

**EVALUATION OF POPLAR (*POPULUS
DELTOIDES*) FOR SPACING UNDER NURSERY
AND FIELD PLANTATION**

By

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(2013A63D)

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requirement for the degree of*

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2017

CERTIFICATE-I

This is to certify that the thesis entitled, “**Evaluation of poplar (*Populus deltoides*) for spacing under nursery and field plantation**” submitted for the degree of **Doctor of Philosophy**, in the subject of “**Forestry**” to the CCS Haryana Agricultural University, is a bonafide research work carried out by **Pradyuman Singh (Admn. No. 2013A63D)** under my supervision and that no part of this dissertation has been submitted for any other degree.

The assistance and help received during the course of investigation have been fully acknowledged.

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LIST OF ABBREVIATIONS

%	Per cent
°C	Degree Celsius
Av.	Average
C.D.	Critical difference
Cm	Centimetre
DAP	Days after planting
B : C ratio	Benefit –Cost ratio
NPV	Net present value
IRR	Internal rate of return
<i>et al</i>	<i>Et alibi</i> (and other)
Fig.	Figure
G	Gram
Ha	Hectare
i.e.	That is
kg.	Kilogram
M	Meter
ETPs	Entire Transplants
Mm	Millimeter
No.	Number
NS	Non significant
T	Tone
<i>Viz;</i>	Namely
HFDC	Haryana Forest Development corporation
Wt.	Weight
CAI	Current annual increment
MAI	Mean annual increment

CHAPTER-I

INTRODUCTION

India faces a critical imbalance in its natural resource base with about 18 % human and 15 % of livestock population of the world being supported only by 2.4 % of geographical area, 1.5% of forest and pasture lands and 4.2% of water resources. The increasing deforestation for human habitation, developmental activities and intensive agriculture resulted in ecological imbalance. Therefore, need has been realized for conservation of natural resources and protection of the deteriorating environment so that the required growth in countries GDP is maintained with sustainability (Chauhan *et al.*, 2012). For such a scenario, diversification of land-use systems with agroforestry is a necessary strategy for providing a variety of products to meet out the requirements of the people, insurance against risks caused by weather aberrations, controlling erosion hazards and ensuring sustainable production on a long-term basis and must play an important role in achieving country's food security at large. Agroforestry, growing of multipurpose trees along with agricultural crops is one of the key paths towards the prosperity of poor people suffering from hunger, malnutrition, poverty and deterioration of the environment in the areas that have been passed by the Green revolution (Garrity 2004; Luedeling *et al.*, 2016).

The total forest area and tree cover of the India estimated to be 24.16 percent of its geographic area as per the latest State of Forest Report of India. The total growing stock of wood in the country is estimated to be 5,768 million m³ that includes 4,195 million m³ inside forest area and 1, 573 million m³ of trees outside forests (TOF). The current approximate area under agroforestry is estimated to be 11.54 m ha, which is 3.39 % of the total geographical area of the country. The total growing stock of wood in agroforestry system of the country is estimated to be 1,022.85 million m³ (FSI, 2015). According to National Forest Policy 1988, one-third of the land area should be under the tree cover for sound ecological balance. The National Forest Policy also states that the natural forest serve as a gene pool resource and help in maintaining ecological balance, therefore such forest will not be made available to industries.

Agroforestry is increasingly seen as a promising approach to improving food security (Glover *et al.*, 2012), largely because the trees are associated with enhancing and sustaining soil health and more so crop yield (Barrios *et al.*, 2012). Agroforestry plays a vital role in the Indian economy in terms of tangible and intangible benefits. At present, agroforestry meets 100 million cubic meter timber/pulpwood for industrial and domestic use and 150 million tonnes firewood, add approximately 15 million tonnes organic matter through leaf fall, sequester 60 million tonnes carbon annually in tree components (excluding in soil and that

locked in the wood products), and generate employment of 4000 million person days/ annum in nursery and plantation activities. The value of wood/pulpwood produced is estimated to be around Rs. 10,000 billion and that of firewood as Rs. 30,000 million annually. It is evident from the fact that the private enterprises like pulpwood, match wood and other plywood industries are in huge demand for raw material supply which can be fulfilled through PPP model or any new approaches that will be beneficial to the farmer also and will indirectly help in achieving forest cover (NAP, 2014).

Realizing the importance of agroforestry, Government of India has pronounced a National Agroforestry Policy (2014) and directed the stakeholders for speedy implementation. As our Government owned forests cannot meet ever increasing requirements of industrial round-wood, National Forest Policy, 1988 suggests that wood based industries should source their future wood supplies through persuading farmers to raise agroforestry plantations. Substantial improvement in productivity of forest resources on sustainable basis and promotion of large scale agroforestry plantations are most essential for meeting the national needs for fuel-wood, timber and wood products on sustainable basis and conservation of the forest resources. Productivity and net returns from seed based agroforestry plantations have been generally very low mainly because of extremely poor genetic quality of seed most often used and non- availability of adequate quantities of genetically improved planting stock. Establishing plantation of fast- growing tree species is currently being advanced around the world as a means to meet as realizing goals such as increasing biodiversity and sequestering carbon (Sedjo, 1999; Mckenney *et al.*, 2004).

Among several industrial fast growing tree species, *Populus deltoides* Bartr. Ex Marsh., is one such promising species recognized as important tree component in agroforestry system to fulfill the timber demand and to obtain environmental benefits on sustainable basis (Pandey, 2007). Poplar (*Populus deltoides*) is now widely grown all over the Northern India mainly concentrated in Punjab, Haryana, Western Uttar Pradesh, *etc.* and is considered as most suitable agroforestry tree because of its desirable characteristics and multiple uses. Poplar prefers neutral soils, but can be grown well on soils having pH from 5.5 to 8.0. In India, about 225 clones of various poplars were introduced and some of them performed extremely well in Northern conditions (Mathur and Sharma, 1983). The species was introduced in India to enhanced the productivity and maintain the ecological balance and to cater the increasing demand of paper and plywood industry. Recently poplar has got much attention because of its preference by the plywood and paper industry. Development and large scale deployment of tested genetically superior clones of poplar supplemented with improved scientific package of practices have redefined productivity standards making agroforestry plantations an attractive land-use option with net returns significantly higher than those from traditional tree crops. It is successfully planted under

irrigated conditions and success is restricted to correct choice of clone, spacing and better management practices. Various adopted clones like G-3, G-48, L-34, S7C15, Uday, Kranti and Bahar are suitable for the different agroclimatic conditions of North India. The absolute major efforts of WIMCO Seedlings Ltd., Rudrapur (Uttaranchal) helped to develop agroforestry in India's Green revolution heart land. They had tested several new clones for better performance and adaptability. Recently, they had registered six new clones of poplar viz; WSL-22, WSL-27, WSL-32, WSL-39, WSL-A26 and WSL-A49 with the International Poplar Commission of FAO, Italy (Bangarwa, 2007). In successful agroforestry plantations, wider spacing, choice of clones, proper agronomic practices helps for greater returns. Wider spacing permits enough sunlight for crop production and provides space for proper soil working. It is worthwhile to mention here that poplar responds more to deep and frequent soil working than application of plant nutrients. Generally poplar is planted at 5×4 m, 5×5 m, 7×3.5 m, 8×2.5 m spacing, which permit for easy movement of agricultural machineries. As the farmers have taken up poplar cultivation in a big way, they are curious to know the quality and the quantity of their produce and also want to know an estimation of their standing tree crop and return from its sale before the final decision about its marketing but they have no tools available to make such an estimate. Average productivity of commercial poplar clones is $20-25 \text{ m}^3 \text{ ha}^{-1} \text{ yr}^{-1}$. However, many farmers have achieved trend setting high productivity of $50 \text{ m}^3 \text{ ha}^{-1} \text{ yr}^{-1}$ for poplar plantations. The annual returns from its cultivation are estimated to be up to Rs.250,000 $\text{ha}^{-1} \text{ yr}^{-1}$.

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. With intensive management of poplar based agroforestry models, the farmers are getting better financial returns than from other cropping rotations. It has not only benefitted farmers but has also helped the wood based industry. Therefore, keeping in view, the importance of poplar in agroforestry the present investigation was planned to analyze the suitable spacings of poplar under nursery and field plantation with the following main objectives:

1. To find optimum spacing for maximum growth of poplar in nursery and field plantations
2. To study the growth pattern of Poplar in nursery and field plantation
3. To find economic return from nursery raising and field plantation of poplar and to identify best stage of harvesting

CHAPTER-II

REVIEW OF LITERATURE

Planting of high density short rotation tree species is the best option to meet increasing food and industrial raw material requirement through sustainable utilization of natural resources (Sarvade *et al.*, 2014). The proper choice of spacing for field plantation of species will have a significant impact on the success of the agroforestry system. Appropriate selection of tree and crop species helps to increase yield, improve soil fertility, promote land sustainability and resource use efficiency (Sharma *et al.*, 2004; Muthuri *et al.*, 2005; Jose, 2009; Dhyani *et al.*, 2009; Jha *et al.*, 2010; Antonio and Gama- Rodrigues, 2011). There is wide scope of practicing alternate land use management system in order to increase production capability of land and to achieve sustainable, nutritional and ecological security. Poplar based agroforestry systems are economically viable and more profitable than many of the other crop rotations (Jain and Singh, 2000). The past three decades have witnessed the rapid increase in poplar based agroforestry as an alternate land use practice in north-western states of India. It is a general practice to combine agricultural crops with poplar plantations.

In this chapter an attempt has been made to review the literature on different aspects of study with emphasis on poplar for spacing under nursery and field plantation in Yamunanagar district of Haryana. The relevant literature available globally is being reviewed under the following heads:

2.1. Effect of spacing on growth of poplar under nursery condition and agroforestry system

Kumar (2004) studied the effect of various spacings ranging from 30 × 30 cm to 90 × 90 cm on the growth of poplars in the nursery under flood plain zone of Punjab. He reported that plants grown at wider spacing of 90 × 90 cm recorded maximum height and diameter growth. However, close spacing of 30 × 30 cm had minimum plant growth. In general, wider spacing resulted in more plant height and diameter, whereas narrower spacing reduced the plant growth.

Puri *et al.* (2002) conducted an experiment to evaluation of 106 clones for 4 years at Raipur, Madhya Pradesh. Under this experiment 19 clones were selected for field evaluation based on growth and survival performance in the nursery for two successive years. Out of 19 the best five clones (G3, G48, 65/ 27, D121 and S7C1) were planted in an agrisilviculture system at spacing of 4 × 4 m with soybean grown as an intercrop. They reported that after 4 years these clones had an increment of DBH by 66.5 to 77.5% and of height by 42.2 to 78.6% within one year when compared to that observed at 3 years of age. Total biomass varied between 20.9 to 35.8 Mg ha⁻¹ in different clones that followed the order 65/27 > D-121 > G-

48 > G-3 > S7C1. Among the tree components, stem wood accounted for 52-61% of the total biomass, followed by branches (20-25%), bark (9-13%) and leaves (7-10%). No significant variation between net primary productivity and photosynthetic efficiency was found in different clones. The productivity of soybean decreased with the advancement of age, reaching 40.5 to 58.1% in 4-year-old trees.

Stefanou *et al.* (2017) conducted an experiment to study the growth characters like diameter and height as well as mineral fertilization in young poplar. The two forest nurseries of northern Greece were undertaken for the study, where the growth of *Populus* spp. clone I-214 under five fertilization treatments per dosage was 120 kg $(\text{NH}_4)_2\text{SO}_4 \text{ ha}^{-1}$, 200 kg $(\text{NH}_4)_2\text{SO}_4 \text{ ha}^{-1}$, 150 kg $(\text{NH}_4)_2\text{SO}_4 \text{ ha}^{-1}$ and 300 kg mixed fertilizer 11-15-15 (i.e. 11 kg N, 15 kg P_2O_5 and 15 kg K_2O per 100 kg of fertilizer) ha^{-1} , 150 kg $(\text{NH}_4)_2\text{SO}_4 \text{ ha}^{-1}$, 200 kg mixed fertilizer 16-20-0 (i.e. 16 kg N and 20 kg P_2O_5 per 100 kg of fertilizer) ha^{-1} and 100 kg $\text{K}_2\text{SO}_4 \text{ ha}^{-1}$, and no fertilization. It was revealed that initial diameter had the greatest effect on growth, while the fertilization with 150 kg $(\text{NH}_4)_2\text{SO}_4 \text{ ha}^{-1}$ and 300 kg mixed fertilizer 11-15-15 ha^{-1} improved significantly diameter growth. Nevertheless, no specific pattern was found statistically for the best fertilization treatment concerning the height growth of young poplar trees.

The effect of fertilizer levels and spacings on growth parameters, biomass production, nutrients and litter production in poplar nursery were studied by Mohsin and Singh (2008). They were observed that fertilizer application showed significantly positive effect on collar diameter, height, shoot and root biomass, concentration, litter production and its nutrient concentration. Effect of higher fertilizer dose was also observed on litterfall and increased nutrient contents of soil under poplar nursery. Wider spacing (80 × 60 cm) produced plants having significantly higher biomass and growth parameters. The nutritional studies as well as litter production by the plants were significantly higher in closer spacing of 30 × 30 cm as compared to wider spacing (80 × 60 cm).

Yan *et al.* (2015) conducted an experiment to evaluate seasonal patterns of soil inorganic N pools as well as rates of nitrification and N mineralization of three soil layers (0-5, 5-10, and 10-20 cm) under four tree spacing treatments of poplar (6 × 6 m, 4.5 × 8 m, 5 × 5 m, and 3 × 8 m). They reported that tree spacing significantly affected annual net N mineralization, whereas inorganic N content in surface soils was significantly affected by tree spacing only during the growing season. The total annual cumulative net N mineralization ranged from 80.3-136.0 mg kg^{-1} in the surface soils (0-20 cm), whereas the cumulative net N mineralization of 6 × 6 m and 4.5 × 8 m spacings was 65 % and 24 % higher than that of the 5 × 5 m spacing, respectively. The obtained results suggest that suitable spacing could lead to enhanced N mineralization, but seasonal variation of soil N mineralization may not only be directly related to plantation productivity but also to understory vegetation productivity.

Similar temporal variation in mineral N availability in Silver birch stands and grasslands were also reported by Uri *et al.* (2008).

Debell *et al.* (1996) studied the performance of two *Populus* hybrids (11-11 and D-01) which were planted in monoclonal block plantings at three spacings (0.5, 1.0 and 2.0 m) near Olympia, Washington, and evaluated over a 7-year period for individual tree growth rates and above-ground stand productivity. They reported that the differences were substantial between clones and among spacings in both individual tree characteristics (height and diameter growth) and stand productivity (leaf area, basal area, or biomass production). They reported that the relative differences in growth between the clones tended to increase with spacing. Woody biomass production of clone 11-11 averaged 18.2 Mg ha⁻¹ yr⁻¹ at 1.0 m spacing, whereas clone D-01 averaged only 10.1 Mg ha⁻¹ yr⁻¹. The clones differed in phenology of height and diameter growth, maximum rate of periodic height growth, tendency to produce sylleptic branches, partitioning of woody biomass, and sensitivity of growth rates to competition. All of these characteristics have important influences on the productivity of short-rotation plantations.

Sharma *et al.* (2014) carried out an experiment to developed new clones of poplar (*Populus deltoides*) at UHF, Nauni and FRI, Dehradun over the fifteen years. Under this study, the promising clones were further aimed to screen in the backdrop of two established commercial clones (G-48 and L-200/86) repeatedly for two years (2011 and 2012). They revealed that 23 clones in plant height and volume index and 22 clones in basal diameter were significantly superior against check clone G-48. Check clone L- 200/86 recorded at par plant height with clones 6503, 5303, T-50, T- 46, and 1007, at par basal diameter with clones 6503, 1007, T-47, H- 11 and T-16 at par volume index with clone 6503. The growth parameters varied significantly among clones and years, except volume index in the year 2012. Ranking of clones with respect to different characters changed over the years. Regression values revealed that clones 6503, L200/86 and 1007 gave consistent performance for both the years.

Dhillon (2011) reported that 16 clones of *Populus deltoides* planted in semi-arid region of Punjab. The data collected on survival and growth traits at age of 2 and 4.5 year were analyzed, where observed that significant differences among clones were found for diameter at 4.5 year and for height at both the ages. Clones *viz.*, 'D-4', '104', 'L-188/84' 'L-313/85', 'G-48', 'L-71/84' and 'L-154/84' were found to be superior having higher volume production.

Kumari and Nandal (2017) studied that the nursery of poplar showed significant effect of different weed control methods and fertilizer levels on the growth parameters like fresh weight of shoot and root per plant, dry weight of shoot and root per plant and total biomass per plant. Application of organic and inorganic fertilizers produced significantly higher fresh and dry weight of shoot and root and total biomass. Further they reported that

spraying with glyphosate at 1.0 % solution on product basis 60 days after bud emergence even at higher doses was found to have little effect on the all growth parameters of poplar plants in the absence of efficient weed control.

Mishra *et al.* (2010) conducted an experiment to evaluate the variations in growth and above- and below-ground biomass of five promising clones (G3, G48, 65/27, D121 and S7C1) of *Populus deltoides*. Monoclonal plantations were established in a randomized block design with three replications. They reported that diameter at breast height (dbh) and tree height were consistently higher in clone 65/27 and lowest in clone S7C1. Total biomass varied from 48.5 to 62.2 Mg ha⁻¹ in 6-year old clones; it followed the order 65/27 > D121 > G48 > G3 > S7C1. Stem wood accounted for 60.4-68.9% of total biomass, followed by coarse roots (12.2-18.9 %), branches (12.3-15 %), leaves (3.02-6.9 %) and fine roots (1.5-2.7 %) under this study.

Luna *et al.* (2012) evaluated 12 clones of poplar for height, diameter growth and volume production at the age of 3 years in Punjab. Under this study, the results revealed that among the poplar clones, the clone WSL-39 achieved best growth and maximum volume production, attaining diameter of 14.74 cm, height 14.42m and volume 0.104 cubic m tree⁻¹ at the age of 3 years. The clone WSL-39 outperformed for growth and volume since the beginning. However, the volume production of clone Udai was at par with WSL-39 at 2 and 3 years of age.

Singh and Bangarwa (2006) conducted an experiment at CCS HAU, Hisar, to evaluate the performance of 15 clones of poplar under nursery condition. Under this study, the analysis of variance indicated presence of variation for basal girth, shoot length, fresh shoot weight, dry shoot weight, root length, root spread, fresh root weight, dry root, weight, root length: shoot length ratio and root weight: shoot weight ratio in 15 clones of *Populus deltoides* under nursery conditions. They reported that little difference between genotype coefficient of variation and phenotypic coefficient of variation and medium to high estimates of heritability for all the characters revealed the heritable nature of variability present. Estimates of genotypic advance as percentage of mean were observed high for all the characters under study. The clones *viz.*, 146 and 154 of M/s WIMCO Seedlings Ltd. were observed as best clones and the clones *viz.*, 28, 156, 139 were considered as potential clones.

Kumar (2006) carried out an experiment to determine the effect of planting time of cuttings on growth of cutting of *Populus deltoides* under nursery condition in Punjab. The results showed that among the various planting dates tried, cutting inserted during first fortnight of January and first fortnight of February produced plants of maximum mean height and basal diameter, respectively. However, minimum plant height and diameter was recorded when cuttings were inserted during first fortnight of March.

Toky *et al.* (1996) conducted an experiment in nursery condition at CCS HAU, Hisar to studied the growth of 1-year old saplings, 2-year and 5-year old trees of 27 clones of *Populus deltoides*. They found that significant ($P=0.01$) differences in survival percentage and growth of plants among different clones. The height and diameter (dbh) varied from 2.6 to 5.2 m and 1.10 cm to 2.95 cm, respectively at sapling stage while it ranged from 10.5 to 20.2 m and 12.4 to 23.9 cm, respectively, after 5 years of transplanting. The results revealed that at the age of 5 years, CP-82-4-1 and CP-86-6-2 were outstanding clones for girth increment under study.

Joshi *et al.* (2004) carried out an experiment to determine the influence of diameter of cuttings on growth, establishment and stock quality attributes of 5 provenances of poplar in a nursery trial for two consecutive years. Under this study, results of the analysis indicated that increase in diameter of cuttings significantly increased sprouting and survival per cent and number of roots. The cuttings of intermediate thickness (>15 -20 mm) gave maximum juvenile growth at the end of growing season.

Rawat and Kapoor (2008) carried out an experiment under nursery conditions to assess the significant clonal variations with respect to their sprouting, survival, height, collar diameter and biomass production amongst twenty different clones of *Populus deltoides*. They reported that the significant clonal variations with respect to their sprouting, survival, height, collar diameter and biomass production were recorded amongst the clones under study. Further they reported that, overall, clones namely L-12/82, L-165/84, L-13/82, L-14, 8262 and 22 were found to be the best performers in nursery stage.

Das *et al.* (2008) conducted an experiment to find out the best planting period for the cuttings of G-3 and G-48 clones of poplar (*Populus deltoides*) in North Bihar. The experiment was initiated on 15th November, 1993 and planting of cuttings of length of 22 cm obtained from one-year-old shoots of poplar was repeated after one week interval up to 14th March, 1994. Each shoot was divided into top, middle and bottom portions. There was a decline trend of sprouting of G-3 clone planted between 15th to 29th November and then increased gradually up to December. In between 3rd January to 21st February, bottom and middle cuttings showed 90 to 100 % and 60 to 100 % sprouting in G-3 and G-48 clones of poplar, respectively. The height and collar diameter of G-3 clone after 18 months varied from 2.05 to 6.32 m and 1.45 to 6.06 cm, respectively. On the other hand, the height and collar diameter of G-48 clone varied from 1.42 to 4.94 m and 1.01 to 4.01 cm, respectively.

