clone variation (Van Buijtenen *et al*., 1962). Variation in *P. deltoides* was examined in 8-yr old trees of six different clones. Significant inter- clonal variation was observed in specific gravity, fiber length, vessel element length, fiber diameter, lumen diameter, vessel frequency and vessel diameter. (Chauhan *et al*., 1999). Inter-clonal variation in *P. deltoides* in specific gravity and wood parameters of 18 clones in 10-yr old trees was observed. The inter-clonal differences were significant in anatomical parameters and specific gravity while within clones showed no significant effect (Chauhan *et al*., 2001). Gautam (2010) reported significant intra-clonal variation in specific gravity in L-34 clone of *P. deltoides*. Significant intra- and inter-clonal variations were reported in most of the F1 hybrid clones of *P. deltoides* (Pande, 2011). Significant intra- and inter-clonal variations in specific gravity were obtained in micro- and macro-propagated plantation wood of *P. deltoides* (Pande and Dhiman, 2010) and also in G48 and G3 clones of *P. deltoides* (Pande *et al*., 2012). Inter-progeny variation was reported in 21 half sib progenies of *P. deltoides* (Pande and Dhiman, 2012).

Genetic variation in wood properties among and within three provenances of balsam poplar was investigated. Thirty clones from each provenance, with four ramets per clone were measured for growth characteristics, and specimen disks were cut at tree base. The result showed significant difference among the three provenances in growth rate and cell length. Growth rate, relative density and fiber length as dependent variable showed differences between the southern and northern provenance with the local source in an intermediate position. Both genetic and environmental variances for a certain trait differed from provenance to provenance (Ivkovich, 1996). Wood characteristics of twenty poplar clones grown under short rotation intensive culture in Himalchal Pradesh at the end of 9th year was studied by Venkaiah *et al*. (2007). Inter-clonal variation was significant for specific gravity. Clone '5-18' (0.427) showed maximum specific gravity and minimum by clone 'C-181' (0.333). Variation within tree of wood anatomical properties and basic density of I-214 poplar in Beijing and their relationship modeling equations was reported by (Jiang *et al*., 2003). This includes the length and width, fiber wall thickness, tissue ratio, fiber wall ratio, basic density and width of growth rings. Different studies on intra- and inter-clonal variations in different clones of *P. deltoides* indicated that most of the clones were different from each other for specific gravity.

Comparison with other species: Significant differences among the different clones of different species in average fiber-length were also reported by many workers (Murphey *et al*., 1979; Phelps *et al*., 1982; Chauhan *et al*,. 1999; Chauhan *et al.,* 2001; Rao *et al*., 2002). Einspahar *et al.* (1963); Kennedy (1970); Cheng and Bensend (1979) and Peszlen (1994) reported that fiber-length was under genetic control. Such types of results were also obtained by Pande and Singh (2005) for *D. sissoo*. Clone to clone variation was also reported in vessel element and fiber dimensions and specific gravity in *Tectona grandis* for wood properties (Rao *et al*., 2003); in *D. sissoo* by Pande and Singh (2005) and in *E. tereticornis* by Pande and Singh (2009). The view is also in consonance with Chauhan *et al.* (1999, 2001) and Pande (2011, 2011a).

Wood Anatomical Properties and Density

The dimensions of wood elements and specific gravity in different species and clones of *Populus* reported in Indian literature are given in Table 2.

The average fiber length for different species/ clones of *Populus* ranged from 550 (*P. euphratica*) to 1,700 µm (*P. ciliata*); fiber diameter ranged from 21.91 (Micro L-34) to 34 µm (*P. ciliata*); wall thickness from 2.69 to 5.50 µm (G3) and specific gravity ranged from 0.326 (66, M, F1) to 0.518 (S7C3). Average vessel element length ranged from 108.56 (14) to 935 µm (*P. ciliata*) and vessel element diameter from 58.30 (L12/82) to 150 µm (*P. euphratica*).

Table 3 shows the wood properties of some commercially grown clones of *P. deltoides* grown in India. W-34, Bahar and G48 clone showed higher fiber length, specific gravity; G48, G3, Kranti and Udai showed higher fiber diameter and wall thickness and vessel element dimensions. In general, fiber length was higher in female while wall thickness in male clones**.** Specific gravity showed mixed trend.

Variation in Proportion of Tissues

Inter-ramet and variation due to site in proportion of tissue and vessel frequency (mm^{-2}) was non-significant. Radial variation was non-significant for fiber (per cent), vessel (per cent) and parenchyma (per cent) whereas significant for ray (per cent). Further, the variations in proportion of tissue between macro- and micro-propagated plantation's wood and within and inter-ramet variations were non-significant for all the wood traits in L-34 clone of *P. deltoides* (Gautam, 2010). Inter-clonal significant variation in fiber, vessel and parenchyma percentage was reported in parents and F1 female hybrids. Intra – clonal variation was significant for fiber (per cent) only while radial variation was for vessel frequency (Pande, 2011).

Correlation analysis indicated that fiber (per cent) was significantly negatively correlated with vessel (per cent), parenchyma (per cent) and ray (per cent) while significantly positively correlated with vessel element diameter and specific