Pal *et al.* (2004) carried out an experiment for testing of 39 poplar (*Populus deltoides*) clones, mostly of exotic origin, during 1999 under nursery condition. Under this study, field observations were recorded during June and December after raising the plants from stem cutting in January. The survivability percentage of the clones varied from 54.16 to 95.17. At the middle of growth phase, the clones G-3, G-48, 82-354, 33-24, 41-N and 42-N were

observed better performing with respect to plant height and collar diameter. However, the clones which were found to have better height along with collar diameter, internodal length, less branch number per plant were G-48, 82-35-4, 421-2, 33-24, 22-N, 37-N, 41-N, 42-N, 63-N and RD-01 during December. While comparing taper values (plant height/collar diameter), all the clones except 421-2, S7C1, 26-N and RD-01 were observed to have higher magnitude in plants of December observation period as compared to that of June, indicating the increase in plant height was more as compared to increased in collar diameter.

2.2. Biomass and Volume estimation:-

Arora *et al.* (2014) were assessed the growth, biomass, carbon storage, and carbon sequestration potential along an age series in *Populus deltoides* plantations. They reported that the growth rate of diameter at breast height and height was higher in trees of 4 to 7 years and 2 to 5 years, respectively. The total aboveground biomass (AGB) increased with age and reached its maximum (180.2 Mg ha⁻¹) at 11 years of age. Mean carbon concentration in aboveground components varied from 39.7 % to 51.7 %. Allometric equations were developed to estimate biomass and biomass carbon in different tree components, which had adjusted R squares greater than 94 %. Aboveground carbon stocks in *Populus deltoides* increased from 0.5 Mg ha⁻¹ at 1 year to 90.1 Mg ha⁻¹ at 11 years. The carbon sequestration rate (*i.e.* carbon sequestered in wood products and by the substitution of biomass for coal) in mature plantations (7-11 years) varied from 5.8 to 6.5 Mg C ha⁻¹ yr⁻¹. Soil carbon stocks increased with age (1-11 years) from 61.2 to 66.8 Mg ha⁻¹ and decreased with soil depth. Soil carbon stock in different ages of plantations varied from 63.9 to 83.8 Mg ha⁻¹ at 0-30 cm depth, 57.5 to 60.1 Mg ha⁻¹ at 30-60 cm depth, and 55.5 to 59.7 Mg ha⁻¹ at 60-90 cm depth. The amount of total carbon stock (AGB and soil) increased from 64.4 Mg ha⁻¹ at 1 year to 173.9 Mg ha⁻¹ at 11 years.

Chauhan *et al.* (2015) carried out an experiment to assess six years poplar plantations for productivity, carbon storage and economics in comparison to sole cropping. Wheat grain yield was significantly higher in control plots (4.55 t ha⁻¹) than boundary plantation (3.28 t ha⁻¹) and block plantation (2.03 t ha⁻¹). Similar trend was recorded for straw yield (6.61 t ha⁻¹ in control plots, 4.83 t ha⁻¹ in boundary plantation and 3.5 t ha⁻¹ in block plantation). The boundary plantation produced higher DBH (24.23 cm) than the block plantation (19.71 cm). The crown spread itself followed the same trend but both the planting methods had almost similar plant height. However, the total tree biomass was higher with block plantation (96.31 t ha⁻¹) than boundary plantation (30.14 t ha⁻¹) but per tree biomass was more in boundary plantation than block plantation. The total carbon storage was higher in block planting method (55.43 t ha⁻¹) than in boundary plantation (32.70 t ha⁻¹) and lowest total carbon storage in sole cropping system (31.20 t ha⁻¹). The heat from biomass combustion and carbon storage from coal substituted of timber was also higher in the block plantation (18.67 t

C t ha⁻¹) as compared with boundary plantation (4.43 t C ha⁻¹). Under this study, the economic benefits were also higher in block plantation than boundary and sole cropping of rice-wheat (B: C ratio of 3.30, 1.90 and 1.61, respectively).

Results of a 12 year study on growth and yield of *Populus* I-214 in the East Slovakian lowlands presented by Kohan (1995) observed the maximum mean height and diameter of 23 m and 27.1 cm, respectively. Maximum total volume production was 359.9 m³ ha⁻¹ at a spacing of 3.0 x 1.5 m. Height and diameter growth of individual tree was greater at wider spacing. Lodhiyal *et al* (1995) reported biomass and net primary productivity of eight year old poplar plantations in Haldwani Forest Division, Uttar Pradesh. Out of total biomass (176.4 t ha⁻¹) and net primary productivity (24.5 t ha⁻¹ yr⁻¹), above ground contribution was 96.4 and 89 % respectively.

An experiment was conducted at regional centre of Pantnagar by Mohsin *et al.* (2005) and reported net primary production of poplar at different ages in pure as well as in intercropped stands. The total net primary productivity of pure poplar plantation varied from 18.31 t ha⁻¹ yr⁻¹ (3 years) to 21.03 (2 years) t ha⁻¹ yr⁻¹ in different age groups, whereas, values for the same in poplar stands intercropped with crops at various ages ranged between 18.83 t ha⁻¹ yr⁻¹ (3 years) to 24.74 (2 years) t ha⁻¹ yr⁻¹, which was more than pure stands. Whereas, Swamy *et al.* (2006) also recorded variation in growth, above and below ground biomass and nutrient distribution in five poplar clones (G3, G48, 65/27, D121 and S7C1) grown under agri-silviculture system in sub-humid tropics of central India and ranked them according to total biomass of clones (65/27 > D121 > G48 > G3 > S7C1). They also observed that root: shoot ratio was highest in clone G48 and lowest in clone S7C1. Stem wood accounted 60.4-68.9 per cent to total biomass followed by coarse roots (12.2-18.9 %), branches (12.3-15 %), leaves (3.02-6.9 %) and fine roots (1.5-2.7 %).

In a study on biomass and carbon allocation in different parts of 13 agroforestry tree species, Chauhan *et al.* (2009) recorded maximum biomass accumulation in stem, whereas, minimum in bark except in four species i.e., *Eucalyptus tereticornis*, *Acacia nilotica*, *Acacia catechu* and *Populus deltoides*, whereas, the minimum value was recorded in leaves. *Populus deltoides* recorded maximum above ground biomass i.e., 33.28 kg tree⁻¹ followed by *Acrocarpus fraxinifolius* (32.18 kg), whereas, the minimum values was observed in *Syzygium cumini* (6.70 kg). Dowell *et al.* (2009) examined the *Populus deltoides* and *Populus deltoides* × *Populus nigra* clones in USA to study the above and below ground biomass production, leaf area and photosynthetic attributes. *Populus deltoides* clones accumulated significantly higher biomass and photosynthetic capacity.

Kumar *et al.* (2011) conducted a study to estimate the biomass production and nutrient removal by eight years old poplar plantation raised at three different spacing i.e., 5 × 4m, 10 × 2.5 m and 13 × 2.5 m in a replicated randomized block design and reported that

biomass of all the plant parts decreased with increasing tree spacing except that the differences between 10×2.5 m and 15×2.5 m spacing in respect of leaves and branches biomass were non-significant. They also concluded that the total biomass including litter fall was higher in 5×4 m (415 t ha^{-1}) followed by 10×2.5 m (330 t ha^{-1}) and 15×2.5 m (192 t ha^{-1}) spacing. Similar effect of spacing has also been reported by Mishra and Gupta (1993) in poplar plantation. They also reported that stem accumulated more than 75 % of total biomass, whereas, poplar branches and roots accumulated about 20 % of the total biomass with most equal partitioning between roots and branches and poplar leaves accounted for only 1-2 % of total biomass. An another study by Chauhan *et al.* (2011) to access the productivity poplar-wheat inter-cropping system in irrigated agro-ecosystem, recorded maximum annual productivity of poplar after fourth year and later the annual wood increment decreased (42.4 , 39.8 and $35.6 \text{ m}^3 \text{ ha}^{-1} \text{ yr}^{-1}$ after 4th, 5th and 6th year, respectively). Banerjee and Prakasam (2013) reported that *Tectona grandis* above ground biomass contributed 82 % of the total biomass and below ground (root biomass) contributed only 18 %. Litter biomass varied from 1.36 to 1.60 t ha^{-1} .

Chauhan and Dhiman (2002) studied the tree growth (diameter at breast height, crown width and crown length of poplar trees) among various spacings (8×3 m, 6×4 m, 5×5 m and 4×6 m) in poplar based agroforestry system and they found that tree growth was significantly higher with a spacing of 8×3 m.

Rizvi *et al.* (2008) constructed and validated non-linear models for aboveground biomass of *Populus deltoides* planted in agroforestry system in Haryana, India. Six models were separately fitted using D and D^2H (D and H represent Diameter and Height respectively) as explanatory variable. Both variables are highly correlated with the aboveground biomass (B). The model $B = 0.936D^{1.809}$ was found to be a good fit ($R^2=0.914$, Mean square error = 840.432). Mean error of predictions was 10.52 kg with model efficiency of 94.9% .

Dhanda and Verma (2001) developed timber volume, fresh timber weight, aboveground biomass and firewood estimate tables based on the regression equations. Four sample regression models tested for single-entry and multi-entry regression equations, linear and multiplicative models of the form $Y=a + bx$ and $Y=ax^b$, respectively, provides the best fit to observe limits of data. Applicable of multi-entry tables was checked through statistical analyses and were found to be applicable without correction.

Singh *et al.* (2005) carried out an experiment to evaluate the one year growth performance and biomass of *Populus deltoides* which were planted from the cuttings from clone S₇C₂₀ at different time of intervals in nursery beds. They reported that the month of planting has significant impact on growth and biomass yield of cuttings of poplar. Under this study, cuttings planted in February had significantly ($P=0.01$) better growth and biomass performance, followed by planted in January while, cuttings planted in April exhibited poor

growth and biomass production in all the plantation years i.e., 1997, 1998 and 1999. On average stem, root and leaf components contributed 71.5, 23.1 and 5.4 %, respectively to total biomass production. Plant height had a significant ($P=0.01$) correlation with biomass, stem diameter and volume production after one year's growth. Biomass performance of seedling also exhibited significant ($P=0.05$) correlation with air/soil temperature and photoperiod. However, there was no relationship between rainfall and growth performance of the clone planted at any time.

2.3. Economics:

Gaur and Pyare (2003) recorded that the annual net profit obtained from poplar + agricultural crops was Rs. 20 590.00, while poplar alone had only Rs. 15 000.00. The yield of sugarcane varies from 22.5 to 35.0 tha^{-1} , while the yield of ratoon crop decreased from 46 to 12 % in block plantations. The average yield of wheat was 1.9 tha^{-1} . In boundary plantations, no effect on agricultural production was observed when tree line was at north-south direction, while negligible effect was observed at the east west direction. The net profit of agroforestry was almost double of the agricultural crops.

Dhillon *et al.* (2001) analyzed the cost of plant material accounted to maximum; i.e., 34 % of total establishment cost. The operational cost was Rs. 2,800 $\text{annum}^{-1} \text{acre}^{-1}$ during first six years. The total annual cost also did not vary much with age of trees. The discounted cash flow of poplar plantation results in constant annual net returns acre^{-1} over the entire rotation was Rs. 22,156 and Rs. 29,332 without intercropping and within intercropping, respectively.

Singh *et al.* (2016) conducted a study to evaluate the outcome of current status and economic evaluation of Poplar based agroforestry practices followed by farmers in Haridwar and Yamunanagar. Tree species like *Populus deltoides*, *Eucalyptus* spp., *Mangifera indica* and *Dalbergia sissoo*, were dominant species of commercial agroforestry. The patterns of planting were block (53.74 %) and (88.47 %) followed by boundary plantation (46.26 %) and (11.53 %) in Haridwar and Yamunanagar districts respectively. Composition of different species was poplar (77.12 % and 90.64 %) followed by eucalyptus (18.26 % and 7.92 %), mango (3.36 % and 0.72 %) and others (1.26 % and 0.72 %) in Haridwar and Yamunanagar districts. The net return from block system (Rs.1, 96, 950) $\text{ha}^{-1} \text{annum}^{-1}$ was found higher than the bund system (Rs.1, 02, 249) $\text{ha}^{-1} \text{annum}^{-1}$ in agri-silviculture system. The net return from tree produce (Rs.1, 48, 067) $\text{ha}^{-1} \text{annum}^{-1}$ in block system was higher than the bund system of (Rs.48, 883) $\text{ha}^{-1} \text{annum}^{-1}$ respectively. In commercial region, B: C ratio was found higher for poplar based agrisilviculture block planting (3.85) than poplar based agri-silviculture bund system (2.22). Comparatively as per net returns and B: C ratio the block systems were found more economic to bund systems. Therefore, commercial agroforestry seems better promising as compared to traditional agroforestry, and also relevant to the farmers livelihood.

Singh and Mavi (2016) conducted a study to analyze the viability of the poplar based agroforestry system under Riparian wet land conditions of Punjab. From riparian wet land of Roopnagar district, five villages were selected having a sufficient number of poplar adopters. Maximum number of farmers adopted 6.0×1.5 m spacing, whereas, few of them adopted 5.5×2.0 m and 7.0×2.5 m. The cost and income analysis from intercrop as well as poplar plantation indicated that B-C ratio was 2.87, internal rate of return was 57.50 % and net present worth was Rs. 12, 28, 162 ha⁻¹, which showed that poplar based agroforestry was economically viable in the study area. The B: C ratio, internal rate of return and net present worth were found to be higher for large poplar plantation followed by medium and small farms.

CHAPTER-III

MATERIALS AND METHODS

The present investigation entitled “Evaluation of Poplar (*Populus deltoides*) for spacing under nursery and field plantation” was carried out in Yamunanagar district of Haryana (77° 28' E longitude and 30° 10' N latitude and elevation of Yamunanagar is 255 m above mean sea level). The mean monthly temperature of Yamunanagar, ranges from 6.8°C in January to 39.4°C in summer months of May and June. . The present study was conducted in Yamunanagar district of Haryana for economic analysis of production and marketing of poplar plantation during 2015-16 and 2016-17. Both primary as well as secondary data have been used for attaining the objectives of the study undertaken.

3.1 Selection of study area

Out of 21 districts of Haryana state, Yamunanagar district was selected purposively, as it has the highest area under poplar plantation, it is worth mentioning here that present forest and tree cover of Yamunanagar district is 24.6% whereas the forestland is just 12.1% of the total geographical area.

3.1.1 Selection of block

From the above selected district, Radaur, Jaghadhri, Chhachhrauli and Bilaspur block having the largest area under the poplar cultivation was selected purposively for the present study.

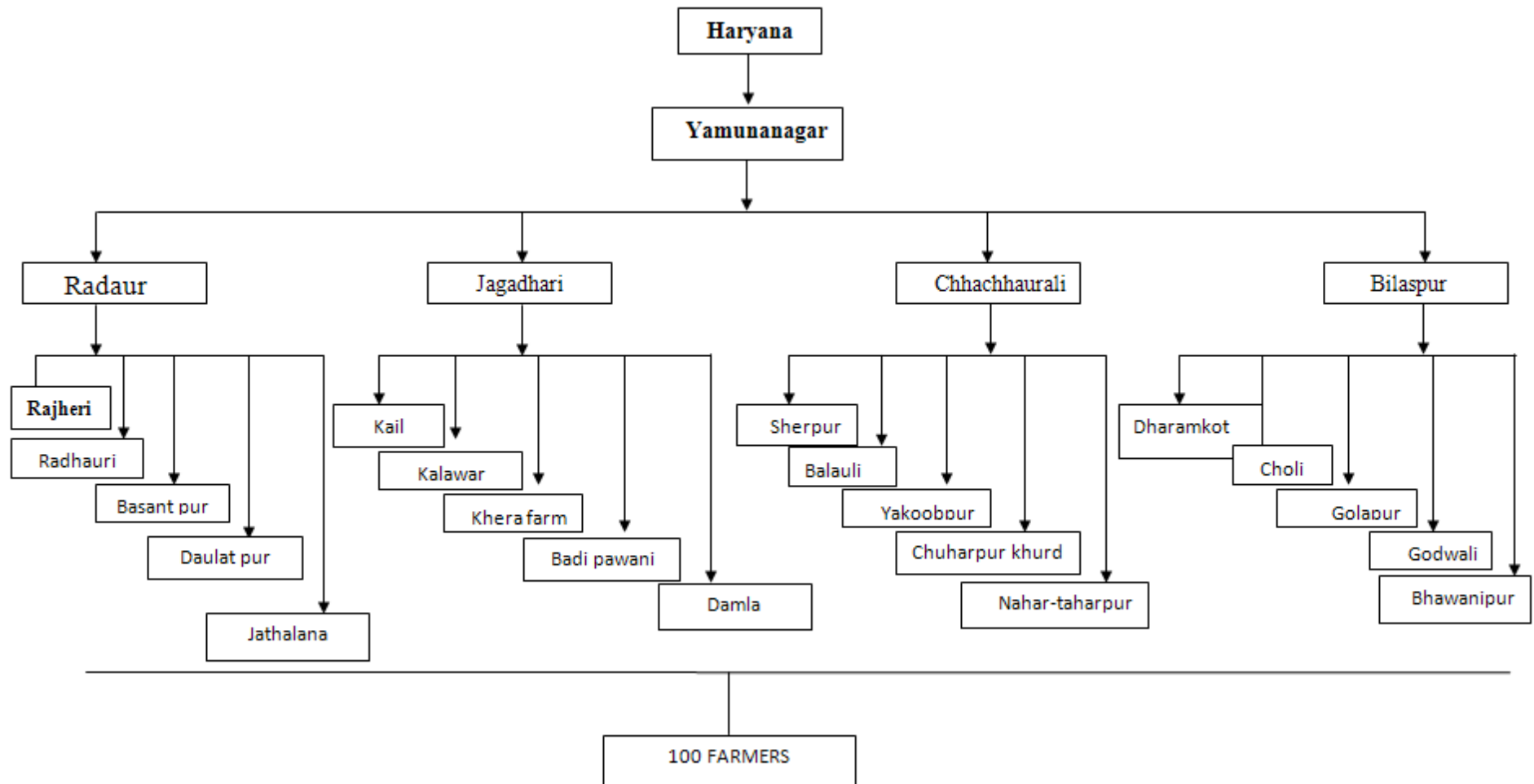
3.1.1.1 Selection of villages

A list of all the poplar growing villages of Radaur, Jaghadhri, Chhachhrauli and Bilaspur block was obtained from Deputy Director of Agriculture (DDA) Office, Yamunanagar. Five villages were selected from each block having highest area under poplar plantation. From Jagadhri block Kail, Kalawar, Kherafarm, Badipawani and Damla and from Bilaspur block, Dharmkot, choli, Bhawanipur, Gadwali and Golapur were selected. From Chhachharauli block, Balauli, Yakoobpur. Sherpur, Ismailpur, Chuharpur khurd and Nahar-taharpur. From Radhaur block, Raheri, Radhauri, basantpur, Dualatpur and Jathalana were selected

3.1.1.2 Selection of farmers

From all the selected villages a list of poplar growers was prepared. From each sampled village, five poplar growers were selected from the comprehensive list of all farmers. Thus, a total of 100 farmers were selected from all the twenty villages for conducting the present study.

Fig. 1 Sampling procedure adapted in the study area



Five types of spacing were observed in case of block plantation of poplar in the study area that was different from the recommended spacings. Maximum number of farmers adopted 3.65×3.65 m spacing followed by 4.87×2.74 m and 4.26×4.26 m.

3.2 Experimental details:

Poplar plantation established during the years 2008 to 2014 were selected from farmer's fields. On the farmer's fields, each year plantation with all spacings arrangements was considered as one experimental unit.

3.2.1 Studies on spacing and growth pattern of poplar under field plantation

Treatments details:

a) Poplar spacing : 5

(i) 4.26×4.26 m

(ii) 3.96×3.96 m

(iii) 4.87×2.74 m

(iv) 3.65×3.65 m

(v) 3.65×2.13 m

b) Clones: WSL-39, WSL-22, WSL-81, G-48 and G-3.

c) **Statistical design:** Factorial Randomized Block Design

d) **Replications:** Four

3.2.2 Observation recorded during February 2015 and February 2016

3.2.2.1 Total height (m)

3.2.2.2 Diameter at breast height(DBH) (cm)

The data were analyzed to find out the growth pattern and optimum spacing for maximum growth of poplar.

3.2.3 Growth potential of poplar under different spacings:

One to seven years old plantations of poplar with different spacings of 4.26×4.26 m, 3.96×3.96 m, 4.87×2.74 m, 3.65×3.65 m, 3.65×2.13 m were selected for recording data in order to find out growth potential (total tree height and DBH) of the poplar. Ten trees per replication were selected randomly in each of four replications in all the spacings for one to seven years old plantations for recording total height and DBH.

(a) Total height (m): The height of ten randomly selected trees was measured up with the help of clinometer and expressed in meter.

(b) DBH (cm): Randomly ten trees were selected and marked at a height of 1.37 m from the ground level. The diameter at breast height (DBH) was measured with the help of a diameter tape and expressed in cm. Current annual increment (CAI) for both total height and basal diameter were worked out from first to seven years in all spacings and mean annual increment (MAI) for both the attributes in seven year old plantation at the harvesting stage.

3.3 Statistical analysis of data:

The analysis of variance was carried out using replicated data to find out the effect of spacing and age of poplar obtained during the course of this investigation as per method given by Panse and Sukhatme, (1989).

3.3.1 Standard Errors differences: Standard errors for differences of two means were calculated with help of the error mean square from the analysis of variance tables like:

$$S E (\text{difference}) = \sqrt{\frac{2MSE}{r}}$$

Where,

MSE = mean square error

r = number of replication

3.3.2 Critical difference: Critical difference for the characters was calculated to compare the treatment means. Critical differences were calculated with the help of standard error for the differences of two means and tabulated value of 't' at 5 % level of significance for error degree of freedom like:

C.D. = S.E. × t at 5 % error d.f.

3.4 Collection of data

Both primary as well as secondary data were used for attaining the objectives of the study undertaken. For studying the cost of production, marketing pattern, marketing cost and marketing margins and problem faced by the poplar growers in selling their produce, primary data were collected from the selected respondents by conducting personal interviews on a specifically designed pre-tested schedule. Primary data were also collected on marketing cost; purchase price, sale prices, etc.

3.4.1 Cost structure for raising the plantation

Cost components for raising the plantation have been divided into main categories as given under:

3.4.2 Establishment cost

Establishment cost is the cost of establishment of the species incurred in the beginning of the year of planting, which includes three main cost i.e., cost of planting material which includes the transportation cost also; cost in and preparation and transplanting which includes cost of digging pits and then transplanting the seedling and finally of the cost incurred on plant protection.

3.4.3 Operational cost

This cost is incurred in the subsequent years for the maintenance of the crop. It includes the cost incurred in irrigation, fertilizer application and miscellaneous costs including the interest component. Miscellaneous cost includes cost of hoeing and weeding, cultivation in between the rows to get rid of unwanted vegetation when no crop is raised.

3.4.4 Analytical Tools

To analyze the results, simple tabular analysis was used. Budgeting technique was used to work out the economics of poplar along with other selected agricultural crops grown i.e., wheat, sugarcane, sorghum and berseem. In order to further examine the plantations along with crops in terms of productivity of capital, the concept of discounting was used. The costs and benefits were discounted at the rate of 12 percent. Cost and income from intercrop as well as poplar plantation was calculated. The three efficiency measures [Present net worth (PNW); Benefit-cost ratio (BCR) and Internal rate of return (IRR)] were used.

3.4.4.1 Net present value

In poplar plantation a heavy amount of investment was made in establishing the poplar plantation in the initial years and the returns from the poplar plantation can be obtained only after a period of 7 years. Therefore, it becomes essential to estimate the discounted cash flow or net present value (NPV) of both cost incurred and returns obtained over the years has been as follows:

$$NPV = \sum_{i=1}^n \frac{Ct}{(1+r)^t}$$

Where,

- Ct = Cash flow and net returns in present
- r = Prevailing rate of interest (Discount rate)
- i = 1, 2, 3 n year,

3.4.4.2 Internal rate of return

To estimating the internal rate of return, the investment cost and incremental gross returns for each year in the life of poplar plantation were calculated. The internal rate of return was calculated at the different rate of discount until it satisfies the relationship $B - C = 0$ where 'B' is the sum of discounted stream of positive value (returns) and 'C' is taken as the sum of discounted stream of negative values (costs).

$$IRR = \frac{\text{(Lower discount rate)} + \frac{\text{difference between two discount rates}}{\text{(Present worth of the cash flow at lower discount rate)}}}{\text{(absolute difference between the Present worth of the cash flow at two discount rates)}}$$

3.4.4.3 Benefit cost ratio

The benefit cost ratio is the ratio between the sum of discounted net benefits of returns (R) and the sum of discounted cost (K), i.e. $B = R/K$. If this ratio is greater than one so that the investment in poplar plantation is considered to be economically viable.

3.4.4.4 Payback period

It is the period within which the cost of the poplar plantation is fully recovered from its own returns. In other words, it indicates the number of years by which the net returns (R)

equal, to the cost of poplar plantation (K). For this condition the following relationship must be satisfied.

$$\sum_{i=1}^n R_i = K$$

Where,

i = 1, 2, 3 n year,

R = Indicates the return over a number of year,

K = Indicate the cost of poplar plantation.

3.5 Studies on Economic return of system: The entire expenditure and income were recorded in order to find out economic returns from poplar plantation with best spacing. These findings have been based on the interviews and discussions with the help of farmers of selected villages during the observation period.

3.5.1 Name of clone: The clones of poplar like as G-48, G-3, Uday, WSL-81, WSL-22 and WSL-39 mainly planted in Yamunanagar district of Haryana.

3.5.2 Establishment time: The establishment time of entire transplants (ETPs) was last week of January to mid of February months for both the years.

3.5.3 Spacings: Farmers generally follow 4.26×4.26 m, 3.96×3.96 m, 4.87×2.74 m, 3.65×3.65 m, 3.65×2.13 m spacing in their fields.

3.5.4 Input use: The inputs like fungicide aldrex-30, DAP, Zink Sulphate and irrigation were applied.

3.5.5 Time of different management operation:

3.5.5.1 Manures and fertilizers: The dose of manure and fertilizers depends upon the soil fertility level. The FYM, DAP, Urea were applied during July and August.

3.5.5.2 Pruning: Pruning was done during October to November month, when trees are leavesless. This is important to produce quality timber with large clear bole free from knots. It is restricted to be lower $1/3^{\text{rd}}$ part of the stem.

3.5.6 Intercropping: Farmers grown sugarcane in the poplar plantations for the first two years. Onward 3^{rd} year, during *Rabi* season, crops like wheat, mustard, potato, oats, berseem, etc. were raised throughout the tree rotation and during *kharif* season, various fodders like sorghum, cowpea and bajra were grown successfully.

3.5.7 Crop production potential: In first year, production of sugarcane was approximately $20.0-25.0 \text{ t ha}^{-1}$ and 2^{nd} year production was $8.0-10.0 \text{ t ha}^{-1}$. In case of wheat productivity have 4.3 t ha^{-1} in 3^{rd} year. In the seven year production of wheat was near about $1.5-1.6 \text{ t ha}^{-1}$.

3.5.8 Economic return: The cost of cultivation and gross income of various treatments were calculated on the bases of approved market rates for inputs and outputs. To find out the net return, the cost was subtracted from the gross income of the received treatments.

3.6 Studies on economic stage of harvesting

The following data were recorded after felling and before selling for the experiments which was complete the rotation and put on sale.

3.6.1 Diameter at breast height (DBH): After felling operation randomly ten trees were selected from each spacing and marked at a height of 1.37 m from the ground level. The diameter at breast height (DBH) was measured with the help of a diameter tape and expressed in cm.

3.6.2 Total tree height: After felling total tree height was measured with measuring tape from ground surface to top of the tree.

3.6.3 Measurement of volume and weight of poplar tree at the time of harvesting: The different poplar clones with different spacings of seven year old poplar plantation were selected for recording the data by visiting felling site of different villages in Yamunanagar district. Ten trees of each clone from each spacings were selected for data recording. The total tree height and diameter at breast height (DBH) at 1.37 m from ground level, was taken after felling of trees. Uprooted stump portion of felled trees and main bole were cut into 2.34 m and 1.32 m sections up to a top diameter of 20 cm (over bark). Diameters at both ends of each section were recorded and mean diameter was calculated. Each section was then weighed through weighing balance. Weights of all sections of a tree were averaged. Similarly, the volume was calculated for all sections of a tree to know the total timber volume over-bark.

3.7 Nursery grower/growers raising nursery of different poplar clones with different spacing were identified.

3.7.1 Studies on different clones of poplar under different spacings in nursery condition

3.7.1.1 Treatment details:

3.7.1.1.1 Clone :

- (i) G-48, WSL-22
- (ii) WSL-81, WSL-110
- (iii) WSL-109, G-3
- (iv) Uday
- (v) WSL-39

3.7.1.1.2 Spacings: 5

- (i) 80 × 60 cm
- (ii) 60 × 50 cm
- (iii) 65 × 45 cm
- (iv) 70 × 35 cm
- (v) 60 × 40 cm

3.7.1.1.3 Statistical design: Factorial Randomized Block Design

3.7.1.1.4 Replication: Four

3.7.1.2 Observations recorded at three months interval: The observations were recorded under nursery at an interval of three months during both the years were as follows:

3.7.1.2.1 Total height (m)

3.7.1.2.2 Basal diameter (mm)

3.7.1.3 Observations recorded during nursery growing period (both the years):

- (i) Planting time
- (ii) Pre planting treatment
- (iii) Spacings
- (iv) Method of planting used
- (v) Inputs used
- (vi) Name of clone with source
- (vii) Time for different management operation including uprooting operations
- (viii) Cost price
- (ix) Sale price
- (x) Economic return

The entire expenditure and income were recorded in order to find out economic return from nursery raising. The best spacing for maximum return of poplar nursery were identified.

3.7.1.3.1 Growth potential of poplar in nursery: The nursery was selected in Kail village of Jagadhari block in Yamunanagar. Different poplar clones with different spacings 80 × 60 cm, 60 × 45 cm, 60 × 35 cm and 70 × 50 cm etc. were identified. Growth potential (plant height and basal diameter) were recorded. Ten plants per replication were selected randomly in each of four replications in all the spacing's.

3.7.1.3.1.1 Plant height: The height of ten randomly selected plants measured up to the terminal point with respect to the ground level at three month interval in both the years with the help of graduated bamboo sticks and expressed in meter. Ten plants per replication were selected randomly in each of four replications in all the spacings.

3.7.1.3.1.2 Basal diameter: Ten plants per replication were selected randomly in each of four replications in all the spacing's. The basal diameter was measured at three month interval in both the year with the help of digital vernier calipers and expressed in mm.

3.7.1.4 Observation to be recorded during nursery growing period:

These findings have been based on the interviews and discussions with help of farmers of selected villages during observation period.

3.7.1.4.1 Planting time: The best time for planting of cuttings of poplar was 15th January-15th February.

3.7.1.4.2 Pre-planting treatment-Treatment of the cuttings of poplar with 250 ml Aldrex 30 E.C. should be thoroughly mixed in 100 ltr. water and the cuttings were soaked in the emulsion for 10 minutes.

3.7.1.4.3 Spacings: Spacings for planting of cutting of poplar were 80 × 60 cm, 60 × 45 cm, 60 × 35 cm and 70 × 50 cm etc. But for production of healthy and vigorous entire plants, planting of cutting at 80 x 60 cm was found best.

3.7.1.4.4 Method of planting used: Planting of cutting of poplar by rods with the lower ends flattened and sharpened like a screw driver was used for making the planting holes. Planting rods had a ring of paint at 22 cm length from the bottom and the same was given to laborers engaged in planting operation. Planting rod was inserted at the point of the stake up to the marked with paint, so that the planting holes were neither too long nor too short. Each cutting with its thinner end up was planted in the hole in such a way that the upper portion is just 2 cm above the ground level.

3.7.1.4.5 Input used: In nursery of poplar, the input like irrigation, farm yard manure (FYM), MOP and zink sulphate (ZnSO₄) were used.

3.7.1.4.6 Name of the clone with source: A number of good quality and high yielding clones of *Populus deltoides* variety namely G-48, Udai, WSL-22, WSL-81, WSL-109, WSL-110 and WSL-39 etc. were most acceptable among farmers brought from WIMCO and other well-known nursery grower.

3.7.1.4.7 Time for different management operations including uprooting operation:

3.7.1.4.7.1 Weeding and Hoeing: Weeding and hoeing were done after 15th days planting of cuttings and continued at 15th days interval up to June -July.

3.7.1.4.7.2 Singling: Singling was done in the month of April, in these practices dead, diseased and weak plants were removed from nursery.

3.7.1.4.7.3 De-budding-For improvement of plant growth axillary buds were removed from 15thMay to 15thOctober.

3.7.1.4.7.4 Uprooting-Uprooting of plants was done at 15thFebruary to 15th march without damage the roots of plant.

3.7.1.4.8 Economics of production:

To analyze the economics of production, it was essential to study the cost in two parts viz., establishment costs and operational costs. The former consists of cost of rental value of land, preparation of land, fencing and irrigation for one year, cost of irrigation including fuel, cost of planting materials, cost of plant protection, cost of manures and fertilizers (incurred before plantation) etc. Operational and maintenance costs include the expenditure on manuring (farm yard manure and fertilizer), intercultural operation, irrigation, plant

protection, depreciation on fixed investment and interest on working capital. For analysis of data, various economic tools were used.

3.7.1.4.9 Economic return:

Economic return= Gross income – Total expenditure (land rent, land preparation, irrigation rent for one year + Cost of labours + opportunity cost).

The results of the experiment entitled “Evaluation of poplar (*Populus deltoides*) for spacing under nursery and field plantation” conducted during 2015-16 and 2016-17 at Yamunanagar district of Haryana, are presented in this chapter. The present study resolved into two broad experiments as per the objectives of the study. Accordingly, the results obtained have been presented under the different heads:

4.1 Growth of poplar under different spatial arrangements

The overall growth pattern of poplar under different spacings generally followed increasing trend with the advancement of age. The height and collar diameter of one year old entire transplants (ETPs) are presented in Table 1. It is evident from the data that there was significant effect of both the spacings and clones on the height and collar diameter of one year old poplar ETPs in nursery stage. The height was found significantly higher in poplar clone WSL-39 (5.34 m) which was followed by WSL-22 (5.32 m), WSL-81 (5.28 m), G-48 (5.17) and G-3 (4.78 m) in wider spacing (4.26 × 4.26 m) under this study. The poplar clone G-3 showed significantly lesser height (4.28 m) and collar diameter (2.53 cm) in closer spacing 3.65 × 2.13 m.

The result presented in Table 2 clearly indicated that in all the poplar clones at the age of one year in field plantation, the height (8.87 m) and dbh (9.48 cm) were recorded significantly higher in poplar clone WSL-39 in wider spacing 4.26 × 4.26 m which was closely followed by 3.96 × 3.96 m spacing during this experimentation. The height (8.21m) and dbh (8.09 cm) were found significantly lesser in poplar clone G-3 in closer spacing 3.65 × 2.13 m. The current annual increment in height (3.56 m) was found significant higher in poplar clone WLS-39 in wider spacing (3.65 × 3.65 m). However, the current annual increment in dbh (6.47 cm) was found significantly higher in poplar clone G-48 in 4.26 × 4.26 m spacing.

It is evident from the data presented in Table 3 that there was significant effect of both the spacings and clones in height and dbh of two year old poplar plantation under this study. The interaction effect between spacing and clone were also found to be significant. The values for height (9.85 m) and dbh (12.04 cm) were recorded significantly higher in poplar clone WSL-39 which was followed by poplar clone WSL-22, WSL-81, G-48 and G-3 in wider spacing 4.26 × 4.26 m. The value for height (8.71m) and dbh (10.27 cm) were found significantly lesser in poplar clone G-3 in closer spacing 3.65 × 2.13 m. The current annual increment in height (1.49 m) was recorded higher in poplar clone WSL-39 in wider spacing (4.26 × 4.26 m).

Table 1: Effect of spacing on the growth of one year old Poplar Entire transplants (ETPs) in nursery

Spacing (cm)	Clone											
	WSL-39		WSL-22		WSL-81		G-48		G-3		Mean	
	Height (m)	Collar diameter (cm)	Height (m)	Collar diameter (cm)	Height (m)	Collar diameter (cm)	Height (m)	Collar diameter (cm)	Height (m)	Collar diameter (cm)	Height (m)	Collar diameter (cm)
80 × 60	5.34	3.42	5.32	3.41	5.28	3.41	5.17	2.68	4.78	2.58	5.18	3.10
60 × 50	5.27	3.41	5.24	3.41	5.20	3.40	5.12	2.72	4.64	2.59	5.09	3.11
60 × 45	5.21	3.40	5.16	3.40	5.12	3.39	5.00	2.65	4.46	2.52	4.99	3.07
70 × 35	5.14	3.40	5.08	3.39	5.07	3.39	4.91	2.70	4.38	2.49	4.91	3.07
60 × 40	5.08	3.39	5.03	3.39	5.01	3.37	4.71	2.58	4.28	2.53	4.82	3.05
Mean	5.21	3.40	5.16	3.40	5.13	3.39	4.98	2.66	4.51	2.54		
C.D. at 5 %	For Height: Spacing: 0.012; For dbh: Spacing: 0.016;		Clone: 0.012; Clone: 0.016;		Spacing × Clone: 0.026 Spacing × Clone: 0.035							

Table 2. Effect of spacing on the growth of one year old poplar plantation

Spacing (m)	Clone											
	WSL-39		WSL-22		WSL-81		G-48		G-3		Mean	
	Height (m)	dbh (cm)	Height (m)	dbh (cm)	Height (m)	dbh (cm)	Height (m)	dbh (cm)	Height (m)	dbh (cm)	Height (m)	dbh (cm)
4.26 × 4.26	8.87	9.48	8.75	9.46	8.72	9.11	8.61	9.02	8.35	8.40	8.66	9.09
3.96 × 3.96	8.82	9.45	8.72	9.33	8.52	9.10	8.40	8.86	8.32	8.32	8.55	9.01
3.65 × 3.65	8.77	9.33	8.68	9.23	8.19	9.06	8.32	8.77	8.27	8.22	8.44	8.92
4.87 × 2.74	8.66	9.30	8.61	9.15	8.15	8.96	8.22	8.67	8.24	8.11	8.38	8.84
3.65 × 2.13	8.22	9.28	8.58	9.13	8.12	9.13	8.19	8.64	8.21	8.09	8.26	8.85
Mean	8.67	9.37	8.67	9.26	8.34	9.07	8.35	8.79	8.28	8.23		
C.D. at 5 %	For Height:		Spacing: 0.01;		Clone: 0.01;		Spacing × Clone: 0.023					
	For dbh:		Spacing: 0.017;		Clone: 0.017;		Spacing × Clone: 0.038					
CAI												
Spacing (m)	WSL-39		WSL-22		WSL-81		G-48		G-3		Mean	
	Height (m)	dbh (cm)	Height (m)	dbh (cm)	Height (m)	dbh (cm)	Height (m)	dbh (cm)	Height (m)	dbh (cm)	Height (m)	dbh (cm)
4.26 × 4.26	3.52	6.19	3.44	6.18	3.44	5.83	3.44	6.47	3.58	5.93	3.48	6.12
3.96 × 3.96	3.55	6.17	3.47	6.05	3.32	5.82	3.28	6.25	3.68	5.84	3.46	6.03
3.65 × 3.65	3.56	6.05	3.52	5.96	3.08	5.79	3.31	6.24	3.81	5.81	3.46	5.97
4.87 × 2.74	3.53	6.03	3.54	5.89	3.09	5.69	3.31	6.09	3.86	5.73	3.47	5.89
3.65 × 2.13	3.14	6.02	3.55	5.86	3.11	5.88	3.49	6.18	3.93	5.66	3.45	5.92
Mean	3.46	6.09	3.51	5.99	3.21	5.80	3.36	6.25	3.77	5.79		
C.D. at 5 %	For Height:		Spacing: 0.09;		Clone: 0.09;		Spacing × Clone: 0.023					
	For dbh:		Spacing: 0.012;		Clone: 0.012;		Spacing × Clone: 0.026					

Whereas, the increment in dbh (2.62 cm) was recorded higher in poplar clone WSL-22 in 3.96×3.96 m spacing. The CAI in height (0.66 m) and dbh (2.14 cm) was recorded significantly lower in poplar clone G-3 and G-48 in closer spacing 3.65×2.13 m. The data in Table 4 showed that there was significant effect of different spacings of poplar on the height and dbh for three year old poplar plantation. The height and dbh were significantly affected both by spacing and clones and the interaction effect between spacings and clones were also found significant. The height (12.70 m) and dbh (13.70 cm) were found significantly higher in poplar clone WSL-39, which was followed by WSL-22, WSL-81, G-48 and G-3 in wider spacing (4.26×4.26 m) under this study. The value for height (11.85 m) and dbh (12.37 cm) was recorded significantly lesser in poplar clone G-3 in closer spacing 3.65×2.13 m. The current annual increment for height (3.41 m) and dbh (2.58 cm) were recorded significantly higher in poplar clone G-3 under wider spacing (4.26×4.26 m). The current annual increment in height (2.52 m) and dbh (1.35 cm) were recorded lesser in poplar clones WSL-81 and WSL-22 in 4.87×2.74 m and 3.65×2.13 m spacing.

It is evident from the data presented in Table 5 that there was significant effect of both the spacings and clones in height and dbh of four year old poplar plantation. The interaction effect between spacing and clone were also found to be significant. Poplar planted at 4.26×4.26 m spacing had attained maximum height (14.76 m) and dbh (15.80 cm) in poplar clone WSL-39 followed by tree planted at 3.96×3.96 m, 3.65×3.65 m, 4.87×2.74 m and 3.65×2.13 m spacings. The value for height (13.72 m) and dbh (14.84 cm) were recorded significantly lesser in poplar clone G-3 in closer spacing 3.65×2.13 m. The current annual increment in height (2.25 m) and dbh (2.21 cm) were recorded significantly higher in poplar clone WSL-81 in spacing 4.26×4.26 m. The current annual increment in dbh (2.06 cm) was recorded lesser in poplar clone G-48 in spacing 3.96×3.96 m. However, the current annual increment in height (1.87 m) was recorded lesser in poplar clone G-3 in closer spacing (3.65×2.13 m).

The data in Table 6 showed that there was significant effect of different spacings of poplar on the height and dbh of five year old poplar plantation. The height and dbh were significantly affected both by spacing and clones and the interaction effect between spacing and clones were also found significant. The height (16.29 m) and dbh (17.20 cm) were found significantly higher in poplar clone WSL-39, which was followed by WSL-22, WSL-81, G-48 and G-3 in wider spacing (4.26×4.26 m) under this study. The value for height (15.61 m) and dbh (16.20 cm) was recorded significantly lesser in poplar clone G-3 in closer spacing 3.65×2.13 m. The increment in height (1.53 m) and dbh (1.55 cm) were recorded higher in poplar clone WSL-39 and G-48 in spacing 4.26×4.26 m and 4.87×2.74 m, respectively. However, the increment in height (1.03 m) and dbh (1.23 cm) were recorded lesser in poplar clone WSL-81 and WSL-22 in 4.87×2.74 m and 3.65×2.13 m spacings.