Table 2. Wood element's dimensions (µm) and specific gravity

FL	FD	WT	VL	VD	SG	Authority
1048.2 (G3) 1229.3 (W-39)	23.3 (Cp82-5-1)-28.3 (G3)	3.9 (W-39)-5.0 (G-3)	531.9 (Bahar)-597.8 (W/A 39)	96.1 (G48)-109.5 (W22)	0.333 (Kranti)- 0. 423 (G48)	Pande, (2011a)
1023 (G-3)-1096 (112910)	23.4 (S7C3)-24.8	4.39 (S7C3) -3.8 (112910)	-	-	(G3) 0.383-(112910) 0.405-(S7C3) 0.441	Goyal *et al.* (2001)
968 (104)-162 (G48)	(104) 22.11-28.1(G3)	3.53(66)-5.04(G3)	532 (W/A 49) -108.56 (14)	96.11 (G48)-108.56 (102)	(66, M, F1) 0.326-(G48, F, P) 0.423	Pande *et al.* (2011)
(G3) 1075.14-(G48) 1244.07	(G3) 23.19 - (G48) 26.68	(G3) 4.08-(G48) 3.09	(G3) 546.04- (G48) 590.32	99.25 (G3)-105.86 (G48)	0.41 (G3)-0.39 (G48)	Pande *et al.* (2012)
Macro 960.29 (L-34)- 1010.29 (S7C15	23.7 (L-34)-22.55 (S7C15)	3.56 (L-34)-4.15 (S7C15)	(L34) 519.31-(G3) 546.04- 554.07 (S7C15)	100.10 (L34)-91.7 (S7C15)	0.38 (L-34)-0.38 (S7C15)	Pande & Dhiman. (2010)
Micro 996.41 (L34)- 954.2 (S7C1)	21.91 (L-34)-23.44 (S7C)	3.55 (L-34)-4.00 (G3)	544.02 (L-34)- 576.42 (G3)	90.94 (L34)- (G3)102.98 (G3)	0.379 (L-34)-0.345 (G-3)	
1100 (S7C15)- 1473.50 (L71/84)	23.0 (L52/8)-28.0 (G3)	3.7 (L52/8)-5.50 (G3)	598.00 (S7C20)-695.50 (L75/84) L188/84)	58.3(L12/82)- 85.25(S7C20)	0.34 (D121)-0.44 (L290/84)	Chauhan *et al.* (2001)
957(G3)-1122 (St121)	22.0 (St63)-26.0 (G48)	3.83 (S7C13)-5.06 (G3)	416 (G3)-552 (St-121)	59.6(S7C13)- 71.3(S7C3)	0.404 (G3)- 0.518 (S7C3)	Chauhan *et al.* (1999)
1196 (D100) 1.236 (IC)	-	-	-	-	0.333 (C181) 0.427)-(5-18)	Venkaiah *et al.* (2007)
P. euphratia 550-1620	27-30	3-4	425-600	135-150	0.47	Pearson Brown (1932)
P. ciliata 635-1700	30-34	3-4	250-935	100-120	0.32	Pearson Brown (1932)
(L-34) 1083.82-1129.70	22.58-23.66	2.69- 2.78	579.81- 603.52	97.43-108.08	0.336-0.401	Gautam (2010)

Table 3. Wood and growth traits of some commercial clones of *P. deltoides*

Clone	Sex	FL±SD (µm)	FD±SD (µm)	WT±SD (µm)	VL±SD (µm)	VD±SD (µm)	Wood density (g/cm^3)
S7C8	F	1140.0±161.00	25.67±4.32	4.47±0.92	560.22±125.78	103.11±26.33	0.368
G48	F	1161.8±169.78	25.78±4.41	4.48±1.07	552.56±113.89	96.11±20.78	0.423
Kranti	F	1048.8±145.78	27.89±4.30	4.77±0.92	560.22±101.22	104.44±19.89	0.333
W/A 49	F	1142.3±116.44	23.67±2.29	3.77±0.34	532.78±84.56	99.67±15.67	0.406
W-39	F	1229.3±131.1	25.3±2.4	3.9±0.42	572.3±88.5	106.7 ±18.6	0.420
Bahar	F	1190.0 ±161.1	24.8±3.4	3.9±0.70	531±107.8	96±18.7	0.420
G3	M	1048.2±201.11	28.11±5.38	5.04±1.36	559.44±142.33	108.44±31.22	0.366
Cp82-5-1	M	1049.0±160.22	23.33±4.28	4.17±1.11	558.22±115.67	105.11±29.56	0.350
W 22	M	1136.3±133.7	26.2±1.2	4.3±8.9	558.0±99.5	558.0±19.9	0.367
Udai	M	1119.16±29.7	25.98±0.6	4.62±0.16	660.05±34.2	107.89±3.60	0.380

Source: Pande and Dhiman (2011)

gravity. Vessel (per cent) was significantly negatively correlated with ray (per cent). Ray (per cent) was significantly negatively correlated with vessel element diameter and significantly positively correlated with specific gravity. Vessel frequency was significantly negatively correlated with fiber length, fiber diameter and vessel element diameter (Gautam, 2010). It reflected that the proportion of different secondary xylem elements were showed their relationship with each other in L-34 *P. deltoides* clone.

Comparison with other species: The higher values of vessel (per cent), ray (per cent) and parenchyma (per cent) and lower values of fiber percentage has been reported by Marsoem *et al*. (2002) in *A. auriculiformis* and by Sahri *et al.* (1993) and Rao and Sujatha (2004) in *A. mangium* may be attributed to the juvenile nature of the materials studied. Since the materials studied were from the juvenile phase of growth (about 41/2-yr old) there might have been a necessity for having more conducting (vessels) and transportation (axial and ray parenchyma cells) tissues than those rendering mechanical strength (fibres). As age advances, the percentage of fibres is expected to increase coinciding with a reduction in proportion of the other cell types. In contrary, Pande, 2011 and Gautam (2010) observed higher percentage of fibers as compared to vessel in parent and F1 hybrid clones and L-34 of *P. deltoides,* respectively. It showed properties of mature wood in the species.

Ramirez *et al.* (2009) reported wide range of variation in *Eucalyptus globules* clones for vessel frequency, vessel area and vessel coverage among the clones. From pith to bark, mean vessel area and vessel coverage increased gradually, whereas the vessel frequency decreased. Vessel frequency decreased with the radius in *E. pilularis* (Bamber and Curtin, 1974); in *E. nitens* (McKimm and Ilic, 1987) and in *E. globules* (Carvallo, 1962; Hudson *et al.*, 1998). Decreasing trend from pith to periphery for vessel frequency was also reported in *E. regnans* (Dadswell, 1958), *E. camaldulensis* (Chudnoff and Tischler, 1963), *E. grandis* (Bamber and Humphreys, 1963), and *E. viminalis* (Nicholls and Phillips, 1970). In one tree of *E. camaldulensis* the fiber, vessel and parenchyma volume (per cent) varied between 47-62, 13-19, 24-37 and in an another tree it varied between 39-40, 11-17, 44-49, respectively (Chudnoff and Tischler, 1963). In *E. deglupta* the fiber and vertical parenchyma, vessel and rays (per cent) were 63.5, 27.9 and 10.5 (Davidson, 1972).

Radial variation in proportion of cell type in *Paraserianthes falcataria* was studied by Ishiguri *et al.* (2009). They observed that vessel (per cent) and axial parenchyma (per cent) showed almost constant values up to 10 cm from pith and then increased toward the bark. On the other hand, no consistent radial pattern was recognized in the ray parenchyma (per cent). The radial variation in vessel morphology and tissue proportions in 8-9 yrs old plantation-grown *A. mangium* raised at the Chandrapura range, Sirsi, Karnataka, India was studied (Kumar *et al.,* 2006). Significant radial variation from pith outwards was observed in respect of vessel (per cent), parenchyma (per cent) and ray (per cent) only in *P. deltoides* L 34 clone (Gautam, 2010).

Correlation studies indicated that fiber, vessel morphology and tissue proportions were independent of basic density (Rao and Sujatha, 2004). Significant pith to periphery variation in vessel frequency, vessel diameter, percentage of solitary vessel was reported in plantation grown *Tecomella undulate* by Rao *et al.* (2003a). Pith to periphery variation in vessel frequency, vessel element diameter, vessel element length and their proportions were investigated in *Artocarpus heterophyllus*, *Albizia lebbek*, *Casuarina equisetifolia*, *Glericidia* spp. and *Syzgium gardnerii.* Results indicated that trends vary from pith to periphery depending upon the species and anatomical features (Rao *et al*., 2003). In general, the trend of the proportion of different tissues for pith to outwards in *P. deltoides* clones was increasing, which also agrees with the results of the Pande (2011).

Variation in Micro Fibril Angle (MFA)

Intra-clonal variation in MFA was significant in L-34 clone (Gautam, 2010). Inter-clonal variation was significant in MFA while intra-clonal and within ramet variations were non-significant in parents and F1 hybrids of *P. deltoides* (Pande, 2011). Intra-ramet and multiplication variations in MFA were non-significant while inter-ramet variation was significant. Variations due to techniques (macro- vs. micro-propagated wood), intra- and inter-ramet variations in MFA were non-significant (Gautam, 2010). Pith to bark variations in *Populus* clones showed MFA ranging from 28^0 (pith) to 8^0 (bark) in 11-yr old trees at breast height (Fang *et al.*, 2006).

In hardwoods, there are also differences in among tree variations in MFA. Evans *et al.* (2000) reported in *E. nitens* MFA declines from 20^0 at the pith to 14^0 at the bark but unlike conifers, the angles are much lower near pith typically 15-$20^{o,}$ this report was in disagreement with the results of Pande (2011). The most notable difference is that among tree variations at the pith is only slightly greater then at then the bark in 15-yr old *E. nitens* (Evans *et al.*, 2000). MFA in *E. grandis* clones, Lima *et al.* (2004) found almost no change from pith to bark. However, the trees in their study were only 8-yr old. Differences in MFA among trees are generally more apparent in the juvenile wood. However, by the age of 15 yrs and beyond, the trees generally have comparable low MFA values (Donaldson, 1992). In contrary to the study of Lima *et al.* (2004), Pande (2011) showed non-significant pith to outwards variation in MFA with increasing trend. It may be explained that lower age of trees of study (Pande, 2011) showed non-stability of MFA in early phase of tree growth showing the impact of juvenile wood.

Vainio *et al*. (2002) have shown significant variation in MFA between provenances in *Picea sitchensis*, with trees from California and Queen Charlotte Islands provenance having higher MFA then trees of Washington and Oregon provenances. In spruce fiber, the pattern and extent of variation were investigated (Gilani *et al.*, 2006) and the results are in agreement of the idea that the orientation of MFA is not uniform along the radial wall of earlywood fibers. Their MFA was found highly variable within the radial wall of earlywood fibers, especially in the vicinity of the bordered pits. On the other hand, in tangential wall of earlywood and in the whole latewood fibers MFA was approximately uniform. In conifers, MFA varies from pith to bark, with the highest angles occurring in the first five growth rings from pith at the base of the tree (Phillips, 1941; Donaldson, 1992; Xu Bin *et al.,* 2004; Jordan *et al.*, 2005; Zhang *et al*., 2007).

MFA in L-34 clone was significantly negatively correlated with vessel element diameter whereas significantly positively correlated with specific gravity (Gautam, 2010). Tracheid length and micro-fibril angle were linearly, negatively and significantly correlated with each other within a tree in slash pine (*P. elliottii*), although there was no significant correlation between tracheid length and MFA among stands on the same location (Xu Youming *et al*., 1999). The result of study conducted by Pande (2011) was also in agreement with the later statement. Pith to bark variations *Populus* clones showed MFA ranging from 28^0 (pith) to 8^0 (bark) in 11-yr old trees at breast height (Fang *et al*., 2006).

The results of Gautam (2010) in *P. deltoides* was disagreement with the report for Douglas-fir trees, where MFA decreased with age from over 30Ú to about age 30 and tracheid length was highly correlated with MFA (Erickson and Tsuneo Arima, 1974), whereas study of Gautam (2010) showed non-linear relationship. McMillan (1973) described MFA of loblolly pine wood as related to specific gravity, growth rate and distance from pith. It was observed that MFA were greater for early-wood (avg.33.4Ú) than for the latewood tracheids (avg.29.6Ú). For early-wood, MFA did not differ between growth rates when the specific gravity was low (avg.33.3Ú) and the specific gravity was high, wood of fast growth had a higher MFA (avg.35.1Ú) than the wood of slow growth (avg.32.0Ú). No differences were detected between core, middle, and outer wood. In latewood trachieds, MFA were greater in core wood (avg. 28.0Ú) than in middle or outer wood (avg.26.3Ú). For whole wood, MFA averaged 30.7Ú and was greater in core wood (avg.32. 2Ú) than in middle or outer wood (avg.29.9Ú).

Sex Related Wood Anatomical Variations

Wood anatomical characters and specific gravity in relation to sex; inheritance from parents to the F_1 offspring of *P. deltoides* was reported by Aziz and Pande (2008, 2009). Fiber length was highest in female offspring (Bahar) followed by male offspring, female (G48) and male parent (G3). Vessel element diameter and specific gravity were higher in male group followed by female group. Offsprings also showed hybrid vigor.

Pande and Dhiman (2011) reported that fiber length and specific gravity were significantly higher in female, while wall thickness and vessel element length were higher in male clones. In another study, Pande *et al*. (2012) reported intra- and inter-ramet, and inter-clonal variation in dimensions of wood elements and specific gravity of six-yr old *P. deltoides* based on sexual dimorphism of a female (G48) and male clone (G3). Both of the clones differ significantly for fiber length and diameter, wall thickness, vessel element length and diameter, and specific gravity. Female (G48) clone showed higher fiber and vessel element dimensions but lower specific gravity than G3 clone, suggesting better fiber dimensions for G48 and specific gravity for G3. It showed female dominance on wood anatomical properties (Table 4).