Table 3: Effect of spacing on the growth of two year old poplar plantation

Spacing (m)	Clone											
	WSL-39		WSL-22		WSL-81		G-48		G-3		Mean	
	Height (m)	dbh (cm)	Height (m)	dbh (cm)	Height (m)	dbh (cm)	Height (m)	dbh (cm)	Height (m)	dbh (cm)	Height (m)	dbh (cm)
4.26 × 4.26	9.85	12.04	9.83	11.98	9.81	11.81	9.69	11.20	9.01	10.71	9.64	11.55
3.96 × 3.96	9.83	11.99	9.77	11.95	9.74	11.72	9.59	11.12	8.94	10.59	9.57	11.47
3.65 × 3.65	9.79	11.93	9.73	11.82	9.65	11.52	9.47	11.00	8.82	10.48	9.49	11.35
4.87 × 2.74	9.75	11.88	9.68	11.76	9.61	11.44	9.33	10.91	8.75	10.41	9.43	11.28
3.65 × 2.13	9.71	11.83	9.58	11.62	9.55	11.33	9.04	10.78	8.71	10.27	9.32	11.17
Mean	9.79	11.93	9.72	11.83	9.67	11.56	9.42	11.00	8.84	10.49		
C.D. at 5 %	For Height:		Spacing: 0.016;		Clone: 0.016;		Spacing × Clone: 0.035					
	For dbh:		Spacing: 0.022;		Clone: 0.022;		Spacing × Clone: 0.05					
CAI												
Spacing (m)	WSL-39		WSL-22		WSL-81		G-48		G-3		Mean	
	Height (m)	dbh (cm)	Height (m)	dbh (cm)	Height (m)	dbh (cm)	Height (m)	dbh (cm)	Height (m)	dbh (cm)	Height (m)	dbh (cm)
4.26 × 4.26	1.49	2.55	1.01	2.52	1.02	2.71	1.10	2.18	0.99	2.31	0.98	2.45
3.96 × 3.96	0.99	2.53	1.06	2.62	1.06	2.63	1.07	2.26	1.08	2.27	1.02	2.46
3.65 × 3.65	1.43	2.60	1.23	2.59	1.46	2.46	1.46	2.23	1.10	2.26	1.04	2.43
4.87 × 2.74	0.85	2.58	1.19	2.61	1.16	2.48	1.11	2.24	1.08	2.30	1.03	2.44
3.65 × 2.13	0.67	2.54	0.63	2.50	0.55	2.21	1.10	2.14	0.66	2.18	1.05	2.31
Mean	1.08	2.56	1.02	2.57	1.05	2.50	1.17	2.21	0.98	2.27		
C.D. at 5 %	For Height:		Spacing: 0.011;		Clone: 0.011;		Spacing × Clone: 0.025					
	For dbh:		Spacing: 0.007;		Clone: 0.007;		Spacing × Clone: 0.015					

Table 4: Effect of spacing on the growth of three year old poplar plantation

Spacing (m)	Clone											
	WSL-39		WSL-22		WSL-81		G-48		G-3		Mean	
	Height (m)	dbh (cm)	Height (m)	dbh (cm)	Height (m)	dbh (cm)	Height (m)	dbh (cm)	Height (m)	dbh (cm)	Height (m)	dbh (cm)
4.26 × 4.26	12.70	13.70	12.61	13.59	12.47	13.48	12.45	13.39	12.42	13.29	12.53	13.49
3.96 × 3.96	12.61	13.63	12.54	13.53	12.36	13.44	12.42	13.35	12.35	13.24	12.46	13.44
3.65 × 3.65	12.54	13.58	12.50	13.43	12.29	13.33	12.35	13.20	12.32	13.04	12.40	13.32
4.87 × 2.74	12.51	13.53	12.42	13.39	12.14	13.29	12.10	13.06	11.95	12.87	12.22	13.23
3.65 × 2.13	12.43	13.41	12.35	12.97	12.11	12.75	12.06	12.64	11.85	12.37	12.16	12.83
Mean	12.56	13.57	12.48	13.38	12.27	13.26	12.27	13.13	12.18	12.96		
C.D. at 5 %	For Height:		Spacing: 0.01;		Clone: 0.01;		Spacing × Clone: 0.022					
	For dbh:		Spacing: 0.012;		Clone: 0.012;		Spacing × Clone: 0.027					
CAI												
Spacing (m)	WSL-39		WSL-22		WSL-81		G-48		G-3		Mean	
	Height (m)	dbh (cm)	Height (m)	dbh (cm)	Height (m)	dbh (cm)	Height (m)	dbh (cm)	Height (m)	dbh (cm)	Height (m)	dbh (cm)
4.26 × 4.26	2.85	1.66	2.78	1.62	2.66	1.67	2.76	2.19	3.41	2.58	2.89	1.95
3.96 × 3.96	2.78	1.65	2.77	1.58	2.62	1.71	2.83	2.23	3.42	2.66	2.88	1.97
3.65 × 3.65	2.75	1.65	2.77	1.61	2.64	1.81	2.88	2.21	3.51	2.56	2.91	1.97
4.87 × 2.74	2.76	1.65	2.74	1.63	2.52	1.85	2.77	2.15	3.20	2.46	2.80	1.95
3.65 × 2.13	2.72	1.58	2.78	1.35	2.56	1.42	3.01	1.86	3.14	2.11	2.84	1.66
Mean	2.77	1.64	2.77	1.55	2.60	1.69	2.85	2.13	3.34	2.47		
C.D. at 5 %	For Height:		Spacing: 0.011;		Clone: 0.011;		Spacing × Clone: 0.024					
	For dbh:		Spacing: 0.015;		Clone: 0.015;		Spacing × Clone: 0.034					

Table 5. Effect of spacing on the growth of four year old poplar plantation

Spacing (m)	Clone											
	WSL-39		WSL-22		WSL-81		G-48		G-3		Mean	
	Height (m)	dbh (cm)	Height (m)	dbh (cm)	Height (m)	dbh (cm)	Height (m)	dbh (cm)	Height (m)	dbh (cm)	Height (m)	dbh (cm)
4.26 × 4.26	14.76	15.80	14.73	15.73	14.72	15.69	14.69	15.57	14.61	15.46	14.70	15.65
3.96 × 3.96	14.72	15.74	14.70	15.67	14.67	15.60	14.65	15.41	14.51	15.35	14.65	15.55
3.65 × 3.65	14.70	15.70	14.66	15.56	14.61	15.55	14.51	15.28	14.36	15.25	14.57	15.47
4.87 × 2.74	14.67	15.65	14.62	15.50	14.57	15.49	14.43	15.19	13.93	15.16	14.44	15.40
3.65 × 2.13	14.65	15.60	14.48	15.40	14.43	15.28	14.38	15.11	13.72	14.84	14.33	15.25
Mean	14.70	15.70	14.64	15.57	14.60	15.52	14.53	15.31	14.22	15.21		
C.D. at 5 %	For Height:		Spacing: 0.22;		Clone: 0.22;		Spacing × Clone: 0.026		Spacing × Clone: 0.023			
	For dbh:		Spacing: 0.01;		Clone: 0.012;							
CAI												
Spacing (m)	WSL-39		WSL-22		WSL-81		G-48		G-3		Mean	
	Height (m)	dbh (cm)	Height (m)	dbh (cm)	Height (m)	dbh (cm)	Height (m)	dbh (cm)	Height (m)	dbh (cm)	Height (m)	dbh (cm)
4.26 × 4.26	2.06	2.10	2.12	2.14	2.25	2.21	2.24	2.18	2.19	2.18	2.17	2.16
3.96 × 3.96	2.11	2.10	2.16	2.14	2.31	2.16	2.24	2.06	2.16	2.11	2.20	2.12
3.65 × 3.65	2.16	2.12	2.16	2.14	2.32	2.22	2.16	2.08	2.08	2.21	2.17	2.15
4.87 × 2.74	2.16	2.12	2.20	2.11	2.43	2.21	2.33	2.13	1.98	2.29	2.22	2.17
3.65 × 2.13	2.23	2.19	2.12	2.43	2.32	2.53	2.33	2.47	1.87	2.47	2.17	2.42
Mean	2.14	2.13	2.15	2.19	2.33	2.26	2.26	2.18	2.05	2.25		
C.D. at 5 %	For Height:		Spacing: 0.005;		Clone: 0.005;		Spacing × Clone: 0.011		Spacing × Clone: 0.013			
	For dbh:		Spacing: 0.06;		Clone: 0.06;							

Table 6. Effect of spacing on the growth of five year old poplar plantation

Spacing (m)	Clone											
	WSL-39		WSL-22		WSL-81		G-48		G-3		Mean	
	Height (m)	dbh (cm)	Height (m)	dbh (cm)	Height (m)	dbh (cm)	Height (m)	dbh (cm)	Height (m)	dbh (cm)	Height (m)	dbh (cm)
4.26 × 4.26	16.29	17.20	16.22	17.12	16.16	17.07	16.09	17.06	16.04	16.98	16.16	17.08
3.96 × 3.96	16.22	17.16	16.16	17.03	16.01	16.99	16.01	16.77	15.83	16.69	16.04	16.93
3.65 × 3.65	16.19	17.07	16.03	16.81	15.67	16.73	15.66	16.76	15.75	16.30	15.86	16.73
4.87 × 2.74	15.80	17.03	15.86	16.71	15.60	16.63	15.62	16.73	15.69	16.24	15.71	16.67
3.65 × 2.13	15.69	16.95	15.69	16.63	15.48	16.53	15.60	16.63	15.61	16.20	15.61	16.59
Mean	16.04	17.08	15.99	16.86	15.78	16.79	15.80	16.79	15.78	16.48		
C.D. at 5 %	For Height: Spacing: 0.11; For dbh: Spacing: 0.013;		Clone: 0.11; Clone: 0.014;		Spacing × Clone: 0.24 Spacing × Clone: 0.23							
CAI												
Spacing (m)	WSL-39		WSL-22		WSL-81		G-48		G-3		Mean	
	Height (m)	dbh (cm)	Height (m)	dbh (cm)	Height (m)	dbh (cm)	Height (m)	dbh (cm)	Height (m)	dbh (cm)	Height (m)	dbh (cm)
4.26 × 4.26	1.53	1.40	1.50	1.39	1.44	1.38	1.41	1.49	1.43	1.52	1.46	1.44
3.96 × 3.96	1.51	1.42	1.46	1.36	1.34	1.40	1.35	1.36	1.32	1.34	1.40	1.38
3.65 × 3.65	1.49	1.37	1.37	1.25	1.07	1.18	1.15	1.48	1.39	1.05	1.29	1.26
4.87 × 2.74	1.13	1.38	1.24	1.21	1.03	1.13	1.20	1.55	1.77	1.08	1.27	1.27
3.65 × 2.13	1.04	1.36	1.22	1.23	1.06	1.25	1.22	1.52	1.89	1.36	1.28	1.34
Mean	1.34	1.38	1.36	1.29	1.18	1.27	1.26	1.48	1.56	1.27		
C.D. at 5 %	For Height: Spacing: 0.008; For dbh: Spacing: 0.06;		Clone: 0.009; Clone: 0.06;		Spacing × Clone: 0.019 Spacing × Clone: 0.012							

It is evident from the data presented in Table 7 that there was significant effect of both the spacing and clone in height and dbh of six year old poplar plantation. The interaction effect between spacing and clone were also found to be significant. Poplar planted at 4.26×4.26 m spacing had attained maximum height (20.35 m) and dbh (21.27 cm) in poplar clone WSL-39 followed by tree planted at 3.96×3.96 m, 3.65×3.65 m, 4.87×2.74 m and 3.65×2.13 m spacings. The value for height (18.37m) and dbh (19.41 cm) were recorded significantly lesser in poplar clone G-3 in closer spacing 3.65×2.13 m. The current annual increment in height (4.29 m) and dbh (4.26 cm) were recorded significantly higher in poplar clone WSL-39 and WSL-22 in same spacing 4.87×2.74 m. The current annual increment in height (2.76 cm) was recorded lesser in poplar clone G-3 in spacing 4.87×2.74 m. However, the current annual increment in dbh (3.22 cm) was recorded lesser in poplar clone G-3 in closer spacing (3.65×2.13 m).

The data in Table 8 showed that there was significant effect of different spacings of poplar on the height and dbh of seven year old poplar plantation. The height and dbh were significantly affected both by spacing and clones and the interaction effect between spacing and clones were also found significant. Poplar planted at 4.26×4.26 m spacing had attained maximum height (22.24 m) and dbh (23.80 cm) in poplar clone WSL-39 followed by tree planted at 3.96×3.96 m, 3.65×3.65 m, 4.87×2.74 m and 3.65×2.13 m spacings. The value for height (19.78 m) and dbh (22.31cm) were recorded significantly lesser in poplar clone G-3 in closer spacing 3.65×2.13 m. The poplar clone G-3 showed significantly lesser height (19.78 m) and dbh (22.31 cm) under all the spacings of poplar in the present investigation. The current annual increment in height (1.89 m) and dbh (2.90 cm) were recorded significantly higher in poplar clone WSL-39 and G-3 in 4.26×4.26 m and 3.65×2.13 m spacings. However, the current annual increment in height (0.99 m) and dbh (2.04 cm) were recorded significantly lesser in poplar clone G-48 and WSL-22 in 3.96×3.96 m and 3.65×2.13 m spacings.

It is evident from the data presented in Table 9 that there was significant effect of different spacings of poplar on the mean annual increment in height and dbh of seven year old poplar plantation. Poplar planted at 4.26×4.26 m spacing had attained maximum mean annual increment for height (3.18 m) and dbh (3.40 cm) in poplar clone WSL-39 followed by tree planted at 3.96×3.96 m, 3.65×3.65 m, 4.87×2.74 m and 3.65×2.13 m spacings. However, the mean annual increment in height (2.83 m) and dbh (3.19 cm) were recorded significantly lesser in poplar clone G-3 in closer spacing 3.65×2.13 m spacings.

The result presented in Table 10 clearly indicated that in all the poplar clones, volume ($0.441 \text{ m}^3/\text{tree}$) and weight (392.70 kg/tree) were recorded significantly higher in poplar clone WSL-39 in 4.26×4.26 m spacing, which was closely followed by poplar clone WSL-

22 during this experimentation. However, poplars clone G-3 recorded lower weight (353.43 kg/tree) and volume (0.263 m³/tree) in seven year old poplar plantation.

Table 7. Effect of spacing on the growth of six year old poplar plantation

Spacing (m)	Clone											
	WSL-39		WSL-22		WSL-81		G-48		G-3		Mean	
	Height (m)	dbh (cm)	Height (m)	dbh (cm)	Height (m)	dbh (cm)	Height (m)	dbh (cm)	Height (m)	dbh (cm)	Height (m)	dbh (cm)
4.26 × 4.26	20.35	21.27	20.18	21.07	19.93	21.00	19.90	20.77	19.37	20.37	19.94	20.90
3.96 × 3.96	20.23	21.17	20.07	21.02	19.83	20.86	19.78	20.50	19.10	20.14	19.80	20.74
3.65 × 3.65	20.11	21.05	19.93	21.07	19.74	20.37	19.37	20.35	18.90	20.03	19.61	20.57
4.87 × 2.74	20.09	20.95	19.76	20.97	19.43	20.24	19.28	20.27	18.45	19.99	19.40	20.48
3.65 × 2.13	19.94	20.91	19.52	20.84	19.38	20.12	19.24	20.18	18.37	19.41	19.29	20.29
Mean	20.14	21.07	19.89	21.00	19.66	20.52	19.51	20.41	18.84	19.99		
C.D. at 5 %	For Height:		Spacing: 0.021;		Clone: 0.021;		Spacing × Clone: 0.046					
	For dbh:		Spacing: 0.019;		Clone: 0.018;		Spacing × Clone: 0.041					
CAI												
Spacing (m)	WSL-39		WSL-22		WSL-81		G-48		G-3		Mean	
	Height (m)	dbh (cm)	Height (m)	dbh (cm)	Height (m)	dbh (cm)	Height (m)	dbh (cm)	Height (m)	dbh (cm)	Height (m)	dbh (cm)
4.26 × 4.26	4.06	4.08	3.96	3.95	3.77	3.94	3.81	3.71	3.34	3.39	3.79	3.81
3.96 × 3.96	4.00	4.01	3.91	3.99	3.83	3.87	3.77	3.72	3.28	3.45	3.76	3.81
3.65 × 3.65	3.93	3.98	3.90	4.25	4.07	3.64	3.71	3.59	3.15	3.73	3.75	3.84
4.87 × 2.74	4.29	3.93	3.90	4.26	3.84	3.61	3.66	3.54	2.76	3.75	3.69	3.82
3.65 × 2.13	4.24	3.96	3.83	4.22	3.90	3.59	3.65	3.55	2.77	3.22	3.68	3.71
Mean	4.11	3.99	3.90	4.14	3.88	3.73	3.72	3.62	3.06	3.51		
C.D. at 5 %	For Height:		Spacing: 0.016;		Clone: 0.016;		Spacing × Clone: 0.035					
	For dbh:		Spacing: 0.011;		Clone: 0.011;		Spacing × Clone: 0.024					

Table 8. Effect of spacing on the growth of seven year old poplar plantation

Spacing (m)	Clone											
	WSL-39		WSL-22		WSL-81		G-48		G-3		Mean	
	Height (m)	dbh (cm)	Height (m)	dbh (cm)	Height (m)	dbh (cm)	Height (m)	dbh (cm)	Height (m)	dbh (cm)	Height (m)	dbh (cm)
4.26 × 4.26	22.24	23.80	21.70	23.59	21.46	23.36	21.07	23.15	20.45	22.99	21.38	23.38
3.96 × 3.96	22.11	23.67	21.45	23.28	21.05	23.26	20.77	22.98	20.14	22.83	21.10	23.20
3.65 × 3.65	21.49	23.48	21.16	23.12	20.97	23.15	20.69	22.84	19.95	22.74	20.85	23.07
4.87 × 2.74	21.39	23.36	21.07	23.03	20.87	23.03	20.47	22.64	19.83	22.39	20.73	22.89
3.65 × 2.13	21.15	23.05	20.89	22.88	20.77	22.92	20.37	22.54	19.78	22.31	20.59	22.74
Mean	21.67	23.47	21.25	23.18	21.02	23.14	20.67	22.83	20.03	22.65		
C.D. at 5 %	For Height:		Spacing: 0.024;		Clone: 0.024;		Spacing × Clone: 0.054					
	For dbh:		Spacing: 0.018;		Clone: 0.018;		Spacing × Clone: 0.041					
CAI												
Spacing (m)	WSL-39		WSL-22		WSL-81		G-48		G-3		Mean	
	Height (m)	dbh (cm)	Height (m)	dbh (cm)	Height (m)	dbh (cm)	Height (m)	dbh (cm)	Height (m)	dbh (cm)	Height (m)	dbh (cm)
4.26 × 4.26	1.89	2.53	1.53	2.52	1.54	2.36	1.18	2.38	1.08	2.63	1.44	2.48
3.96 × 3.96	1.88	2.50	1.39	2.25	1.22	2.39	0.99	2.49	1.04	2.70	1.30	2.47
3.65 × 3.65	1.38	2.43	1.24	2.05	1.24	2.79	1.32	2.50	1.06	2.71	1.24	2.50
4.87 × 2.74	1.30	2.40	1.32	2.06	1.44	2.80	1.19	2.37	1.39	2.40	1.33	2.41
3.65 × 2.13	1.22	2.14	1.38	2.04	1.39	2.80	1.12	2.37	1.41	2.90	1.30	2.45
Mean	1.54	2.40	1.37	2.18	1.36	2.63	1.16	2.42	1.19	2.67		
C.D. at 5 %	For Height:		Spacing: 0.009;		Clone: 0.009;		Spacing × Clone: 0.021					
	For dbh:		Spacing: 0.010;		Clone: 0.011;		Spacing × Clone: 0.022					

Table 9: Mean annual increment (MAI) of seven year old poplar plantation

Clone												
Spacing (m)	WSL-39		WSL-22		WSL-81		G-48		G-3		Mean	
	Height (m)	dbh (cm)	Height (m)	dbh (cm)	Height (m)	dbh (cm)	Height (m)	dbh (cm)	Height (m)	dbh (cm)	Height (m)	dbh (cm)
4.26 × 4.26	3.18	3.40	3.10	3.37	3.07	3.34	3.01	3.31	2.92	3.29	3.06	3.34
3.96 × 3.96	3.16	3.38	3.07	3.33	3.01	3.32	2.97	3.29	2.88	3.26	3.02	3.32
3.65 × 3.65	3.07	3.36	3.02	3.31	3.00	3.31	2.96	3.27	2.85	3.25	2.98	3.30
4.87 × 2.74	3.06	3.34	3.01	3.29	2.98	3.29	2.93	3.24	2.84	3.20	2.96	3.27
3.65 × 2.13	3.02	3.29	2.98	3.27	2.97	3.28	2.91	3.22	2.83	3.19	2.94	3.25
Mean	3.10	3.35	3.04	3.31	3.00	3.31	2.95	3.26	2.86	3.24		
C.D. at 5 %	For height:		Spacing: 0.004;		Clone: 0.004;		Spacing × Clone: 0.009					
	For dbh:		Spacing: 0.002;		Clone: 0.002;		Spacing × Clone: 0.005					



Plate 1: Harvesting operation of poplar wood in Yamunanagar, Haryana

Table 10: Volume and weight of different poplar clones after felling operation in 4.26 × 4.26 m spacing

Poplar clone	Height (m)	Merchantable height (m)	DBH (cm)	Volume (m ³ /tree)	Biomass (kg/tree)
WSL-39	22.23	19.87	23.68	0.441	392.70
WSL-22	22.11	19.76	23.26	0.393	383.35
WSL 81	21.48	19.48	22.94	0.345	381.48
G-48	21.38	19.16	22.74	0.326	370.26
G-3	20.36	18.43	22.06	0.263	353.43
C.D. at 5%	0.075	0.054	0.06	0.01	1.48

It is evident from the data presented in Table 11 that there was significant effect of poplar clones in weight and volume of seven year old poplar plantation under this study. The poplar clone WSL-39 showed significantly higher volume (0.403 m³/tree) and weight (388.03 kg/tree) in 3.96 × 3.96 spacing, which was followed by poplar clone WSL-22 with volume (0.365 m³/tree) and weight (374.94 kg/tree).