Table 4. Clone mean wood element dimensions (µm) and specific gravity of G48 and G3

Wood trait	Clone	Mean±S.E.	95% Confidence interval	
			Lower bound	Upper bound
Fiber length (Unit)	G3	1075.14± 11.97	1051.55	1098.73
	G48	1244.07±11.97	1220.47	1267.66
Fiber diameter (Unit)	G3	23.19±0.47	22.27	24.12
	G48	26.68±0.47	25.75	27.60
Wall thickness (Unit)	G3	4.08±0.16	3.77	4.38
	G48	3.09±0.16	2.79	3.40
Vessel element length	G3	546.04±4.45	537.26	554.81
(Unit)	G48	590.32±4.45	581.54	599.09
Vessel element	G3	99.25±0.76	97.76	100.74
diameter (Unit)	G48	105.86±0.76	104.37	107.35
Specific gravity (Unit)	G3	0.41±0.004	0.40	0.42
	G48	0.39±0.004	0.38	0.40

Source: Pande and Dhiman, 2012

Variations in Micro- and Macro-Propagated Plantations

Intra- and inter-ramet variation in wood traits of micro-propagated L-34 clone plantation of *P. deltoides* was studied (Gautam *et al*., 2008). Intra- and inter-ramet variation in fiber diameter and vessel diameter was significant. Non-significant differences in most of the wood element's dimensions for height, direction and location showed homogeneous wood properties within the macro-propagated ramet of L-34 clone of *P. deltoides*. Significant intra-clonal variations for vessel element diameter and fiber diameter showed that these characters were not controlled in micro-propagated plantation wood of L-34 clone, while, important characters like fiber length, wall thickness and specific gravity were well controlled in L-34 clone. The site variations also affected the wood properties of the micro-propagated plantation wood. The dimensions of wood elements and standard deviation are set in Table 5.

Intra- and inter-clonal variations in fiber length, fiber diameter, wall thickness, vessel element length, vessel element diameter and specific gravity in the ramets of L34, G3 and S7C15 clones of *P. deltoides* at the age of 6-yr old produced from planting material grown by macro- and micro-propagation techniques were reported by Pande and Dhiman (2010). Intra-ramet variations were non-significant for all the characters except specific gravity for height in L-34 for macro and specific gravity and vessel element diameter for radial locations for micro, and fiber length for G3 (micro) for height, and specific gravity for radial location and fiber length for height for S7C15 clone for both the techniques. The variations were significant for vessel element length and specific gravity between the

Table 5. Mean ± SD for wood element's dimensions (µm) and specific gravity

Parameter/Clone			FL	FD	WT	VL	VD	SG
L34	Macro	Mean	960	24	3.56	519	100	0.384
		SD	80	1	0.27	32.0	6.1	0.039
	Micro	Mean	996	22	3.55	544	91	0.379
		SD	70	1	0.23	46	6	0.040
G3	Macro	Mean	1075	23	4.08	546	99	0.411
		SD	112	1	2.27	42	9	0.039
	Micro	Mean	1079	24	4.00	576	103	0.345
		SD	124	2	0.42	33	11	0.030
		% CV	12	7	11	6	11	9
S7C15	Macro	Mean	1010	23	4.15	554	92	0.383
		SD	129	1	0.30	47	6	0.036
	Micro	Mean	954	23	3.73	539	97	0.369
		SD	47	1	0.13	19	8	0.035

FL=fiber length, FD=fiber diameter, WT=wall thickness, VL=vessel element length, VD=vessel element diameter, SG=specific gravity and SD=standard deviation.
Source: Pande and Dhiman (2010).

wood produced from planting stocks grown by two techniques. Intra-clonal variations were significant for fiber length, fiber diameter and vessel element length. In general wood element's dimensions and specific gravity increased from bottom to top and pith to periphery radial locations. G3 clone was different from the L34 and S7C15 clone for the wood traits. The three different clones of *P. deltoides* showed variability in wood anatomical properties and specific gravity in the woods grown from macro- and micro-propagated planting stock. So, the plantation raised by two techniques could not produce similar type of wood even from the same clone. G3 clone was the exception as it did not show variation in wood traits for two techniques. Intra-clonal variations in all the three clones of *P. deltoides* indicated that wood traits were not stable within the population of same clone grown by either method (Pande and Dhiman, 2010).

Inheritance Patterns and Heritability

The inheritance of fiber characteristics in hardwoods was reviewed by Zobel (1965) but there has been a great deal of information developed since then, especially for the genera *Eucalyptus* and *Populus*. Evidence for hardwood is somewhat scant, but those studies reported indicate that there is a moderate genetic control of cell length. A striking example of a large increase in fiber length was that obtained through polyploidy in *Populus* spp., where van Buijtenen *et al.* (1958) found fiber length to be increased by 21-26 per cent. Genetic gain for all the wood and growth traits was positive particularly for most important wood trait like specific gravity, wall thickness (Pande, 2011).

Inheritance patterns of wood traits were reported by Aziz and Pande (2008) in parents and F1 hybrid clones of *P. deltoides*. The variations were significant for wall thickness and were found to be highest in offspring than parents showing hybrid vigor. Characters like fiber length, wall thickness and vessel element length were higher in the offsprings followed by parents whereas fiber diameter, vessel element diameter, specific gravity and Runkel ratio were higher in parents followed by the offspring.

The inheritance patterns of different wood traits in different three crosses (G48*G3, G48*St-63 and C7S8*G3) of *P. deltoides* were reported by Pande (2011). The combination of all the wood traits indicated that wood anatomical properties and specific gravity inherited male parent to male offsprings while female parent to female offsprings. The exception was CC01 (male clone) which clustered with female parent (G48) and indicated that there might be possibility of inheritance of wood traits from female parent to male offspring. Further, in the cross of G48*St-63, the pattern of inheritance from both the parents to female hybrid clones only. It may be due to the divergence of male parent, viz. St-63 from all the F1 offsprings and female parent. The inheritance pattern in C7S8*G3 cross was male parent to male and female offsprings and female parent to female offsprings only. Hence, it indicated that wood traits mostly inherited in *P. deltoides* from same parental sex to same offspring sex. Further, enhancement in the dimensions of wood traits in F1 male offsprings showed the influence of hybrid vigor. On the basis of different crosses, following pattern of inheritance for wood traits were reported (Pande, 2011):

1. Female parent to female offsprings and male parent to male offsprings.
2. Female parent to both male and female offsprings and male parent to both male and female offsprings.
3. Male parents to female offsprings and female parent to male offsprings.
4. The traits are higher in the offsprings than of the parents showing hybrid vigor.