Table 11: Volume and weight of different poplar clones after felling operation in 3.96 × 3.96 m spacing

Poplar clone	Height (m)	Merchantable height (m)	DBH (cm)	Volume (m ³ /tree)	Weight (kg/tree)
WSL-39	22.11	19.75	23.59	0.403	388.03
WSL-22	21.16	19.52	22.84	0.365	374.94
WSL 81	21.07	19.10	22.67	0.335	371.20
G-48	20.86	18.94	22.24	0.298	365.59
G-3	20.13	17.67	21.85	0.225	358.11
C.D. at 5%	0.065	0.052	0.07	0.008	1.07

Table 12: Volume and weight of different poplar clones after felling operation clone in 3.65 × 3.65 m spacing

Poplar clone	Height (m)	Merchantable height (m)	DBH (cm)	Volume (m ³ /tree)	Weight (kg/tree)
WSL-39	21.28	19.73	23.35	0.355	385.22
WSL-22	21.16	19.18	22.76	0.308	372.13
WSL 81	20.68	19.05	22.60	0.263	363.72
G-48	20.47	18.82	22.00	0.243	361.85
G-3	19.93	17.34	21.61	0.215	354.37
C.D. at 5%	0.052	0.051	0.06	0.007	1.11

The data presented in Table 12 showed that the poplar clone WSL-39 had significantly higher volume (0.355 m³/tree) and weight (385.22 kg/tree) in 3.65 × 3.65 m

spacing, which was followed by WSL-22 under this study. However, the poplar clones G-48 and G-3 had minimum volume and weight in this spacing.

The result presented in Table 13 clearly indicated that in all the poplar clones, volume (0.328 m³/tree) and weight (374.94 kg/tree) were recorded significantly higher in poplar clone WSL-39 in 4.26 × 4.26 m spacing, which was closely followed by poplar clone WSL-22 during this experimentation. However, poplars clone G-3 recorded lower weight (341.28 kg/tree) and volume (0.198 m³/tree) at the age of seven year plantation.

It is evident from the data presented in Table 14 that there was significant effect of poplar clones in weight and volume of seven year old poplar plantation under this study. The poplar clone WSL-39 showed significantly higher volume (0.298 m³/tree) and weight (369.33 kg/tree) in 3.65× 2.13 spacing, which was followed by poplar clone WSL-22 with volume (0.276 m³/tree) and weight (358.11 kg/tree).

Table 13: Volume and weight of different poplar clone after felling operation in 4.87 × 2.74 spacing

Poplar clone	Height (m)	Merchantable height (m)	DBH (cm)	Volume (m ³ /tree)	Weight (kg/tree)
WSL-39	21.17	19.54	23.15	0.328	374.94
WSL-22	20.99	18.32	22.55	0.293	368.39
WSL 81	20.69	18.24	22.34	0.235	361.85
G-48	20.36	18.31	21.88	0.215	354.37
G-3	19.01	17.94	21.42	0.198	341.28
C.D. at 5%	0.086	0.050	0.064	0.007	1.27

Table 14: Volume and weight of different poplar clone after felling operation in 3.65 × 2.13 m spacing

Poplar clone	Height (m)	Merchantable height (m)	DBH (cm)	Volume (m ³ /tree)	Weight (kg/tree)
WSL-39	21.16	19.54	22.99	0.298	369.33
WSL-22	20.36	18.45	22.37	0.276	358.11
WSL 81	20.08	18.24	21.90	0.253	350.63
G-48	19.83	18.18	21.70	0.228	346.89
G-3	19.77	17.78	21.45	0.213	328.19
C.D. at 5%	0.056	0.049	0.055	0.02	1.47

4.2 Economic return from poplar based agroforestry system:

4.2.1. Cost and return from Poplar-Sugarcane- Wheat crop rotation

It is evident from the data presented in Table 15-19 that the cost and return for growing poplar in intercropping with sugarcane and wheat under different spacings. The higher input cost (Rs. 9, 05522) for trees and crops were recorded in 3.65 × 2.13 m spacing, whereas the lower input costs (Rs. 8, 58, 611) for trees and crops were recorded in wider

spacing (4.26 × 4.26 m). The returns from trees were found higher (Rs. 13, 42,500) in 3.65 × 3.65 m spacing, which was closely followed by 4.87 × 2.74 m spacing with the returns (Rs. 13, 40,710) however, the returns from crops were recorded higher (Rs. 4, 82,742) in 4.26 × 4.26 m spacing. It might be due to the fact that wider spacing provided maximum space for better growth and yield for agricultural crops. Whereas, the total returns from trees and crops were recorded higher (Rs. 18, 03,154) in 4.87 × 2.74 m spacing, which was followed by 3.65 × 3.65 m spacing with the returns (Rs. 17, 98,484). The overall net returns from the rotation were also recorded higher (Rs. 9, 34,079) under 4.87 × 2.74 m spacing. On the basis of the above results it was found that 4.87 × 2.74 spacing gave higher benefit from poplar-sugarcane- wheat crop rotation.

Table 15: Streams of costs and returns from Poplar -Sugarcane-Wheat crop rotation in 4.26 × 4.26 m spacing in Rs/ha

Age (Year)	Incurred cost (Rs/ha)			Income (Rs/ha)			Net Benefit (Rs/ha)
	Trees	Crops	Total	Trees	Crops	Total	
1	79195	70994	150188	0	140000	140000	-10188
2	67405	48559	115964	0	128625	128625	12661
3	72078	26222	98300	0	46532	46532	-51768
4	82084	30372	112456	0	42635	42635	-69821
5	86214	32795	119009	0	44850	44850	-74159
6	91677	34710	126387	0	39200	39200	-87187
7	99130	37177	136307	986290	40900	1027190	890883
Total	577782	280829	858611	986290	482742	1469032	610421

#For poplar rates of HFDC, Haryana (2015-16) had taken to estimate return If Girth of tree i) 60 -69:- 708 ii) 69-79 :- 1790

Table16: Streams of costs and returns from Poplar -Sugarcane-Wheat crop rotation in 3.96 × 3.96 m spacing in Rs/ha.

Age (Year)	Incurred cost (Rs/ha)			Income (Rs/ha)			Net Benefit (Rs/ha)
	Trees	Crops	Total	Trees	Crops	Total	
1	82553	70994	153546	0	141500	141500	-12046
2	67405	48559	115964	0	126525	126525	10561
3	72078	26222	98300	0	43294	43294	-55006
4	83425	30372	113797	0	39390	39390	-74407
5	87672	32795	120467	0	40200	40200	-80267
6	93639	34710	128349	0	39960	39960	-88389
7	101255	37177	138432	1140230	40200	1180430	1041998
Total	588027	280829	868856	1140230	471069	1611299	742443

#For poplar rates of HFDC, Haryana (2015-16) had taken to estimate return If Girth of tree i) 60 -69:- 708 ii) 69-79 :- 1790

Table 17: Streams of costs and returns from Poplar -Sugarcane-Wheat crop rotation in 4.87 × 2.74 m spacing in Rs/ha

Age (Year)	Incurred cost (Rs/ha)			Income (Rs/ha)			Net Benefit (Rs/ha)
	Trees	Crops	Total	Trees	Crops	Total	
1	86215	70994	157209	0	139000	139000	-18209
2	67405	48559	115964	0	124950	124950	8986
3	72078	26222	98300	0	42694	42694	-55606
4	82755	30372	113127	0	38940	38940	-74187
5	86943	32795	119738	0	39900	39900	-79838
6	92658	34710	127368	0	38560	38560	-88808
7	100192	37177	137370	1340710	38400	1379110	1241740
Total	588246	280829	869075	1340710	462444	1803154	934079

#For poplar rates of HFDC, Haryana (2015-16) had taken to estimate return If Girth of tree i) 60 -69:- 708 ii) 69-79 :- 1790

Table 18: Streams of costs and returns from Poplar -Sugarcane-Wheat crop rotation in 3.65 × 3.65 m spacing in Rs/ha

Age (Year)	Incurred cost (Rs/ha)			Income (Rs/ha)			Net Benefit (Rs/ha)
	Trees	Crops	Total	Trees	Crops	Total	
1	86248	70994	157242	0	136500	136500	-20742
2	67405	48559	115964	0	124425	124425	8461
3	72078	26222	98300	0	42094	42094	-56206
4	82755	30372	113127	0	38715	38715	-74412
5	86943	32795	119738	0	39300	39300	-80438
6	92658	34710	127368	0	37600	37600	-89767
7	100192	37177	137370	1342500	37350	1379850	1242480
Total	588278	280829	869107	1342500	455984	1798484	929377

#For poplar rates of HFDC, Haryana (2015-16) had taken to estimate return If Girth of tree i) 60 -69:- 708 ii) 69-79 :- 1790

Table 19: Streams of costs and returns from Poplar -Sugarcane-Wheat crop rotation in 3.65 × 2.13 m spacing in Rs/ha

Age (Year)	Incurred cost (Rs/ha)			Income (Rs/ha)			Net Benefit (Rs/ha)
	Trees	Crops	Total	Trees	Crops	Total	
1	105446	70994	176439	0	134500	134500	-41939
2	67405	48559	115964	0	121275	121275	5311
3	72078	26222	98300	0	39456	39456	-58844
4	86106	30372	116478	0	37205	37205	-79273
5	90589	32795	123384	0	37650	37650	-85734
6	97563	34710	132273	0	35560	35560	-96712
7	105506	37177	142683	911196	34500	1671564	1528880
Total	624693	280829	905522	911196	440146	1351342	445820

#For poplar rates of HFDC, Haryana (2015-16) had taken to estimate return If Girth of tree i) 60 -69:- 708 ii) 69-79 :- 1790

4.2.2. Net present value in Poplar-Sugarcane- Wheat crop rotation

Costs and returns data presented in Tables 20-24 do not serve as true guide for making choice to go for poplar plantation vis-a-vis other annual crops. This is mainly because of the fact that costs incurred and returns obtained from poplar plantation over time is not comparable with annual crops grown in the area. Whereas in poplar plantation returns from investment in annual crops can be obtained within a year, while minimum six to seven years period must be lapse after planting before any returns are obtained over operational costs from poplar plantation. Hence, it is necessary to estimate the net present value of future returns which can be determined by discounting both the costs as well as returns at the prevailing rate of interest. In the present study the prevailing interest rate as 12 per cent per annum taken as discount rate of the costs and returns to determine NPV of the poplar plantation.

Net present value is defined as the present value of all future cash flows associated with the investment, including the outlay. The net present value thus computed has been shown in Tables 20 to 24 for different spacing's arrangement such as 4.26×4.26 m, 3.96×3.96 m, 3.65×3.65 m, 4.87×2.74 m and 3.65×2.13 m spacings, respectively. The figures given in these tables show that net present values (NPVs) for one hectare poplar-Sugarcane-Wheat crop rotation came to be Rs. 2, 36, 515, Rs. 2, 92, 244, Rs. 3, 75, 584, Rs. 3, 71, 842 and Rs. 1, 40, 120 in 4.26×4.26 m, 3.96×3.96 m, 4.87×2.74 m, 3.65×3.65 m, and 3.65×2.13 m spacings, respectively for the at end of the rotation. The positive NPV of all the spacings showed that poplar-sugarcane-wheat crop rotation is a profitable crop enterprise in the Yamunanagar district of the state. The NPV was found higher in 4.87×2.74 m spacing, which was followed by 3.65×3.65 m spacing. The reason for this higher value could be the higher yield from agriculture crops and maximum income from trees were found in this spacing.

4.2.3. Internal rate of return (IRR) from Poplar-Sugarcane- Wheat crop rotation

The internal rate of return (IRR) is also a time-discounted measure of investment worth. It is one of the important indicators for evaluating the desirability of the investment with long gestation period. It is defined as the rate of discount or earning power of the investment which equalizes discounted benefits or returns (B) with the discounted cost (C) i.e. the rate of discount which will satisfy the relationship, $B-C = 0$.

In estimating the internal rate of return, the investment costs, gross returns from first to seventh year of poplar plantation have been depicted in Tables 25 to 29 for different spacing's arrangement such as 4.26×4.26 m, 3.96×3.96 m, 3.65×3.65 m, 4.87×2.74 m and 3.65×2.13 m spacings, respectively. The net cash flow was obtained by using these single values which may have negative and positive signs depending on the quantum of costs and benefits or returns in each year.

To find out the present value, the discounted rate was estimated by different discount rate at random until the difference between the sum of discounted streams of positive and negative values is reduced either to zero or to a lowest minimum value. Thus, computed values of internal rate of returns are shown in Tables 25 to 29 in different spacings. The data presented in these Tables indicates internal rate of return of 46.62, 47.50, 48.51, 48.04 and 28.47 per cent annum⁻¹ in 4.26 × 4.26 m, 3.96 × 3.96 m, 4.87 × 2.74 m, 3.65 × 3.65 m and 3.65 × 2.13 m spacings, respectively. This indicates that investment on poplar-sugarcane-wheat crop rotation is more profitable and internal rate of return in the districts was more than the present market interest rate i.e. 12 per cent per annum. The higher rate of returns from poplar-sugarcane- wheat crop rotation in 4.87 × 2.74 m followed by 3.65 × 3.65 m.

Table 20: Net present value from Poplar -Sugarcane-Wheat crop rotation in 4.26 × 4.26 m spacing in Rs/ha

Year	Cost	Net Return	Discount coefficient $1/(1+r)^n$	Present value		NPV
				Cost	Net return	
1	10188		0.8929	9096		0
2		12661	0.7972		10093	0
3	51768		0.7118	36847	0	0
4	69821		0.6355	44372	0	0
5	74158		0.5674	42079	0	0
6	87186		0.5066	44171	0	0
7		890883	0.4523		402990	236515
Total	293123	903544		176568	413083	

r =12%

Table 21: Net present value from Poplar -Sugarcane-Wheat crop rotation in 3.96 × 3.96 m spacing in Rs/ha

Year	Cost	Net Return	Discount coefficient $1/(1+r)^n$	Present value		NPV
				Cost	Net return	
1	12046		0.8929	10755		0
2		10561	0.7972		8419	0
3	55006		0.7118	39152	0	0
4	74407		0.6355	47287	0	0
5	80267		0.5674	45545	0	0
6	88388		0.5066	44780	0	0
7		1041998	0.4523		471346	292244
Total	310115	1052559		187521	479766	

r =12%



Plate 2: Poplar + Sugarcane based agroforestry system in Yamunanagar

Table 22: Net present value from Poplar -Sugarcane-Wheat crop rotation in 3.96 × 2.74 m spacing in Rs/ha

Year	Cost	Net Return	Discount coefficient $1/(1+r)^n$	Present value		NPV
				Cost	Net return	
1	18208		0.8929	16257		0
2		8986	0.7972		7163	0
3	55606		0.7118	39579		0
4	74186		0.6355	47147		0
5	79838		0.5674	45302		0
6	88807		0.5066	44992		0
7		1241740	0.4523		561700	375584
Total	316647	1250727		193279	568864	

r =12%

Table 23: Net present value from Poplar -Sugarcane-Wheat crop rotation in 3.65 × 3.65 m spacing in Rs/ha

Year	Cost	Net Return	Discount coefficient $1/(1+r)^n$	Present value		NPV
				Cost	Net return	
1	20741		0.8929	18519		0
2		8461	0.7972		6745	0
3	56206		0.7118	40006	0	0
4	74411		0.6355	47290	0	0
5	80438		0.5674	45642	0	0
6	89767		0.5066	45479	0	0
7		1242480	0.4523		562035	371842
Total	321565	1250942		196937	568780	

r =12%

Table 24: Net present value from Poplar -Sugarcane-Wheat crop rotation in 3.65 × 2.13 m spacing in Rs/ha

Year	Cost	Net Return	Discount coefficient $1/(1+r)^n$	Present value		NPV
				Cost	Net return	
1	41939		0.8929	37446		0
2		5311	0.7972		4234	0
3	58844		0.7118	41884		0
4	79273		0.6355	50379		0
5	85734		0.5674	48647		0
6	96712		0.5066	48997		0
7		803012	0.4523		363242	140120
Total	362504	808324		227355	367476	

r =12%

Table 25: Internal rate of return from Poplar -Sugarcane-Wheat crop rotation in 4.26 × 4.26 m spacing in Rs/ha

Year	Net cash flow	Present value coefficient r=36% $1/(1+r)^n$	Corresponding present value	Present value coefficient r= 37% $1/(1+r)^n$	Corresponding present value
1	-10188	0.7353	-7491	0.7299	-7436
2	12661	0.5407	6845	0.5328	6745
3	-51768	0.3975	-20580	0.3889	-20132
4	-69821	0.2923	-20409	0.2839	-19820
5	-74158	0.2149	-15939	0.2072	-15365
6	-87186	0.1580	-13778	0.1512	-13186
7	890883	0.1162	103525	0.1104	98350
Total			32172		29154

$$IRR = 36 + 1(32172.16) / (32172.16 - 29154.7) = 46.62$$

Table 26: Internal rate of return from Poplar -Sugarcane-Wheat crop rotation in 3.96 × 3.96 m spacing in Rs/ha

Year	Net cash flow	Present value coefficient r=36% $1/(1+r)^n$	Corresponding present value	Present value coefficient r= 37% $1/(1+r)^n$	Corresponding present value
1	-12046	0.7353	-8857	0.7299	-8792
2	10561	0.5407	5710	0.5328	5627
3	-55006	0.3975	-21867	0.3889	-21391
4	-74407	0.2923	-21749	0.2839	-21121
5	-80267	0.2149	-17252	0.2072	-16631
6	-88388	0.1580	-13968	0.1512	-13368
7	1041998	0.1162	121086	0.1104	115033
Total			43100		39353

$$IRR = 36 + 1(43100.21) / (43100.21 - 39353.48) = 47.50$$

Table 27: Internal rate of return from Poplar -Sugarcane-Wheat crop rotation in 4.87 × 2.74 m spacing in Rs/ha

Year	Net cash flow	Present value coefficient r=36% $1/(1+r)^n$	Corresponding present value	Present value coefficient r= 37% $1/(1+r)^n$	Corresponding present value
1	-18208	0.7353	-13388	0.7299	-13291
2	8986	0.5407	4858	0.5328	4787
3	-55606	0.3975	-22105	0.3889	-21625
4	-74186	0.2923	-21685	0.2839	-21059
5	-79838	0.2149	-17159	0.2072	-16542
6	-88807	0.1580	-14035	0.1512	-13431
7	1241740	0.1162	144297	0.1104	137084
Total			60780		55921

$$IRR = 36 + 1(60780.67) / (60780.67 - 55921.95) = 48.51$$



Plate 3: Poplar + Wheat based agroforestry system in Yamunanagar

Table 28: Internal rate of return from Poplar -Sugarcane-Wheat crop rotation in 3.65× 3.65 m spacing in Rs/ha

Year	Net cash flow	Present value coefficient r=36% $1/(1+r)^n$	Corresponding present value	Present value coefficient r= 37% $1/(1+r)^n$	Corresponding present value
1	-20741	0.7353	-15251	0.7299	-15139
2	8461	0.5407	4574	0.5328	4508
3	-56206	0.3975	-22344	0.3889	-21858
4	-74411	0.2923	-21751	0.2839	-21123
5	-80438	0.2149	-17288	0.2072	-16667
6	-89767	0.1580	-14186	0.1512	-13576
7	1242480	0.1162	144383	0.1104	137165
Total			58135		53308

$$IRR = 36 + 1(58135.56) / (58135.56 - 53308.51) = 48.04$$

Table 29: Internal rate of return from Poplar -Sugarcane-Wheat crop rotation in 3.65 × 2.13 m spacing in Rs/ha

Year	Net cash flow	Present value coefficient r=36% $1/(1+r)^n$	Corresponding present value	Present value coefficient r= 37% $1/(1+r)^n$	Corresponding present value
1	-41939	0.7353	-30837	0.7299	-30612
2	5311	0.5407	2871	0.5328	2829
3	-58844	0.3975	-23393	0.3889	-22884
4	-79273	0.2923	-23172	0.2839	-22503
5	-85734	0.2149	-18427	0.2072	-17764
6	-96712	0.1580	-15284	0.1512	-14627
7	803012	0.1162	93314	0.1104	88649
Total			-14928		-16912

$$IRR = 36 + 1(-14928.8) / (-14928.8 + 16912.46) = 28.47$$

4.2.4 Benefit-Cost ratio in Poplar-Sugarcane- Wheat crop rotation

The benefit cost ratio is the ratio between the sum of discounted benefits or returns (R) and sum of discounted cost (K) which is presented in Table 30 at discount rate of 12 per cent. The benefit-cost ratios were found as 2.34, 2.56, 2.94, 2.89 and 1.62 in 4.26 × 4.26 m, 3.96 × 3.96 m, 4.87 × 2.74 m, 3.65 × 3.65 m and 3.65 × 2.13 m spacing's , respectively. Higher value of benefit-cost ratio in 4.87 × 2.74 m as compared to 3.65 × 3.65 m and 3.96 × 3.96 m spacing indicates that 4.87 × 2.74 m is more appropriate spacing of poplar based agroforestry system from efficiency and profitability point of view.

Table 30: Benefit Cost Ratio, Internal rate of return and Pay Back Period in poplar – sugarcane-wheat crop rotation with different spacings

Spacings (m)	Return	Cost	B:C	IRR (%)	Pay Back Period
4.26 × 4.26 m	413083	176568	1 : 2.34	46.62	7
3.96 × 3.96 m	479766	187521	1 : 2.56	47.50	7
4.87 × 2.74 m	568864	193279	1 : 2.94	48.51	7
3.65 × 3.65 m	568780	196937	1 : 2.89	48.04	7
4.26 × 4.26 m	367476	227355	1 : 1.62	28.47	7

4.2.5. Cost and return from Poplar-Sugarcane-Sorghum- Wheat crop rotation

The data presented from Table 31 to 35 showed that the cost and return for growing poplar in intercropping with sugarcane, sorghum and wheat under different spacing arrangements. The highest cost (Rs. 9, 32,035) incurred on trees and crops were found in 3.65 × 2.13 m spacing, whereas the lower input cost (Rs. 8, 90,722) for trees and crops were observed in wider spacing (4.26 × 4.26 m). The returns from trees were recorded higher (Rs. 13, 42,500) in 3.65 × 3.65 m spacing, which was closely followed by 4.87 × 2.74 m spacing with the returns (Rs. 13, 40,710) however, the higher returns from crops were observed (Rs. 5,91,482) in 4.26 × 4.26 m spacing. Whereas, the lower returns from crops were recorded (Rs. 5, 41,345) in 3.65 × 2.13 m spacing. It might be due to the fact that more competition between tree and crop due to various aspects such as space, moisture, sun light and nutrient. However, the total returns from trees and crops were found higher (Rs. 19, 08,606) in 4.87 × 2.74 m spacing, which was closely followed by 3.65 × 3.65 m spacing with the returns (Rs. 19, 02,447). The overall net returns from the rotation were also found higher (Rs. 10, 07, 420) in 4.87 × 2.74 m spacing. On the basis of net returns from the rotation, it was found that 4.87 × 2.74 m spacing highly profitable for poplar -sugarcane - sorghum -wheat crop rotation.