Heritability, Genetic Advancement and Genetic Gain for Growth and Wood Traits

The genetic parameters like total genetic variations and genetic control for a particular trait are important tools to predict the amount of gain to be expected from the genetic material (Foster and Shaw, 1988; Kumar, 2007). The genotypic and phenotypic coefficient of variation for all the wood traits indicated the adequate amount of genotypic variations. The higher genotypic and phenotypic coefficient of variations were showed by wall thickness and vessel element dimensions. The higher values of phenotypic coefficient of variation as compared to genotypic coefficient of variations for fiber length and vessel element length indicated that these characters were also influenced by the other factors. The fiber wall thickness and specific gravity are the characters which are more in genetic control (Pande, 2011).

Heritability expresses the degree to which a character is influenced by genes as compared to environment. Broad sense heritability (h2) was 0.54 for fiber length, 0.68 for fiber diameter, 0.85 fiber wall thickness, 0.64 for vessel element length, 0.84 for vessel element diameter and 0.60 for specific gravity (Pande, 2011). The heritability values reported for different species of *Populus* and their clones were in the range of 0.56 - 0.70 (Farmer and Wilcox, 1966, 1968; Reck, 1974; Nepveu *et al.*, 1978) for specific gravity. The heritability values for fiber length for *P. deltoides* was reported as 0.36 (Farmer and Wilcox, 1968); for *Populus* polyploids was 0.50 (Einspahr *et al.*, 1963) and for *P. trichocarpa* was 0.71 (Reck, 1974). The values of heritability reported by Pande (2011) were well within the range of the above reported values for fiber length and specific gravity. Though, evidences on heritability for hardwoods are somewhat scant, yet those studies indicate that there is moderate genetic control of cell length (Zobel and Buijtenen, 1989). Heritability values express the proportion of variation in the clones that is attributed the genetic differences among the clones, genetic advance indicates average improvement in the offspring over the parents. In the study of Pande (2011), genetic advance was higher for vessel element length (82.13) followed by fiber length (73.88), vessel element diameter (31.87), fiber diameter (2.59), wall thickness (0.95) and lowest for specific gravity (0.04). Genetic gain (per cent) was higher for vessel element diameter (28.39) followed by wall thickness (25.82), vessel element length (14.26), fiber diameter (10.84), specific gravity (8.99) and fiber length (6.45) for the wood traits.

The narrow sense heritability was also calculated for the studied traits from parent -offspring regression. The trend between broad sense and narrow sense heritability was more or less similar (Pande, 2011). It is important to calculate so that additive genetic variance associated with individual trait component can be calculated. In case of full sib families are measured, and progeny value were regressed on the average value of two parents (midparent value), then equals to narrow sense heritability (Zobel and Tilbert, 1984).

Most of the work on specific gravity and fiber dimensions of hardwood has concentrated on the eucalypts and poplars. Although some of the studies were not as rigorous as could be desired, it appears that wood specific gravity in these two genera is inherited as strongly or stronger than in conifers. This seems to be true for sycamore (*Platanus*) and *P. deltoides* (Pande, 2011). The inheritance of specific gravity in *Swietenia* and teak (*Tectona*) is somewhat weaker, but results are based on fewer studies. However, in the study (Pande, 2011), higher values of heritability of *P. deltoides* indicated that heritability studies were also important for wood traits like fiber dimensions and specific gravity for breeding program. There is a current upsurge of interest in inheritance of wood properties in hardwoods, and soon many results will be available for trees beyond the juvenile stage (Zobel and Buijtenen, 1989).

Higher heritability values and positive genetic gain for wood traits for *P. deltoides* showed that there was a great possibility of the improvement of the species for wood and growth traits through different and defined breeding programs.

Conclusion

The work of various authorities in the context of wood anatomy and other physical properties of wood leads to the following conclusions:

1. The anatomical structure of *P. ciliata*, *P. alba*, *P.euphratica* and *P. deltoides* is more or less similar, however, the colour differentiation in wood was reported; grey or brownish grey in *P. ciliata*, sapwood white and heartwood red coloured and black near the pith in *P. euphratica*, whereas white often with red or yellowish tinge in *P. alba* white to offwhite in *P. deltoides*.
2. Within ramet vertical and radial variations in wood traits namely fiber- and vessel element-dimensions and specific gravity were significant and non-significant for different clones of *P. deltoides* for different wood traits differently. It showed that some clones were stable for wood properties while some were not. Different clones do not follow the similar trend for the wood traits.
3. Intra- and inter – ramet significant variations for some of the clones of *P. deltoides* showed variation with in the population of same clone and different clones. Stable clones which showed within-tree and intra-clonal non-significant variations for wood traits may be preferred for stable wood properties in tree improvement program.
4. Higher fiber percentage showed mature properties of poplar clones.

5. Female dominance was reported for wood anatomical traits in *P. deltoides*.
6. The plantation raised by two techniques, viz., micro- and macro-propagation could not produce similar type of wood even from the same clone. Intra-clonal variations in all the three clones of *P. deltoides* indicated that wood traits were not stable within the population of same clone grown by either method. The site variations also affect the wood properties of the micro-propagated plantation wood.
7. The wood traits mostly inherited in *P. deltoides* from same parental sex to same offspring sex. Further, enhancement in the dimensions of wood traits in F1 male offsprings showed the influence of hybrid vigor.
8. Higher heritability values and positive genetic gain for wood traits for *P. deltoides* showed that there was a great possibility of the improvement of the species for wood traits through different and defined breeding programs.

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Mapping Research on Poplar (*Populus* spp.) in 'Forest Science Database'

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Introduction

The *Populus* genus consists of more than thirty species distributed across the cold temperate region in northern hemisphere. According to the foreword of 23rd Session of International Poplar Commission, Beijing, China... Poplars and willows contribute significantly to people, their lives, and livelihoods through the provision of wood products (industrial roundwood and poles, pulp and paper, reconstituted boards, plywood, veneer, sawn timber, packing crates, pallets, furniture, etc.), non-wood products (fodder, medicines, etc.) and environmental and social services (shelter, shade and protection of soil, water, crops, livestock and dwellings). Poplars and willows play an important role in phyto-remediation of severely degraded sites, rehabilitation of fragile ecosystems, landscape restoration, sequestration of carbon and, increasingly, as a viable source of bioenergy. The environmental applications of poplars and willows are also being recognized as effective means for recreational and amenity purposes. Of late, multifarious uses of crops like poplar have made inroads to the livelihood issues of people in both developed and developing economies.