Table 31: Streams of costs and returns from Poplar -sugarcane-sorghum-wheat crop rotation in 4.26 × 4.26 m spacing in Rs/ha

Age (Year)	Incurred cost (Rs/ha)			Income (Rs/ha)			Net Benefit (Rs/ha)
	Trees	Crops	Total	Trees	Crops	Total	
1	79195	70993	150188	0	140000	140000	-10188
2	67405	48559	115964	0	128625	128625	12661
3	72078	36443	108521	0	83772	83772	-24749
4	77392	46882	124274	0	80985	80985	-43289
5	81109	47972	129082	0	78000	78000	-51081
6	91677	34710	126387	0	39200	39200	-87186
7	99130	37177	136307	986290	40900	1027190	890883
Total	567984	322737	890722	986290	591482	1577772	687050

#For poplar rates of HFDC, Haryana (2015-16) had taken to estimate return If Girth of tree i) 60 -69:- 708 ii) 69-79 :- 1790

Table 32: Streams of costs and returns from Poplar -sugarcane-sorghum-wheat crop rotation in 3.96 × 3.96 m spacing in Rs/ha

Age (Year)	Incurred cost (Rs/ha)			Income (Rs/ha)			Net Benefit (Rs/ha)
	Trees	Crops	Total	Trees	Crops	Total	
1	82553	70993	153546	0	141500	141500	-12046
2	67405	48559	115964	0	126525	126525	10561
3	72078	36443	108521	0	80249	80249	-28272
4	78062	46882	124944	0	77268	77268	-47676
5	81838	47972	129811	0	72440	72440	-57370
6	93639	34710	128349	0	39960	39960	-88388
7	101255	37177	138432	1140230	40200	1180430	1041998
Total	576830	322737	899567	1140230	578142	1718372	818805

#For poplar rates of HFDC, Haryana (2015-16) had taken to estimate return If Girth of tree i) 60 -69:- 708 ii) 69-79 :- 1790

Table 33: Streams of costs and returns from Poplar -sugarcane-sorghum-wheat crop rotation in 4.87× 2.74 m spacing in Rs/ha

Age (Year)	Incurred cost (Rs/ha)			Income (Rs/ha)			Net Benefit (Rs/ha)
	Trees	Crops	Total	Trees	Crops	Total	
1	86215	70993	157208	0	139000	139000	-18208
2	67405	48559	115964	0	124950	124950	8986
3	72078	36443	108521	0	79174	79174	-29347
4	78062	46882	124944	0	76582	76582	-48362
5	81838	47972	129811	0	71230	71230	-58580
6	92658	34710	127368	0	38560	38560	-88807
7	100192	37177	137370	1340710	38400	1379110	1241740
Total	578448	322737	901186	1340710	567896	1908606	1007420

#For poplar rates of HFDC, Haryana (2015-16) had taken to estimate return If Girth of tree i) 60 -69:- 708 ii) 69-79 :- 1790

Table 34: Streams of costs and returns from Poplar -sugarcane-sorghum-wheat crop rotation in 3.65 × 3.65 m spacing in Rs/ha

Age (Year)	Incurred cost (Rs/ha)			Income (Rs/ha)			Net Benefit (Rs/ha)
	Trees	Crops	Total	Trees	Crops	Total	
1	86248	70993	157241	0	136500	136500	-20741
2	67405	48559	115964	0	124425	124425	8461
3	72078	36443	108521	0	78289	78289	-30232
4	78062	46882	124944	0	75413	75413	-49531
5	81838	47972	129811	0	70370	70370	-59440
6	92658	34710	127368	0	37600	37600	-89767
7	100192	37177	137370	1342500	37350	1379850	1242480
Total	578481	322737	901219	1342500	559947	1902447	1001228

#For poplar rates of HFDC, Haryana (2015-16) had taken to estimate return If Girth of tree i) 60 -69:- 708 ii) 69-79 :- 1790

Table 35: Streams of costs and returns from Poplar -sugarcane-sorghum-wheat crop rotation in 3.65 × 2.13 m spacing in Rs/ha

Age (Year)	Incurred cost (Rs/ha)			Income (Rs/ha)			Net Benefit (Rs/ha)
	Trees	Crops	Total	Trees	Crops	Total	
1	105446	70993	176439	0	134500	134500	-41939
2	67405	48559	115964	0	121275	121275	5311
3	72078	36443	108521	0	75461	75461	-33060
4	78732	46882	125615	0	72369	72369	-53245
5	82567	47972	130540	0	67680	67680	-62859
6	97563	34710	132273	0	35560	35560	-96712
7	105506	37177	142683	911196	34500	945696	803012
Total	609298	322737	932035	911196	541345	1452541	520506

#For poplar rates of HFDC, Haryana (2015-16) had taken to estimate return If Girth of tree i) 60 -69:- 708 ii) 69-79 :- 1790

4.2.6. Net Present Value in Poplar- Sugarcane-Sorghum –Wheat crop rotation

It is evident from the data presented in Table 36 to 40 for different spacings arrangement such as 4.26 × 4.26 m, 3.96 × 3.96 m, 4.87 × 2.74 m, 3.65 × 3.65 m and 3.65 × 2.13 m spacings, respectively. The data recorded in these Tables shown that net present values (NPVs) for one hectare poplar –Sugarcane-Sorghum- Wheat crop rotation came to be Rs.2, 85, 703, Rs.3, 41, 253, Rs.4, 22, 749, Rs. 4, 18, 057 and Rs. 1,87, 993 in 4.26 × 4.26 m, 3.96 × 3.96 m, 4.87 × 2.74 m, 3.65 × 3.65 m, and 3.65 × 2.13 m spacings, respectively for at the end of the rotation. The net present value was found higher under 4.87 × 2.74 m, which was followed by 3.65 × 3.65 m spacing. The NPV was recorded lower in closer spacing (3.65 × 2.13 m).The reason for this higher value to obtained maximum returns from agriculture crops and trees. This spacing showed optimum growth and yield for agriculture crops as well as trees.

4.2.7. Internal rate of return in Poplar- Sugarcane-Sorghum –Wheat crop rotation

The result presented in Table 41 to 45 clearly indicated that the internal rate of return of 51.23, 51.17, 51.24, 50.80 and 39.01 per cent annum⁻¹ in 4.26 × 4.26 m, 3.96 × 3.96 m, 4.87 × 2.74 m, 3.65 × 3.65 m and 3.65 × 2.13 m spacings, respectively. This indicates that investment on poplar-sugarcane-sorghum-wheat crop rotation is more profitable and internal rate of return in all spacings are more than the present market interest rate i.e. 12 per cent annum⁻¹. The higher rate of returns from poplar-sugarcane- sorghum-wheat crop rotation under 4.87 × 2.74 m followed by 3.65 × 3.65 m and lower internal rate of returns was recorded in closer spacing (3.65 × 2.13m), because this spacing recorded lower growth and yield in both tree and crop.

4.2.8. Benefit- Cost ratio in Poplar- Sugarcane-Sorghum –Wheat crop rotation

It is evident from the data presented in Table 46 that the higher value (3.89) of benefit-cost ratio was recorded in 4.87 × 2.74 m as compared to 3.65 × 3.65 m and 3.96 × 3.96 m spacing and minimum value (2.05) of benefit cost ratio was observed in closer spacing (3.65 × 2.13m). On the basis of B: C ratio, it may be concluded that higher value presented in

4.87 × 2.74 m spacing is more appropriate spacing for poplar –sugarcane- sorghum –wheat rotation obtained maximum benefit.

Table 36: Net present value from Poplar -sugarcane-sorghum-wheat crop rotation in 4.26 × 4.26 m spacing in Rs/ha

Year	Cost	Net Return	Discount coefficient $1/(1+r)^n$	Present value		NPV
				Cost	Net return	
1	10188		0.8929	9096		0
2		12661	0.7972		10093	0
3	24749	0	0.7118	17616		0
4	43289	0	0.6355	27510		0
5	51081	0	0.5674	28985		0
6	87186	0	0.5066	44171		
7		890883	0.4523		402990	285703
Total	216494	903544		127380	413083	

r =12%

Table 37: Net present value from Poplar -sugarcane-sorghum-wheat crop rotation in 3.96 × 3.96 m spacing in Rs/ha

Year	Cost	Net Return	Discount coefficient $1/(1+r)^n$	Present value		NPV
				Cost	Net return	
1	12046		0.8929	10755		0
2		10561	0.7972		8419	0
3	28272		0.7118	20123		0
4	47676		0.6355	30299		0
5	57370		0.5674	32553		0
6	88388		0.5066	44780		0
7		1041998	0.4523		471346	341253
Total	233754	1052559		138512	479766	

r =12%

Table 38: Net present value from Poplar -sugarcane-sorghum-wheat crop rotation in 4.87 × 2.74 m spacing in Rs/ha

Year	Cost	Net Return	Discount coefficient $1/(1+r)^n$	Present value		NPV
				Cost	Net return	
1	18208		0.8929	16257		0
2		8986	0.7972		7163	0
3	29347		0.7118	20888		0
4	48362		0.6355	30735		0
5	58580		0.5674	33240		0
6	88807		0.5066	44992		0
7		1241740	0.4523		561700	422749
Total	243306	1250727		146114	568864	

r =12%

Table 39: Net present value from Poplar -sugarcane-sorghum-wheat crop rotation in 3.65× 3.65 m spacing in Rs/ha

Year	Cost	Net Return	Discount coefficient $1/(1+r)^n$	Present value		NPV
				Cost	Net return	
1	20741		0.8929	18519		0
2		8461	0.7972		6745	0
3	30232		0.7118	21518		0
4	49531		0.6355	31478		0
5	59440		0.5674	33728		0
6	89767		0.5066	45479		0
7		1242480	0.4523		562035	418057
Total	249713	1250942		150723	568780	

r =12%

Table 40: Net present value from Poplar -sugarcane-sorghum-wheat crop rotation in 3.65× 2.13 m spacing in Rs/ha

Year	Cost	Net Return	Discount coefficient $1/(1+r)^n$	Present value		NPV
				Cost	Net return	
1	41939		0.8929	37446		0
2		5311	0.7972		4234	0
3	33060		0.7118	23531		0
4	53245		0.6355	33838		0
5	62859		0.5674	35668		0
6	96712		0.5066	48997		0
7		803012	0.4523		363242	187993
Total	287818	808324		179482	367476.3	

r =12%

Table 41: Internal rate of return from Poplar -Sugarcane- Sorghum-Wheat crop rotation in 4.26 × 4.26 m spacing in Rs/ha

Year	Net cash flow	Present value coefficient $r=36\%$ $1/(1+r)^n$	Corresponding present value	Present value coefficient $r= 37\%$ $1/(1+r)^n$	Corresponding present value
1	-10188	0.7353	-7491	0.7299	-7436
2	12661	0.5407	6845	0.5328	6745
3	-24749	0.3975	-9838	0.3889	-9625
4	-43289	0.2923	-12653	0.2839	-12288
5	-51081	0.2149	-10979	0.2072	-10584
6	-87186	0.1580	-13778	0.1512	-13186
7	890883	0.1162	103525	0.1104	98350
Total			55629		51975

$IRR = 36 + 1(55629.13)/(55629.13 - 51975.75) = 51.23$



Plate 4: Poplar + Sorghum based agroforestry system in Yamunanagar during *Kharif* season

Table 42: Internal rate of return from Poplar -Sugarcane- Sorghum-Wheat crop rotation in 3.96× 3.96 m spacing in Rs/ha

Year	Net cash flow	Present value coefficient r=36% $1/(1+r)^n$	Corresponding present value	Present value coefficient r= 37% $1/(1+r)^n$	Corresponding present value
1	-12046	0.7353	-8857	0.7299	-8792
2	10561	0.5407	5710	0.5328	5627
3	-28272	0.3975	-11239	0.3889	-10995
4	-47676	0.2923	-13936	0.2839	-13533
5	-57370	0.2149	-12330	0.2072	-11887
6	-88388	0.1580	-13968	0.1512	-13368
7	1041998	0.1162	121086	0.1104	115033
Total			66463		62082

$$IRR = 36 + 1(66463.02)/(66463.02 - 62082.63) = 51.17$$

Table 43: Internal rate of return from Poplar -Sugarcane- Sorghum-Wheat crop rotation in 4.87 × 2.74 m spacing in Rs/ha

Year	Net cash flow	Present value coefficient r=36% $1/(1+r)^n$	Corresponding present value	Present value coefficient r= 37% $1/(1+r)^n$	Corresponding present value
1	-18208	0.7353	-13388	0.7299	-13291
2	8986	0.5407	4858	0.5328	4787
3	-29347	0.3975	-11666	0.3889	-11413
4	-48362	0.2923	-14136	0.2839	-13728
5	-58580	0.2149	-12591	0.2072	-12138
6	-88807	0.1580	-14035	0.1512	-13431
7	1241740	0.1162	144297	0.1104	137084
Total			83337		77869

$$IRR = 36 + 1(83337.34)/(83337.34 - 77869.41) = 51.24$$

Table 44: Internal rate of return from Poplar -Sugarcane- Sorghum-Wheat crop rotation in 3.65 × 3.65 m spacing in Rs/ha

Year	Net cash flow	Present value coefficient r=36% $1/(1+r)^n$	Corresponding present value	Present value coefficient r= 37% $1/(1+r)^n$	Corresponding present value
1	-20741	0.7353	-15251	0.7299	-15139
2	8461	0.5407	4574	0.5328	4508
3	-30232	0.3975	-12018	0.3889	-11757
4	-49531	0.2923	-14478	0.2839	-14060
5	-59440	0.2149	-12775	0.2072	-12316
6	-89767	0.1580	-14186	0.1512	-13576
7	1242480	0.1162	144383	0.1104	137165
Total			80247		74823

$$IRR = 36 + 1(80247.09)/(80247.09 - 74823.29) = 50.80$$

Table 45: Internal rate of return from Poplar -Sugarcane- Sorghum-Wheat crop rotation in 3.65 × 2.13 m spacing in Rs/ha

Year	Net cash flow	Present value coefficient r=36% $1/(1+r)^n$	Corresponding present value	Present value coefficient r= 37% $1/(1+r)^n$	Corresponding present value
1	-41939	0.7353	-30837	0.7299	-30612
2	5311	0.5407	2871	0.5328	2829
3	-33060	0.3975	-13142	0.3889	-12857
4	-53245	0.2923	-15564	0.2839	-15114
5	-62859	0.2149	-13510	0.2072	-13024
6	-96712	0.1580	-15284	0.1512	-14627
7	803012	0.1162	93314	0.1104	88649
Total			7846		5243

$$IRR = 36 + 1(7846.04)/(7846.04 - 5243.01) = 39.01$$

Table 46: Benefit Cost Ratio, Internal rate of return and Pay Back Period in poplar – sugarcane-sorghum-wheat crop rotation with different spacings

Spacings (m)	Return	Cost	B:C	IRR (%)	Pay Back Period
4.26 × 4.26 m	413083	127380	1 : 3.24	51.23	7
3.96 × 3.96 m	479766	138512	1 : 3.46	51.17	7
4.87 × 2.74 m	568864	146114	1 : 3.89	51.24	7
3.65 × 3.65 m	568780	150723	1 : 3.77	50.80	7
4.26 × 4.26 m	367476	179482	1 : 2.05	39.01	7

4.2.9. Cost and return from Poplar- Sorghum- Berseem crop rotation

It is evident from the data presented in Table 47 to 51 the cost and return from poplar –sorghum-berseem crop rotation in different spacings. The highest input cost (Rs. 8, 40,110) for trees and crops were recorded in 3.65 × 2.13 m spacing, however the lowest input cost (Rs. 8, 08,594) for trees and crops were found in wider spacing (4.26 × 4.26 m). The returns from trees were recorded higher (Rs. 13, 42,500) under 3.65 × 3.65 m spacing, which was closely followed by 4.87 × 2.74 m spacing with the returns (Rs. 13, 40,710) however, the higher returns from crops were observed (Rs. 4,01437) in 4.26 × 4.26 m spacing. . The reason behind this, wider spacing provided maximum space for better growth and yield for agricultural crops. However, the total returns from trees and crops were found higher (Rs. 17, 25,947) in 3.65 × 3.65 m spacing, which was closely followed by 4.87 × 2.74 m spacing with the returns (Rs. 17, 21, 070). The overall net returns from the rotation were also found higher (Rs. 9, 05,587) in 3.65 × 3.65 m spacing, which was followed by 4.87 × 2.74 m spacing with the returns (Rs. 9, 01, 172). On the basis of the above results it was found that 3.65 × 3.65 m spacing gave higher benefit from poplar - sorghum -berseem crop rotation.

Table 47: Streams of costs and returns from Poplar-Sorghum- Berseem crop rotation in 4.26 × 4.26 m spacing in Rs/ha

Age (Year)	Incurred cost (Rs/ha)			Income (Rs/ha)			Net Benefit (Rs/ha)
	Trees	Crops	Total	Trees	Crops	Total	
1	79195	26917	106111	0	78120	78120	-27991
2	67405	37512	104917	0	72850	72850	-32066
3	72078	38748	110826	0	72462	72462	-38364
4	82084	27375	109460	0	49560	49560	-59899
5	86214	30670	116884	0	53820	53820	-63063
6	91677	34244	125921	0	41020	41020	-84901
7	99130	35346	134475	986290	33605	1019895	885419
Total	577782	230812	808594	986290	401437	1387727	579133

#For poplar rates of HFDC, Haryana (2015-16) had taken to estimate return If Girth of tree i) 60 -69:- 708 ii) 69-79 :- 1790

Table 48: Streams of costs and returns from Poplar-Sorghum- Berseem crop rotation in 3.96 × 3.96 m spacing in Rs/ha

Age (Year)	Incurred cost (Rs/ha)			Income (Rs/ha)			Net Benefit (Rs/ha)
	Trees	Crops	Total	Trees	Crops	Total	
1	82553	26917	109470	0	77625	77625	-31844
2	67405	37512	104917	0	73278	73278	-31638
3	72078	38748	110826	0	70964	70964	-39862
4	83425	27375	110800	0	48498	48498	-62302
5	87672	30670	118342	0	51220	51220	-67122
6	93639	34244	127883	0	38920	38920	-88963
7	101255	35346	136601	1140230	33033	1173263	1036662
Total	588027	230812	818839	1140230	393538	1533768	714929

#For poplar rates of HFDC, Haryana (2015-16) had taken to estimate return If Girth of tree i) 60 -69:- 708 ii) 69-79 :- 1790

Table 49: Streams of costs and returns from Poplar-Sorghum- Berseem crop rotation in 4.87 × 2.74 m spacing in Rs/ha

Age (Year)	Incurred cost (Rs/ha)			Income (Rs/ha)			Net Benefit (Rs/ha)
	Trees	Crops	Total	Trees	Crops	Total	
1	86215	26917	113132	0	76520	76520	-36612
2	67405	37512	104917	0	71992	71992	-32924
3	72078	38748	110826	0	68962	68962	-41864
4	78732	27375	106108	0	46492	46492	-59615
5	82567	30670	113238	0	49660	49660	-63577
6	96582	34244	130826	0	35560	35560	-95266
7	105506	35346	140852	1340710	31174	1371884	1231032
Total	589086	230812	819898	1340710	380360	1721070	901171

#For poplar rates of HFDC, Haryana (2015-16) had taken to estimate return If Girth of tree i) 60 -69:- 708 ii) 69-79 :- 1790

Table 50: Streams of costs and returns from Poplar-Sorghum- Berseem crop rotation in 3.65 × 3.65m spacing in Rs/ha

Age (Year)	Incurred cost (Rs/ha)			Income (Rs/ha)			Net Benefit (Rs/ha)
	Trees	Crops	Total	Trees	Crops	Total	
1	86340	26917	113257	0	76655	76655	-36601
2	67405	37512	104917	0	71573	71573	-33343
3	72078	38748	110826	0	69542	69542	-41284
4	79403	27375	106778	0	46964	46964	-59814
5	83297	30670	113967	0	50570	50570	-63396
6	96582	34244	130826	0	36540	36540	-94286
7	104443	35346	139789	1342500	31603	1374103	1234314
Total	589548	230812	820360	1342500	383447	1725947	905587

#For poplar rates of HFDC, Haryana (2015-16) had taken to estimate return If Girth of tree i) 60 -69:- 708 ii) 69-79 :- 1790

Table 51: Streams of costs and returns from Poplar-Sorghum- Berseem crop rotation in 3.65 × 2.13m spacing in Rs/ha

Age (Year)	Incurred cost (Rs/ha)			Income (Rs/ha)			Net Benefit (Rs/ha)
	Trees	Crops	Total	Trees	Crops	Total	
1	105446	26917	132363	0	75345	75345	-57017
2	67405	37512	104917	0	68764	68764	-36152
3	72078	38748	110826	0	63462	63462	-47364
4	78732	27375	106108	0	45548	45548	-60559
5	82567	30670	113238	0	48360	48360	-64877
6	97563	34244	131807	0	33880	33880	-97927
7	105506	35346	140852	911196	30173	941369	800517
Total	609298	230812	840110	911196	365532	1276728	436617

#For poplar rates of HFDC, Haryana (2015-16) had taken to estimate return If Girth of tree i) 60 -69:- 708 ii) 69-79 :- 1790

4.2.10. Net Present Value in Poplar-Sorghum –Berseem crop rotation

The result presented from Table 52 to 56 clearly indicated that the higher net present value (3, 47, 939) was recorded in 3.65 × 3.65 m as compared to 4.87 × 2.74 m and 3.96 × 3.96 m spacing and minimum net present value (1, 23, 757) was observed in closer spacing (3.65 × 2.13 m). The positive NPV of all the spacing's showed that poplar-sorghum-Berseem crop rotation is a profitable crop enterprise in the Yamunanagar district of the state. It may be concluded that higher value presented in 3.65 × 3.65 m spacing is more appropriate spacing for poplar-sorghum-Berseem crop rotation obtained maximum benefit.