Populus deltoides Marsh. is one of important commercial timber species of the genus, introduced in India for mainly match industry. Other species of the *Populus* genus like *Populus ciliata, P. alba, P. euphratica, P. gamblii, P. jacquemontii* var. *glauca and P. rotundifolia* are indigenous to India and are potential species as raw material for wood and pulp based industries. In India, poplars are extensively cultivated in states of Punjab, Haryana, Uttar Pradesh, Uttarakhand and also in some parts of lower Himachal Pradesh, Jammu and Kashmir in agroforestry system. Poplars cultivation has played and still continues to play very important and significant role in strengthening rural economy, thereby, improvement of life of farmers. Plantations in the Tarai regions of Uttarakhand and fertile lands of Punjab and Haryana have helped in generation of employment and improvement of livelihood of the common people.

In the last decade, considerable amount of research and development work had been carried out in poplars to meet the needs of farmers and industries. Growth of scientific and technical literature is a related manifestation. Therefore, an attempt was made to carry out bibliometric analysis of the published records on poplars.

Considerable amount of research and development work had been carried out in poplars to meet the needs of farmers and industries. Growth of scientific and technical literature is a related manifestation

Bibliographical databases are repository of these bibliographic or publication records. These databases provide an index of articles published in multiple journals including citations, abstracts and even a link to the full text (free or paid). Forest Science Database is the world's richest bibliographic database on forestry and allied disciplines like wood science, agroforestry, etc. It is a source not only for literature survey for research but also an important tool to study trends in research and development in selected, focused topic in forest science. Eleven-year data (2000-2011) on poplars appearing in title or abstract fields in the records of Forest Science Database was analyzed with objectives to identify year-wise distribution of indexed documents, publication types, geographical distribution, language, authorship pattern and ranking of journals.

Review of Literature

Bibliometric or literature mapping studies are available in important subject areas which are referred by wider readers of subject areas such as medicine, social science, climate change, natural disasters, etc. Arrebola and García (2002) in their study observed that international research in pharmaco-epidemiology presents an exponential growth pattern in accordance with Price's law. There is a large degree of publishing dispersion. Indian Pharmaceutical Association (IPA), a premier professional association of pharmacists in India, publishes bibliographic databases that have the greatest number of original articles; nearly half of which were published in pharmaco-epidemiology and drug safety. These databases are, therefore, considered to be appropriate for bibliometric studies in the field of pharmaco-epidemiology.

Ruiz-Perez *et al.* (2002) in their research on Spanish personal name variations in national and international biomedical databases investigated how Spanish names were handled by national and international databases and to identify mistakes that can undermine the usefulness of these databases for locating and retrieving works of Spanish authors. Russell and Rousseau (2002) in their study entitled 'Bibliometrics and institutional evaluation' observed that literature-based or bibliometric indicators, which quantify the production and use of bibliographic material, have been used extensively in the assessment of research performance. The potential of web-based electronic sources for providing comprehensive and accurate production and citation data for bibliometric analysis coupled with the capacity of the Internet to integrate information from a large number of different sources, promises to revolutionize the way indicators are constructed by eliminating many of the methodological constraints experienced today. Wolfgangglanzel (2002) in his study of co-authorship patterns and trends in the sciences from year 1980-1998 described both common and the distinguishing features of co-authorship trends and patterns in selected science fields. The relation between co-authorship schemes and other bibliometric features, such as publication activity and citation impacts were also analyzed in the study. Moed *et al.* (2009) in their research report revealed that the creation of databases of social sciences and humanities in Spain for research development is expected to go on; Thomson Reuters and Elsevier will further enhance the coverage of 50 social sciences and humanities fields; Google will further enhance its products 'Scholar' and 'Book Search' and possibly integrate them; and institutional repositories and research management systems will further develop.

He Ping *et al.* (2009) analysed published work on invasive alien species in forestry. Poplar, an important tree species, is one of the choice species of research for forest scientists. First time, Gao Jie *et al.* (2010) carried out detailed bibliographic analysis of core journals on poplar research in China. They had statistically analyzed the number of papers, their year-wise and periodicals distribution, research subjects, core authors, etc. in the core journals from 2000 to 2009 with the help of literature methodology to demonstrate the research status and level and technological achievements in this subject. Recently, Chong *et al.* (2012) analysed the engineering research papers engaged in the area of 'conversion of farmland back to forests' in China from 1999 to 2010, on aspect of the annual variation in output volume, the authors' institutions, distribution of journals and disciplines, published topics and authors' collaboration degrees.

Materials and Methods

Forest Science Database, a world's leading bibliographic database on forestry containing data of CABI, U.K., published by Ovid Technologies, Wolters Kluwer was selected for the study. It index documents on forest, forestry, wood science, agroforestry research, etc. and is closely associated with the continued advancement in forestry in the world. It covers all aspects of forestry, its administration, management and information on recent development in researches carried out in the world. It is one of the core bibliographical databases most consulted by the scientists and researchers for primary information in forestry. All the research publications indexed in the database during 2000-

2011 containing poplar or *Populus* in abstract or title fields were browsed accessing them through scanned and selected considering year-wise distribution of indexed documents, publication types, geographical distribution, language, authorship pattern and ranking of journals. Finally, all the collected data was manually entered into an Microsoft Excel (2007) and analyzed for trends.

Results

Distribution of the Number of Indexed Documents Published During 2000 – 2011

The year wise distribution (2000-2011) of the indexed documents is presented in Fig. 1. The total number of contributed research papers was 8,946. It was observed that maximum number of research papers; i.e. 1,079 (12.6 per cent) were published in the year 2010. The lowest number of research papers of 606 (6.8 per cent) were published in the year 2003. On an average, more than 800 research papers on poplars were published during the period. Overall, there was an increasing trend in number of articles appearing on poplars during the study period. The number of publication dipped in the year 2003 and 2009. However, sharp increase in the literature on poplars was recorded after 2003 and 2009.