4.2.11. Internal rate of return in Poplar- Sorghum- Berseem crop rotation

It is evident from the data presented in Table 57 to 62 for different spacings arrangement such as 4.26 × 4.26 m, 3.96 × 3.96 m, 4.87 × 2.74 m, 3.65 × 3.65 m and 3.65 ×

2.13 m spacings, respectively. The higher value (43.64%) for internal rate of return was obtained in 3.65 × 3.65 m, which was followed by 4.87 × 2.74 m and 3.96 × 3.96 m spacing. The higher rate of returns from poplar-sorghum-berseem was recorded in 3.65 × 3.65 m spacing compare to other spacing in Yamunanagar district was mainly due to this spacing provide maximum space for utilization of natural resources and produced more income from crops and trees.

4.2.13. Benefit –cost ratio in Poplar- Sorghum- Berseem crop rotation

The result presented in Table 63 indicated that in 3.65 × 3.65 m spacing had higher value (2.65) of benefit-cost ratio, followed by 2.64 and 2.29 in 4.87 × 2.74 m and 3.96 × 3.96 m spacing, respectively. It indicated that at the prevailing rate of interest 12% annum⁻¹ as investment of Rs.1.00 would fetch returns of Rs. 2.65. The higher value of benefit cost ratio in 3.65 × 3.65 m spacing was more appropriate for profitability point of view.

Table 52: Net present value from Poplar-Sorghum- Berseem crop rotation in 4.26 × 4.26 m spacing in Rs/ha

Year	Cost	Net Return	Discount coefficient $1/(1+r)^n$	Present value		NPV
				Cost	Net return	
1	27991	0	0.8929	24992	0	0
2	32066	0	0.7972	25563	0	0
3	38364	0	0.7118	27306	0	0
4	59899	0	0.6355	38067	0	0
5	63063	0	0.5674	35783	0	0
6	84900	0	0.5066	43013	0	0
7		885419	0.4523		400518	205791
Total	306286	885419		194727	400518	

r =12%

Table 53: Net present value from Poplar-Sorghum- Berseem crop rotation in 3.96 × 3.96 m spacing in Rs/ha

Year	Cost	Net Return	Discount coefficient $1/(1+r)^n$	Present value		NPV
				Cost	Net return	
1	31844	0	0.8929	28432	0	0
2	31638	0	0.7972	25222	0	0
3	39862	0	0.7118	28373	0	0
4	62302	0	0.6355	39594	0	0
5	67122	0	0.5674	38086	0	0
6	88962	0	0.5066	45071	0	0
7		1036662	0.4523		468933	264152
Total	321733	1036662		204780	468933	

r =12%

Table 54: Net present value from Poplar-Sorghum- Berseem crop rotation in 4.87 × 2.74 m spacing in Rs/ha

Year	Cost	Net Return	Discount coefficient $1/(1+r)^n$	Present value		NPV
				Cost	Net return	
1	36612	0	0.8929	32689	0	0
2	32924	0	0.7972	26247	0	0
3	41864	0	0.7118	29798	0	0
4	59615	0	0.6355	37886	0	0
5	63577	0	0.5674	36075	0	0
6	95265	0	0.5066	48264	0	0
7		1231032	0.4523		556856	345894
Total	329860	1231032		210962	556856	

r =12%

Table 55: Net present value from Poplar-Sorghum- Berseem crop rotation in 3.65 × 3.65 m spacing in Rs/ha

Year	Cost	Net Return	Discount coefficient $1/(1+r)^n$	Present value		NPV
				Cost	Net return	
1	36601	0	0.8929	32680	0	0
2	33343	0	0.7972	26581	0	0
3	41284	0	0.7118	29385	0	0
4	59814	0	0.6355	38013	0	0
5	63396	0	0.5674	35973	0	0
6	94285	0	0.5066	47768	0	
7		1234314	0.4523		558341	347939
Total	328727	1234314		210401	558341	

r =12%

Table 56: Net present value from Poplar-Sorghum- Berseem crop rotation in 3.65 × 2.13 m spacing in Rs/ha

Year	Cost	Net Return	Discount coefficient $1/(1+r)^n$	Present value		NPV
				Cost	Net return	
1	57017	0	0.8929	50908	0	0
2	36152	0	0.7972	28820	0	0
3	47364	0	0.7118	33712	0	0
4	60559	0	0.6355	38486	0	0
5	64877	0	0.5674	36813	0	0
6	97926	0	0.5066	49612	0	0
7		800517	0.4523		362113	123757
Total	363899	800517		238355	362113	

r =12%



Plate 5: Poplar + Barseem based agroforestry system in Yamunanagar during *Rabi* season

Table 57: Internal rate of return from Poplar - Sorghum-Berseem crop rotation in 4.26 × 4.26 m spacing in Rs/ha

Year	Net cash flow	Present value coefficient r=36% $1/(1+r)^n$	Corresponding present value	Present value coefficient r= 37% $1/(1+r)^n$	Corresponding present value
1	-27991	0.7353	-20581	0.7299	-20431
2	-32066	0.5407	-17337	0.5328	-17084
3	-38364	0.3975	-15251	0.3889	-14919
4	-59899	0.2923	-17509	0.2839	-17003
5	-63063	0.2149	-13554	0.2072	-13067
6	-84901	0.1580	-13417	0.1512	-12840
7	885419	0.1162	102890	0.1104	97747
Total			5238		2399

$$IRR = 36 + 1(5238.87)/(5238.87 - 2399.6) = 37.85$$

Table 58: Internal rate of return from Poplar - Sorghum-Berseem crop rotation in 3.96 × 3.96 m spacing in Rs/ha

Year	Net cash flow	Present value coefficient r=36% $1/(1+r)^n$	Corresponding present value	Present value coefficient r= 37% $1/(1+r)^n$	Corresponding present value
1	-31844	0.7353	-23415	0.7299	-23244
2	-31638	0.5407	-17105	0.5328	-16856
3	-39862	0.3975	-15846	0.3889	-15502
4	-62302	0.2923	-18211	0.2839	-17685
5	-67122	0.2149	-14426	0.2072	-13907
6	-88963	0.1580	-14059	0.1512	-13455
7	1036662	0.1162	120466	0.1104	114444
Total			17400		13792

$$IRR = 36 + 1(17400.12)/(17400.12 - 13729.07) = 40.74$$

Table 59: Internal rate of return from Poplar - Sorghum-Berseem crop rotation in 4.87 × 2.74 m spacing in Rs/ha

Year	Net cash flow	Present value coefficient r=36% $1/(1+r)^n$	Corresponding present value	Present value coefficient r= 37% $1/(1+r)^n$	Corresponding present value
1	-36612	0.7353	-26920	0.7299	-26724
2	-32924	0.5407	-17801	0.5328	-17542
3	-41864	0.3975	-16642	0.3889	-16281
4	-59615	0.2923	-17426	0.2839	-16923
5	-63577	0.2149	-13664	0.2072	-13173
6	-95266	0.1580	-15055	0.1512	-14408
7	1231032	0.1162	143053	0.1104	135901
Total			35541		30849

$$IRR = 36 + 1(35541.03)/(35541.03 - 30849.88) = 43.58$$

Table 60: Internal rate of return from Poplar - Sorghum-Berseem crop rotation in 3.65 × 3.65 m spacing in Rs/ha

Year	Net cash flow	Present value coefficient r=36% 1/(1+r) ⁿ	Corresponding present value	Present value coefficient r= 37% 1/(1+r) ⁿ	Corresponding present value
1	-36601	0.7353	-26913	0.7299	-26716
2	-33343	0.5407	-18027	0.5328	-17765
3	-41284	0.3975	-16412	0.3889	-16055
4	-59814	0.2923	-17484	0.2839	-16979
5	-63396	0.2149	-13626	0.2072	-13136
6	-94286	0.1580	-14900	0.1512	-14260
7	1234314	0.1162	143434	0.1104	136264
Total			36070		31351

$$IRR = 36 + 1(36070.39)/(36070.39 - 31351.17) = 43.64$$

Table 61: Internal rate of return from Poplar - Sorghum- Berseem crop rotation in 3.65 × 2.13 m spacing in Rs/ha

Year	Net cash flow	Present value coefficient r=36% 1/(1+r) ⁿ	Corresponding present value	Present value coefficient r= 37% 1/(1+r) ⁿ	Corresponding present value
1	-57017	0.7353	-41924	0.7299	-41618
2	-36152	0.5407	-19546	0.5328	-19261
3	-47364	0.3975	-18829	0.3889	-18419
4	-60559	0.2923	-17702	0.2839	-17191
5	-64877	0.2149	-13944	0.2072	-13442
6	-97927	0.1580	-15476	0.1512	-14810
7	800517	0.1162	93024	0.1104	88374
Total			-34398		-36371

$$IRR = 36 + 1(-34398.8)/(-34398.8 + 36371.1) = 18.56$$

Table 62: Benefit Cost Ratio, Internal rate of return and Pay Back Period in poplar – sorghum-wheat crop rotation with different spacings

Spacing (m)	Return	Cost	B:C	IRR (%)	Pay Back Period
4.26 × 4.26 m	400518	194727	1 : 2.06	37.85	7
3.96 × 3.96 m	468933	204780	1 : 2.29	40.74	7
4.87 × 2.74 m	556856	210962	1: 2.64	43.58	7
3.65 × 3.65 m	558341	210401	1 : 2.65	43.64	7
4.26 × 4.26 m	362113	238355	1 : 1.52	18.56	7

4.2.14. Cost and return from Poplar- Sorghum- Berseem crop rotation

The data presented from Table 63 to 67 showed that the cost and return for growing poplar in intercropping with sorghum and wheat under different spacing arrangements. The higher input cost (Rs. 6, 57,943) for trees and crops were recorded in 3.65 × 2.13 m spacing,

whereas the lower input costs (Rs. 5, 72,505) for trees and crops were recorded in wider spacing (4.26 × 4.26 m). The returns from trees were found higher (Rs. 9, 94,000) in 3.65 × 3.65 m spacing, which was closely followed by 4.87 × 2.74 m spacing with the returns (Rs. 9, 52,728). However, the returns from crops were recorded higher (Rs. 3, 63,876) in 4.26 × 4.26 m spacing and lower returns from crops were recorded (Rs. 2, 95,784) in 3.65 × 2.13 m spacing. The total returns were obtained higher (Rs. 12, 73,751) in 4.87 × 2.74 m spacing, which was closely followed by 3.65 × 3.65 m spacing with the returns (Rs. 12, 72,854). The net returns from the rotation were observed higher (Rs. 6,92,276) in 3.65 × 3.65 m spacing. On the basis of the above results it was found that 3.65 × 3.65 m spacing gave higher benefit from poplar + sorghum+ wheat crop rotation.

Table 63: Streams of costs and returns from Poplar-Sorghum-Wheat crop rotation in 4.26 × 4.26 m spacing in Rs/ha

Age (Year)	Incurred cost (Rs/ha)			Income (Rs/ha)			Net Benefit (Rs/ha)
	Trees	Crops	Total	Trees	Crops	Total	
1	47728	32837	80565	0	76201	76201	-4363
2	43194	40816	84010	0	74838	74838	-9172
3	43593	41211	84805	0	62132	62132	-22672
4	45209	30203	75412	0	40065	40065	-35346
5	46814	32375	79189	0	40800	40800	-38388
6	51757	33961	85718	0	36840	36840	-48877
7	46814	35992	82806	700872	33000	733872	651066
Total	325109	247395	572505	700872	363876	1064748	492243

#For poplar rates of HFDC, Haryana (2015-16) had taken to estimate return If Girth of tree i) 60 -69:- 708 ii) 69-79 :- 1790

Table 64: Streams of costs and returns from Poplar-Sorghum-Wheat crop rotation in 3.96 × 3.96 m spacing in Rs/ha

Age (Year)	Incurred cost (Rs/ha)			Income (Rs/ha)			Net Benefit (Rs/ha)
	Trees	Crops	Total	Trees	Crops	Total	
1	49508	32837	82345	0	72637	72637	-9707
2	43873	40816	84689	0	69850	69850	-14839
3	44323	41211	85535	0	58634	58634	-26900
4	46013	30203	76216	0	35535	35535	-40681
5	47397	32375	79772	0	36150	36150	-43622
6	52934	33961	86895	0	35440	35440	-51455
7	46814	35992	82806	810264	33000	843264	760458
Total	330863	247395	578258	810264	341246	1151510	573251

#For poplar rates of HFDC, Haryana (2015-16) had taken to estimate return If Girth of tree i) 60 -69:- 708 ii) 69-79 :- 1790

Table 65: Streams of costs and returns from Poplar-Sorghum-Wheat crop rotation in 4.87 × 2.74 m spacing in Rs/ha

Age (Year)	Incurred cost (Rs/ha)			Income (Rs/ha)			Net Benefit (Rs/ha)
	Trees	Crops	Total	Trees	Crops	Total	
1	50382	32837	83219	0	70001	70001	-13217
2	44778	40816	85594	0	67051	67051	-18543
3	45297	41211	86508	0	55436	55436	-31071
4	47086	30203	77289	0	32515	32515	-44773
5	48564	32375	80939	0	32850	32850	-48089
6	54112	33961	88072	0	32320	32320	-55752
7	52833	35992	88825	952728	30850	983578	894752
Total	343051	247395	590446	952728	321023	1273751	683304

#For poplar rates of HFDC, Haryana (2015-16) had taken to estimate return If Girth of tree i) 60 -69:- 708 ii) 69-79 :- 1790

Table 66: Streams of costs and returns from Poplar-Sorghum-Wheat crop rotation in 3.65 × 3.65 m spacing in Rs/ha

Age (Year)	Incurred cost (Rs/ha)			Income (Rs/ha)			Net Benefit (Rs/ha)
	Trees	Crops	Total	Trees	Crops	Total	
1	50986	32837	83823	0	69178	69178	-14645
2	43421	40816	84237	0	64980	64980	-19256
3	43837	40034	83871	0	54576	54576	-29295
4	45745	30203	75948	0	32290	32290	-43658
5	47397	32375	79772	0	33900	33900	-45872
6	52542	33961	86503	0	33080	33080	-53422
7	50432	35992	86424	954000	30850	984850	898426
Total	334359	246218	580578	954000	318854	1272854	692276

#For poplar rates of HFDC, Haryana (2015-16) had taken to estimate return If Girth of tree i) 60 -69:- 708 ii) 69-79 :- 1790

Table 67: Streams of costs and returns from Poplar-Sorghum-Wheat crop rotation in 3.65 × 2.13 m spacing in Rs/ha

Age (Year)	Incurred cost (Rs/ha)			Income (Rs/ha)			Net Benefit (Rs/ha)
	Trees	Crops	Total	Trees	Crops	Total	
1	65437	32837	98274	0	64527	64527	-33746
2	51793	40816	92609	0	57449	57449	-35160
3	52838	40034	92873	0	52118	52118	-40754
4	56203	30203	86405	0	30780	30780	-55625
5	58773	32375	91148	0	32250	32250	-58897
6	63922	33961	97882	0	29960	29960	-67922
7	62759	35992	98752	911196	28700	939896	841144
Total	411725	246218	657943	911196	295784	1206980	549036

#For poplar rates of HFDC, Haryana (2015-16) had taken to estimate return If Girth of tree i) 60 -69:- 708 ii) 69-79 :- 1790

4.2.15 Net Present Value in Poplar-Sorghum –Wheat crop rotation

The result presented in Table 68 to 72 clearly indicated that the higher net present value (Rs.2, 76, 283) was found in 3.65 × 3.65 m spacing, which was followed by 4.87 × 2.74 m and 3.96 × 3.96 m spacing. The minimum net present value (Rs.1, 90, 139) was recorded in closer spacing (3.65 × 2.13m) at the age of seven years old poplar – sorghum – wheat crop rotation. The reason for this higher value could be the better utilization of resources and more income from crops as well as trees.

4.2.16 Internal rate of return in Poplar-Sorghum- Wheat rotation

The result presented in Table 73 to 77 clearly indicated that the higher internal rate of return (48.55%) was recorded in 4.26 × 4.26 m, which was followed by 3.96 × 3.96 m and 3.65 × 3.65 m spacing's, respectively. The lower value (35.28 %) of rate of returns obtained in 3.65 × 2.13 m spacing. Because this spacing recorded lower growth and yield in both tree and crop. Finally, it can be said that poplar-sorghum-wheat rotation in this area is profitable, when trees planted in optimum spacing.

4.2.17 Benefit-cost ratio in in Poplar-Sorghum- Wheat rotation

It is evident from the data presented in Table 78 that the higher value (3.12) of benefit-cost ratio was recorded in 3.65× 3.65 m as compared to 4.26 × 4.26 m and 3.96 × 3.96 m spacing and minimum value (2.05) of benefit cost ratio was observed in closer spacing (3.65 × 2.13 m). On the basis of B: C ratio, it is concluded that higher value presented in 3.65 × 3.65 m spacing is more appropriate spacing for poplar-sorghum -wheat rotation obtained maximum benefit. Because this spacing obtained maximum returns from crops and trees.

Table 68: Net present value from Poplar-Sorghum-Wheat crop rotation in 4.26 × 4.26 m spacing in Rs/ha

Year	Cost	Net Return	Discount coefficient $1/(1+r)^n$	Present value		NPV
				Cost	Net return	
1	4363	0	0.8929	3896	0	0
2	9172	0	0.7972	7312	0	0
3	22672	0	0.7118	16138	0	0
4	35346	0	0.6355	22463	0	0
5	38388	0	0.5674	21782	0	0
6	48877	0	0.5066	24763	0	0
7		651066	0.4523		294509	198153
Total	158822	651066		96355	294509	

r =12%

Table 69: Net present value from from Poplar-Sorghum-Wheat crop rotation in 3.96 × 3.96 m spacing in Rs/ha

Year	Cost	Net Return	Discount coefficient $1/(1+r)^n$	Present value		NPV
				Cost	Net return	
1	9707	0	0.8929	8667	0	0
2	14839	0	0.7972	11829	0	0
3	26900	0	0.7118	19147	0	0
4	40681	0	0.6355	25853	0	0
5	43622	0	0.5674	24752	0	0
6	51455	0	0.5066	26068	0	0
7		760458	0.4523		343992	227672
Total	187206	760458		116319	343992	

r =12%

Table 70: Net present value from from Poplar-Sorghum-Wheat crop rotation in 4.87 × 2.74 m spacing in Rs/ha

Year	Cost	Net Return	Discount coefficient $1/(1+r)^n$	Present value		NPV
				Cost	Net return	
1	13217	0	0.8929	11801	0	0
2	18543	0	0.7972	14782	0	0
3	31071	0	0.7118	22116	0	0
4	44773	0	0.6355	28454	0	0
5	48089	0	0.5674	27287	0	0
6	55752	0	0.5066	28245	0	0
7		894752	0.4523		404740	272052
Total	211447	894752		132687	404740	

r =12%

Table 71: Net present value from from Poplar-Sorghum-Wheat crop rotation in 3.65 × 3.65 m spacing in Rs/ha

Year	Cost	Net Return	Discount coefficient $1/(1+r)^n$	Present value		NPV
				Cost	Net return	
1	14645	0	0.8929	13075	0	0
2	19256	0	0.7972	15351	0	0
3	29295	0	0.7118	20851	0	0
4	43658	0	0.6355	27745	0	0
5	45872	0	0.5674	26029	0	0
6	53422	0	0.5066	27065	0	0
7		898426	0.4523		406402	276283
Total	206149	898426		130119	406402	

r =12%

Table 72: Net present value from from Poplar-Sorghum-Wheat crop rotation in 3.65 × 2.13 m spacing in Rs/ha

Year	Cost	Net Return	Discount coefficient $1/(1+r)^n$	Present value		NPV
				Cost	Net return	
1	33746	0	0.8929	30131	0	0
2	35160	0	0.7972	28029	0	0
3	40754	0	0.7118	29008	0	0
4	55625	0	0.6355	35351	0	0
5	58897	0	0.5674	33420	0	0
6	67922	0	0.5066	34411	0	0
7	0	841144	0.4523		380490	190139
Total	292107	841144		190351	380490	

r =12%

Table 73: Internal rate of return from Poplar –Wheat- Sorghum crop rotation in 4.26 × 4.26 m spacing in Rs/ha

Years	Net cash flow	Present value coefficient r=36% $1/(1+r)^n$	Corresponding present value	Present value coefficient r= 37% $1/(1+r)^n$	Corresponding present value
1	-4363	0.7353	-3208	0.7299	-3185
2	-9172	0.5407	-4959	0.5328	-4886
3	-22672	0.3975	-9013	0.3889	-8817
4	-35346	0.2923	-10332	0.2839	-10033
5	-38388	0.2149	-8251	0.2072	-7954
6	-48877	0.1580	-7724	0.1512	-7392
7	651066	0.1162	75657	0.1104	71875
Total			32168		29605

$$IRR = 36 + 1(32168.5)/(32168.5 - 29605.22) = 48.55$$

Table 74: Internal rate of return from Poplar – Wheat-Sorghum crop rotation in 3.96 × 3.96 m spacing in Rs/ha

Year	Net cash flow	Present value coefficient r=36% $1/(1+r)^n$	Corresponding present value	Present value coefficient r= 37% $1/(1+r)^n$	Corresponding present value
1	-9707	0.7353	-7138	0.7299	-7086
2	-14839	0.5407	-8022	0.5328	-7906
3	-26900	0.3975	-10694	0.3889	-10461
4	-40681	0.2923	-11891	0.2839	-11548
5	-43622	0.2149	-9375	0.2072	-9038
6	-51455	0.1580	-8131	0.1512	-7782
7	760458	0.1162	88369	0.1104	83952
Total			33114		30128

$$IRR = 36 + 1(33114.9)/(33114.9 - 30128.96) = 47.09$$

Table 75: Internal rate of return from Poplar – Wheat-Sorghum crop rotation in 4.87 × 2.74 m spacing in Rs/ha