Geographical Distribution of the Indexed Journals Publishing Articles on Poplars

Of 8,946 records appearing in the Forest Science Database, there were maximum numbers of publications from USA (2,415) followed by China (2,089). Canada also published a good number of papers; i.e., 1,168. Yugoslavia (823) and India (593) had close tally (Fig. 2.). The data indicates that the publications on poplar were significantly growing in China making it second to USA.

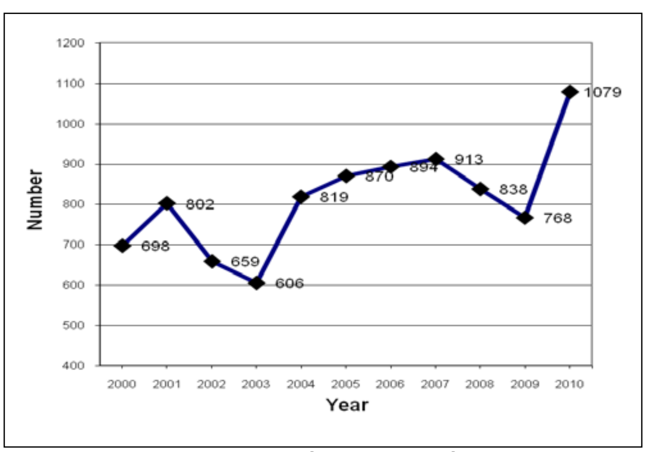

Fig. 1. Yearly distribution of documents from 2000-2011.

Language of the Published Articles

The records in different languages are presented in Table 1. Languages with less than 5 records are clubbed together under the heading 'others'. Text of the indexed journals was in 30 languages. Maximum indexed journals were in English (6,485) as it is an international language for scientific

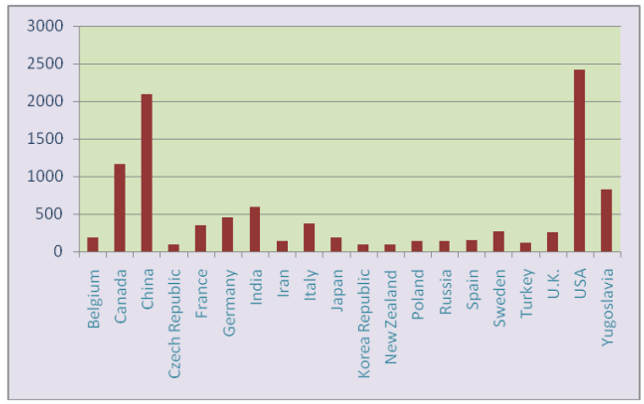

Fig. 2. Country wise distribution of the published articles on poplars.

Table 1. Language of text of the articles

Language	Total no. of records	Per cent
Bulgarian	9	0.1
Chinese	1,352	15.1
Croatian	30	0.3
Czech	15	0.2
Dutch	15	0.2
English	6,485	72.5
Estonian	15	0.2
French	175	2.0
German	134	1.5
Hungarian	16	0.2
Italian	153	1.7
Japanese	14	0.2
Korean	33	0.4
Lithuanian	13	0.2
Persian	112	1.3
Polish	36	0.4
Portugese	18	0.2
Romanian	24	0.3
Serbian	34	0.4
Slovakian	22	0.3
Spanish	91	1.0
Swedish	9	0.1
Turkish	28	0.3
Others (countries with less than five records)	113	1.3
Total	**8,946**	**100.0**

communication. It was followed by Chinese (1,352), French (175), Italian (153), German (134) and Persian (112) which had at least 100 numbers. Hindi language journals were not included in this database. There is a need for promotion of Hindi in forestry research publications, so that, both common man and professional can consult them. Considerable literature is available in Chinese that, unfortunately, not consulted by non Chinese researchers. It makes a strong case of translation into English for larger dissemination of information to the poplar research groups around the world.

Contribution of Authors

Authors' contribution was also analysed and it was found that each publication has single as well as multiple authors. Ten thousand nine hundred and eight authors contributed only one time followed by 2,017 (two times), 277 (three times), 152 (four times), 86 (five times), 95 (six times), 36 (seven times), 26 (eight times), 17 (nine times) and 9 (10 times) and so on (Table 2). Top 10 authors with more than 17 contributions are presented in Fig. 3 and other authors with less than 18 contributions are presented in Fig. 4.

Table 2. Number of authors and their contributions

Author	Contribution	Author	Contribution
1	52	9	10
1	48	12	13
1	29	15	12
1	24	17	11
1	17	17	9
2	30	26	8
2	23	36	7
3	21	86	5
3	19	95	6
4	16	152	4
5	20	277	3
6	15	2,017	2
8	18	10,908	1
9	14		

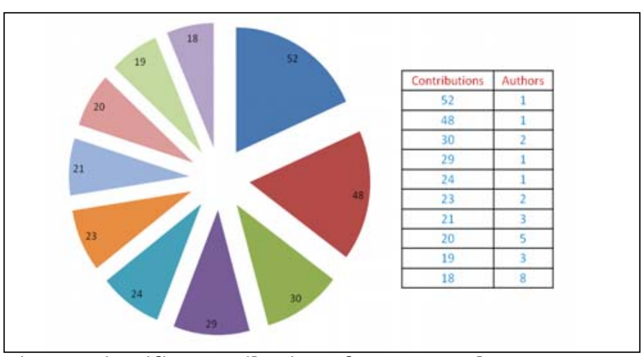

Fig. 3. Scientific contribution of top ten authors.

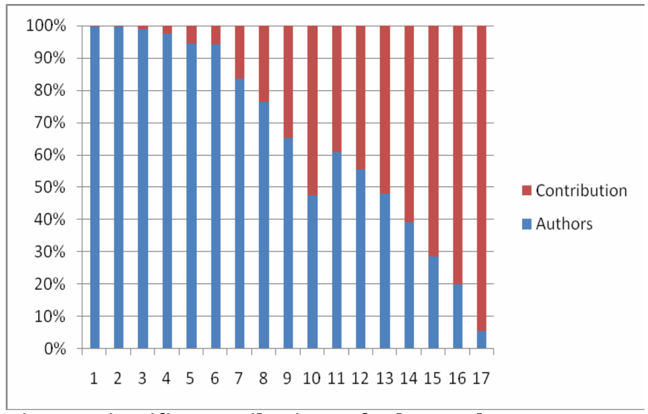

Fig. 4. Scientific contributions of other authors.

Publication Types

Research results are primarily published in journal, conference proceedings, book chapters and theses. Table 3 lists out various types of documents containing research information on poplars during 2000-2011. In the present study, it was observed that maximum literature published as journal articles (8,066) followed by book chapters or conference papers (343) and, then conference papers published in journals (338). Other types of publications included bulletins, bulletin articles, journal issues, books and book chapters. The number and forms of information sources are continuously increasing with advances in information technology.

Journals and Their Ranking

Forest Ecology and Management, Scientia Silvae Sinicae, Canadian Journal of Forest Research, Tree Physiology, Journal of Northeast Forestry University, Journal of Beijing Forestry University, Indian Forester are top journals publishing over 100 articles on poplars from year 2000-

Table 3. Publication types of indexed journals

Publication type	Total no. of records	Per cent
Annual report	06	0.1
Book	16	0.2
Book chapter	62	0.7
Book chapter; Conference paper	343	3.9
Bulletin	64	0.7
Bulletin article	30	0.3
Conference proceedings	02	0.02
Correspondence	01	0.01
Journal article	8,066	89.9
Conference papers published in journals	338	3.8
Journal issue	24	0.3
Miscellaneous	20	0.2
Thesis	04	0.04
Total	**8,976**	**100.0**

2011. More number of journals in Chinese language (Table 4) is probably is one of the reasons for having large number of articles in the Chinese language. In spite the more numbers of publications, the impact factor of the Chinese journals was low. The position of other journals was-60 journals (10-50 times); 699 journals (1 time); 634 journals (2-9 times).

Table 4. Ranking of highly indexed journals based on number of papers on poplars

Source	Total no. of records
Forest Ecology and Management	230
Scientia Silvae Sinicae	212
Canadian Journal of Forest Research	197
Tree Physiology	154
Journal of Northeast Forestry University	151
Journal of Beijing Forestry University	145
Indian Forester	117
Journal of Nanjing Forestry University Natural Sciences Edition	97
New Phytologist	90
Plant Physiology	89
Forest Research, Beijing	86
Forestry Studies in China	75
Biomass and Bioenergy	73
Forest Products Journal	69
Holzforschung	69
Bulletin Trimestriel Centre de Populiculture du Hainaut	58
Plant, Cell and Environment	54
Wood and Fiber Science	54
Environmental Pollution	53
Acta Botanica Boreali Occidentalia Sinica	52
Annals of Forest Science	52
Canadian Journal of Botany	51

Discussion

Poplar along with willow is grown in about 70 countries with its area exceeding 80 million hectares. The Russian Federation, Canada and the United States have the largest reported areas of naturally occurring poplar and willows, while China, India and Pakistan have the largest planted areas (Ball and Lungo, 2005). As per the synthesis of country progress report of the 23rd Session of the International Poplar Commission held at China, there was a positive trend in the growth of area under poplar cultivation in US, China and India grown in agroforestry or trees outside forest area. In China, this area was 1,000,000ha which increased to 2,500,000ha in 2007. In India, this figure was 60,000 ha in both years. Canada had also shown increase in the planted area from 9,000 to 14,000 ha. As plantation there was increase in the area from 3,900,000 to 4,300,000ha in China. There was no change in area under indigenous poplar in USA and India and positive increasing trend in China for indigenous polar. This explains the voluminous publications on poplars from China close to USA. It also indicates that maximum work on poplars is being carried out in developed countries like USA. However, developing country like China is closely following the USA.

Science refines production tools and means of production - in the present case the production technology of poplars. China, a planned economy, reflects this interconnection best in terms of expanding area under poplars as well as raising quantity and quality of research efforts and publications. This relationship may not be so simple in countries like India and needs critical investigation. Journal articles and conference papers are choice publication type for researchers around the world. Largest numbers of publications on poplars were published in journals like Forest Ecology and Management, Scientia Silvae Sinicae, Canadian Journal of Forest Research, etc. To link the research output (in terms of publication) with societal needs, it is essential to map the data based on the subject/discipline for identification of gaps.

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Yeh, Francis C. 2000. Population genetics. In: Young, A.; Boshier, D. and Boyle, T. *Eds.* Forest conservation genetics: Principles and practice. Collingwood, CSIRO. pp. 21-37.

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National Workshop on Rattans (Canes), Banglore, 4-5 February 1999. 1999. Proceedings. Bangalore, Bamboo Society of India. 106p.

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Thesis:

Upadhyay, A. 1987. Transposon induced mutagenesis in *Bacillus brevis* AG 4. M.Sc. thesis. G.B. Pant University of Agriculture and Technology, Pantnagar. 214 p.

‘हे वृक्ष’

हे वृक्ष विनम्र, विशाल, मनीषी!
विरक्त मानो एक तपस्वी,
केवल देना जाना तुमने, नहीं कभी कुछ माँगा तुमने।
जीवन जीना केवल परहित, नन्हें बीज में छिपा अस्तित्व।
सृष्टि की तुम अनुपम रचना, तुम बिन जीवन केवल सपना।
मानव मात्र ने दिया प्यार जब, रोपा, सींचा तुम्हें स्वार्थवश,
तुमने दिया अपार, अपरिमित, मानव ने फिर भी न समझा।
काटा, रौंधा, कुचला तुमको, फिर भी पाया प्यार असीमित।
अपना सा विनीत तुम मुझे बना दो।
जीवन ‘परमार्थ हेतु’ तुम मुझे सिखा दो।
तुम्हारे सम्मुख हूँ नत्मस्तक,
हे वृक्ष विनम्र, विशाल, मनीषी!

मधु षर्मा

‘Oh Divine Tree’

Oh divine tree! such a selfless giver you are..
Yet so detached to stand like an enlightened sage
Selfless giving is your only way to live, would you ever ask anything of us?
You stand humbly in the service of others, how simple despite that life hidden in your little seed
What divine uniqueness you exhibit as universe’s magnificent creation
A world without you is like an ocean without water
Mankind nurtured you for its own benefit, but generously, you gave all of yourself
Alas! Man couldn’t fathom the depth of your loving heart, he exploited and destroyed you endlessly
And even then, received selfless giving from your infinite heart
Oh divine tree! such a selfless giver you are..
Enable me to transform the expanse of my heart to be like yours
Show me the way to your humble greatness
Oh divine tree! such a selfless giver you are..

Madhu Sharma