Year	Net cash flow	Present value coefficient r=36% $1/(1+r)^n$	Corresponding present value	Present value coefficient r= 37% $1/(1+r)^n$	Corresponding present value
1	-13217	0.7353	-9718	0.7299	-9647
2	-18543	0.5407	-10025	0.5328	-9879
3	-31071	0.3975	-12352	0.3889	-12083
4	-44773	0.2923	-13087	0.2839	-12709
5	-48089	0.2149	-10335	0.2072	-9964
6	-55752	0.1580	-8811	0.1512	-8432
7	894752	0.1162	103975	0.1104	98777
Total			39643		36059

$$IRR = 36 + 1(39643.61)/(39643.61 - 36059.87) = 47.06$$

Table 76: Internal rate of return from Poplar –Wheat- Sorghum crop rotation in 3.65 × 3.65 m spacing in Rs/ha

Year	Net cash flow	Present value coefficient r=36% $1/(1+r)^n$	Corresponding present value	Present value coefficient r= 37% $1/(1+r)^n$	Corresponding present value
1	-14645	0.7353	-10768	0.7299	-10689
2	-19256	0.5407	-10411	0.5328	-10259
3	-29295	0.3975	-11646	0.3889	-11392
4	-43658	0.2923	-12761	0.2839	-12393
5	-45872	0.2149	-9859	0.2072	-9504
6	-53422	0.1580	-8442	0.1512	-8079
7	898426	0.1162	104402	0.1104	99183
Total			40512		36862

$$IRR = 36 + 1(40512.49)/(40512.49 - 36862.93) = 47.10$$

Table 77: Internal rate of return from Poplar - Sorghum- wheat crop rotation in 3.65 × 2.13 m spacing in Rs/ha

Year	Net cash flow	Present value coefficient r=36% $1/(1+r)^n$	Corresponding present value	Present value coefficient r= 37% $1/(1+r)^n$	Corresponding present value
1	-33746	0.7353	-24813	0.7299	-24632
2	-35160	0.5407	-19009	0.5328	-18733
3	-40754	0.3975	-16201	0.3889	-15849
4	-55625	0.2923	-16259	0.2839	-15790
5	-58897	0.2149	-12659	0.2072	-12203
6	-67922	0.1580	-10734	0.1512	-10272
7	841144	0.1162	97745	0.1104	92859
Total			-1932		-4622

$$IRR = 36 + 1(-1932.8)/(-1932.8 + 4622.78) = 35.28$$

Table 78: Benefit Cost Ratio, Internal rate of return and Pay Back Period in poplar – sorghum-wheat crop rotation with different spacings

Spacings (m)	Return	Cost	B:C	IRR (%)	Pay Back Period
4.26 × 4.26 m	294509	96355	1 : 3.06	48.55	7
3.96 × 3.96 m	343992	116319	1 : 2.96	47.09	7
4.87 × 2.74 m	404740	132687	1 : 3.05	47.06	7
3.65 × 3.65 m	406402	130119	1 : 3.12	47.10	7
4.26 × 4.26 m	380490	190351	1 : 2.00	35.28	7

4.3. Growth attributes of poplar in nursery stage

The results presented in Table 79 clearly indicate that in all the poplar clones, the plant height was significantly higher under different spacings of poplar during 2015-16 and 2016-17. All the tested poplar clones significantly a variable plant height under different spacings of poplar nursery from 3 MAP to 12 MAP. Plant height of different poplar clones was found significantly different in all the spacings (80 × 60 cm, 60 × 50 cm, 65 × 45 cm, 70 × 35 cm and 60 × 40 cm) of poplar nursery. The performance of poplar clones for plant height was found best with wider spacing (80 × 60 cm) followed by 60× 50 cm, 65 × 45 cm, 70 × 35 cm and 60 × 40 cm spacing. Poplar clone WSL-109 was recorded maximum height at different stages of growth under various spacings followed by WSL-110, WSL-39, WSL-22, WSL-81, G-48 and G-3 during both the years of experimentation. However, poplar clone G-3 was observed lesser plant height at different stages of growth under various spacings during both the years under this study.

It is evident from the data presented in Table 80 that the collar diameter of different poplar clones also differed significantly among different spacings from 3MAP to 12 MAP. The performance of poplar clones for collar diameter was found best with wider spacing (80× 60 cm) followed by 60× 50 cm, 65 × 45 cm, 70 × 35 cm and 60 × 40 cm spacing. Among different Poplar clones, the highest collar diameter was observed in poplar clone WSL-109 and it followed the order: WSL-110 > WSL-39 > WSL-22 > WSL-81 > G-48 and G-3 during both the years of observations. However, poplar clone G-3 was observed lesser collar diameter at different stages of growth under various spacing's during both 2015-16 and 2016-17.

Table 79: Plant height of different poplar clones at periodic change of growth under different spacings during 2015-16 and 2016-17

Spacing (cm)	Plant height (m)															
	2015-16								2016-17							
	Clone															
	WSL -109	WSL -110	WSL -39	WSL -22	WSL -81	G-48	G-3	Mean	WSL -109	WSL -110	WSL -39	WSL -22	WSL -81	G-48	G-3	Mean
	3 Months after planting								3 Months after planting							
80 × 60	0.85	0.83	0.81	0.80	0.77	0.74	0.71	0.78	0.88	0.85	0.84	0.83	0.78	0.67	0.65	0.78
60 × 50	0.84	0.82	0.79	0.78	0.73	0.68	0.67	0.76	0.86	0.81	0.79	0.77	0.69	0.65	0.60	0.74
65 × 45	0.83	0.80	0.75	0.74	0.68	0.66	0.63	0.73	0.82	0.77	0.73	0.71	0.65	0.61	0.58	0.69
70 × 35	0.80	0.78	0.73	0.71	0.67	0.64	0.60	0.70	0.80	0.73	0.70	0.67	0.59	0.57	0.55	0.66
60 × 40	0.78	0.74	0.70	0.69	0.66	0.63	0.60	0.69	0.76	0.69	0.68	0.66	0.57	0.55	0.53	0.64
Mean	0.82	0.79	0.75	0.74	0.70	0.67	0.64		0.82	0.77	0.75	0.73	0.65	0.61	0.58	
C.D. at 5%	Spacing: 0.003; Clone: 0.003; Spacing × Clone: 0.007								Spacing: 0.003; Clone: 0.004; Spacing × Clone: 0.009							
	6 Months after planting								6 Months after planting							
80 × 60	2.37	2.36	2.31	2.32	2.27	2.21	2.13	2.28	2.61	2.56	2.54	2.53	2.50	2.45	2.37	2.51
60 × 50	2.35	2.33	2.25	2.27	2.20	2.17	2.04	2.23	2.58	2.55	2.51	2.50	2.47	2.37	2.26	2.46
65 × 45	2.32	2.26	2.23	2.23	2.16	2.10	1.99	2.18	2.53	2.52	2.48	2.46	2.45	2.26	2.22	2.42
70 × 35	2.30	2.24	2.17	2.17	2.11	2.08	1.85	2.13	2.52	2.46	2.41	2.40	2.41	2.20	2.07	2.35
60 × 40	2.26	2.33	2.19	2.13	2.07	2.03	1.56	2.08	2.48	2.42	2.39	2.37	2.37	2.07	1.98	2.30
Mean	2.32	2.30	2.23	2.22	2.16	2.12	1.92		2.54	2.50	2.47	2.45	2.44	2.27	2.18	
C.D. at 5%	Spacing: 0.006; Clone: 0.007; Spacing × Clone: 0.015								Spacing: 0.005; Clone: 0.006; Spacing × Clone: 0.013							
	9 Months after planting								9 Months after planting							
80 × 60	4.14	4.09	4.08	4.06	4.05	3.72	3.68	3.97	4.44	4.41	4.39	4.38	4.31	4.08	4.03	4.29
60 × 50	4.11	4.04	4.00	3.96	3.94	3.63	3.59	3.89	4.40	4.37	4.36	4.35	4.24	4.04	3.85	4.23
65 × 45	4.06	3.98	3.94	3.92	3.88	3.54	3.50	3.83	4.39	4.26	4.21	4.28	4.22	4.00	3.71	4.15
70 × 35	4.01	3.97	3.91	3.89	3.85	3.44	3.43	3.79	4.34	4.20	4.18	4.20	4.19	3.85	3.64	4.09
60 × 40	4.00	3.94	3.90	3.86	3.84	3.41	3.39	3.76	4.31	4.16	4.11	4.11	4.12	3.54	3.33	3.95
Mean	4.06	4.00	3.97	3.94	3.91	3.55	3.52		4.38	4.28	4.25	4.26	4.22	3.90	3.71	
C.D. at 5%	Spacing: 0.007; Clone: 0.009; Spacing × Clone: 0.019								Spacing: 0.009; Clone: 0.011; Spacing × Clone: 0.024							
	12 Months after planting								12 Months after planting							
80 × 60	5.39	5.30	5.31	5.28	5.27	5.10	4.56	5.17	5.49	5.41	5.38	5.35	5.28	5.25	4.99	5.31
60 × 50	5.32	5.22	5.20	5.18	5.15	5.02	4.38	5.07	5.38	5.30	5.34	5.30	5.25	5.22	4.89	5.24
65 × 45	5.25	5.18	5.11	5.07	5.01	4.93	4.29	4.98	5.31	5.25	5.31	5.25	5.22	5.08	4.62	5.15
70 × 35	5.21	5.11	5.06	5.03	4.94	4.84	4.19	4.91	5.25	5.20	5.21	5.12	5.20	4.98	4.58	5.07
60 × 40	5.13	5.06	5.04	4.98	4.90	4.62	4.11	4.83	5.22	5.14	5.13	5.08	5.12	4.79	4.45	4.99
Mean	5.26	5.17	5.14	5.11	5.05	4.90	4.30		5.33	5.26	5.27	5.22	5.21	5.06	4.71	
C.D. at 5%	Spacing: 0.011; Clone: 0.013; Spacing × Clone: 0.031								Spacing: 0.008; Clone: 0.01; Spacing × Clone: 0.021							

Table 80: Collar diameter of different poplar clones at periodic change of growth under different spacings during 2015-16 and 2016-17

Spacing (mm)	Collar diameter (mm)															
	2015-16								2016-17							
	Clone								Clone							
	WSL-109	WSL-110	WSL-39	WSL-22	WSL-81	G-48	G-3	Mean	WSL-109	WSL-110	WSL-39	WSL-22	WSL-81	G-48	G-3	Mean
	3 Months after planting								3 Months after planting							
80 × 60	7.80	7.72	7.72	7.70	7.68	7.60	7.28	7.64	8.18	8.16	8.13	8.12	7.98	7.46	7.28	7.90
60 × 50	7.75	7.72	7.67	7.68	7.65	7.46	7.18	7.59	8.15	8.12	8.02	7.35	7.33	7.15	7.14	7.61
65 × 45	7.72	7.68	7.64	7.65	7.62	7.36	7.10	7.54	7.46	7.38	7.35	7.29	7.28	6.97	6.86	7.23
70 × 35	7.66	7.46	7.61	7.62	7.59	7.34	7.00	7.47	7.38	7.33	7.30	7.28	7.15	6.86	6.74	7.15
60 × 40	7.60	7.36	7.59	7.58	7.46	7.28	6.90	7.40	7.33	7.30	7.23	7.18	7.08	6.76	6.03	6.99
Mean	7.71	7.59	7.65	7.64	7.60	7.41	7.09		7.70	7.66	7.61	7.44	7.36	7.04	6.81	
C.D. at 5%	Spacing: 0.008; Clone: 0.009; Spacing × Clone: 0.02								Spacing: 0.016; Clone: 0.019; Spacing × Clone: 0.042							
	6 Months after planting								6 Months after planting							
80 × 60	17.25	17.16	17.13	17.12	17.03	16.78	16.71	17.03	17.22	17.15	17.12	17.09	17.06	15.67	15.63	16.71
60 × 50	17.18	17.09	17.06	17.03	16.97	16.70	16.61	16.95	17.19	17.09	17.07	16.97	16.78	15.61	15.46	16.60
65 × 45	17.10	17.03	16.98	16.94	16.71	16.61	16.50	16.84	17.16	17.00	17.03	16.77	16.68	15.56	15.44	16.52
70 × 35	17.00	16.98	16.93	16.63	16.63	16.53	16.42	16.73	17.09	16.76	16.81	16.75	16.63	15.50	15.28	16.40
60 × 40	16.94	16.81	16.73	16.60	16.56	15.88	16.30	16.54	17.03	16.75	16.70	16.73	16.57	15.45	15.22	16.35
Mean	17.09	17.01	16.97	16.86	16.78	16.50	16.51		17.14	16.95	16.95	16.86	16.74	15.56	15.41	
C.D. at 5%	Spacing: 0.011; Clone: 0.013; Spacing × Clone: 0.029								Spacing: 0.021; Clone: 0.025; Spacing × Clone: 0.057							
	9 Months after planting								9 Months after planting							
80 × 60	25.05	25.02	25.00	24.97	24.94	22.24	21.41	24.09	24.99	24.96	24.92	24.90	24.84	24.09	17.44	23.73
60 × 50	25.01	24.95	24.91	24.88	24.81	22.11	21.30	24.00	24.94	24.89	24.85	24.81	24.79	23.15	17.67	23.58
65 × 45	24.95	24.79	24.85	24.83	24.70	21.96	21.18	23.89	24.88	24.85	24.79	24.76	24.71	22.04	17.65	23.38
70 × 35	24.85	24.76	24.71	24.65	24.60	21.85	21.09	23.79	24.85	24.83	24.75	24.69	24.67	19.95	17.44	23.03
60 × 40	24.76	24.68	24.65	24.56	24.42	21.74	20.97	23.68	24.79	24.77	24.69	24.67	24.58	18.27	17.75	22.79
Mean	24.92	24.84	24.83	24.78	24.69	21.98	21.19		24.89	24.86	24.8	24.765	24.718	21.499	17.586	
C.D. at 5%	Spacing: 0.059; Clone: 0.05; Spacing × Clone: NS								Spacing: 0.09; Clone: 0.10; Spacing × Clone: 0.024							
	12 Months after planting								12 Months after planting							
80 × 60	34.27	34.16	34.16	34.14	34.08	26.79	24.92	31.79	34.24	34.16	34.15	34.10	34.00	26.79	26.71	32.02
60 × 50	34.20	34.05	34.12	34.11	34.05	27.83	25.78	32.02	34.20	34.14	34.09	34.04	33.91	26.57	25.96	31.85
65 × 45	34.14	34.02	34.00	33.95	33.99	27.00	25.70	31.83	34.14	34.09	34.04	34.02	33.83	25.95	24.71	31.54
70 × 35	34.11	33.92	33.92	33.84	33.90	28.03	25.02	31.82	34.12	34.04	34.01	33.95	33.77	25.84	24.71	31.49
60 × 40	34.04	33.88	33.84	33.79	33.77	25.85	25.89	31.58	34.08	34.01	33.92	33.92	33.56	25.65	24.80	31.42
Mean	34.15	34.01	34.01	33.97	33.96	27.10	25.46		34.16	34.09	34.04	34.01	33.81	26.16	25.38	
C.D. at 5%	Spacing: 0.13; Clone: 0.116; Spacing × Clone: 0.317								Spacing: 0.12; Clone: 0.14; Spacing × Clone: 0.33							

4.4. Economic of nursery:

It is evident from the data presented in Table 81 that the cost and return (Rs./acre) from poplar nursery in different spacing during 2015-16. The higher input cost (Rs. 1,01,508) for nursery raising were recorded in 60 × 40 cm spacing due to higher cost for planting material and labours for different cultural and management operation and lower cost (Rs.80,743) were recorded in wider spacing (80 × 60 cm). However, highest incomes (Rs. 3, 13,040) were also obtained in same spacing, which was closely followed by 70 × 35 cm spacing with the returns (Rs. 3, 00,000). The net benefit (Rs. 2, 11,532) and benefit cost ratio (1:3.08) were also recorded in 60 × 40 cm spacing. On the basis of net return and B: C ratio, it was found that 60 × 40 cm spacing gave higher benefit from poplar nursery.

Table 81: Economics (Rs/acre) of poplar nursery in different spacings during 2015-16

Sapcing (cm)	Total cost incurred	Total Income	Net benefit	BCR
80 x 60	80743	150000	69257	1.86
60 x 50	92100	240000	147900	2.61
65 x 45	94062	248278	154216	2.64
70 x 35	100350	300000	199650	2.99
60 x 40	101508	313040	211532	3.08

The data presented in Table 82 showed that the cost and return (Rs./acre) from poplar nursery in different spacing during 2016-17. In 60 × 40 cm spacing, the higher input cost (Rs. 1,01,508) were recorded due to higher values for expenditure in different cultural operation, cost of planting material and labour cost. The higher incomes (Rs. 2, 83,333) were recorded in 70 × 35 cm spacing, which was closely followed by in 60 × 40 cm spacing with returns (Rs. 2, 78261). However, the higher net benefits (Rs.1, 82,983) and B: C ratio (1: 2.82) was recorded in same spacing. It might be concluded that 70 × 35 cm spacing more profitable compare to other spacings.

Table 82: Economics (Rs/acre) of poplar nursery in different spacings during 2016-17

Sapcing (cm)	Total cost incurred	Total Income	Net benefit	BCR
80 x 60	81743	141667	60924	1.75
60 x 50	92100	226667	142383	2.55
65 x 45	94062	234483	140421	2.49
70 x 35	100350	283333	182983	2.82
60 x 40	101508	278261	176753	2.74



Plate 6: One year old Entire Transplants (ETPs) of Poplar under nursery condition

The present investigation entitled “Evaluation of poplar (*Populus deltoides*) for spacing under nursery and field plantation” was carried out at Yamunanagar district of Haryana, during 2015-16 and 2016-17. The findings of the investigation presented in the preceding chapter have been discussed and illustrated in this chapter with suitable reasons and evidences based on the principles and literatures cited on the topic. The results obtained during the course of investigation are discussed under the following heads:

5.1 Growth of poplar under different spacings of nursery and field plantation

The poplar growth was influenced under different spatial arrangements at nursery stage. The data in Table 1 depict that the height (5.34 m) and collar diameter (3.42 cm) of one year old ETPs of poplar clone WSL-39 in nursery stage was found to significantly higher in all the spacings, which was followed by poplar clone WSL-22 under 4.26×4.26 m spacing. The height and collar diameter of different poplar clones increased with increasing spacings. The poplar clone WSL-39 outperformed significantly during different periodic interval at nursery stage during this study. This superiority may be ascribed to the difference in genetic potential among the clones as the treatment given to all clones was the same have been reported by several research workers (Nelson and Taucer, 1987; Tokey *et al.*, 1996; Sidhu, 1996; Puri *et al.*, 2001; Dhillon *et al.*, 2010).

The height and dbh growth of poplar was also influenced by different spatial arrangements under block plantation. It is evident from the data presented in Table-2 that the significant difference persists amongst the clones for height and dbh under one year old poplar plantation. The clone WSL-39 and WSL-22 showed better growth performance in all the spacings in respect to height and dbh. The current annual increment in height (3.56 m) was found significant higher in poplar clone WLS-39 in wider spacing (3.65×3.65 m). However, the current annual increment in dbh (6.47 cm) was found significantly higher in poplar clone G-48 in 4.26×4.26 m spacing. The values for height increased from 8.87 m (1st year) to 22.24 m (7th year), whereas dbh ranged from 9.48 cm to 23.80 cm, respectively. The tree height and dbh followed a linear trend and increment was statistically significant up to seven year. The growth characteristics were recorded better in poplar clone WSL-39 and WSL-22 that may be attributed to their genetic potential. These results are also in close conformity with the findings of Dhillon *et al.* (2010). Similar trends in poplar growth under different spacings in irrigated eco-system with slight variable values have been reported by several research workers (Nissen *et al.*, 2001; Dogra *et al.*, 2007; Khan and Chaudhary, 2007; Chauhan *et al.*, 2012).

The current and mean annual increment of different clones, being the function of growth parameters exhibited similar results for height and diameter. CAI and MAI were maximum for the clones WSL-39 and WSL-22 in wider spacing (4.26 × 4.26 m). The current annual increment in height (1.49 m) was recorded higher in poplar clone WSL-39 in wider spacing (4.26 × 4.26 m). Whereas, the increment in dbh (2.62 cm) was recorded higher in poplar clone WSL-22 with 3.96 × 3.96 m spacing in second year plantation. In third year plantation, the increment for height (3.41 m) and dbh (1.85 cm) were recorded significantly higher in poplar clone G-3 and WSL-81 with spacing 4.26 × 4.26 m and 4.87 × 2.74 m, respectively. The current annual increment in height (2.25 m) and dbh (2.21 cm) were recorded significantly higher in poplar clone WSL-81 in spacing 4.26 × 4.26 m under four year old plantation. Whereas, the increment in height (1.53 m) and dbh (1.55 cm) were recorded higher in poplar clone WSL-39 and G-48 with spacing 4.26 × 4.26 m and 4.87 × 2.74 m under five year old poplar plantation. In six year old poplar plantation, the current annual increment in height (4.29 m) and dbh (4.26 cm) were recorded significantly higher in poplar clone WSL-39 and WSL-22 in same spacing 4.87 × 2.74 m. In the seven year plantation, the current annual increment for height (1.89 m) was recorded higher in poplar clone WSL-39 with wider spacing (4.26 × 4.26 m), however increment in dbh (2.90 cm) was found in higher with poplar clone G-3 in 3.65 × 2.13 m spacing. The mean annual increment for height (3.18 m) and dbh (3.40 cm) recorded higher in poplar clone WSL-39 in same spacing. The growth characters of poplar clones were influenced due to the genetic potential of the clone, site quality and management. The overall growth pattern of poplar generally followed a rising trend with age. These results are also in close conformity with the findings of Chauhan *et al.* (2008). The significant variation for CAI and MAI among poplar clones under field in India conditions were reported by (Toky *et al.*, 1996; Singh *et al.*, 2001; Puri *et al.*, 2002; Sidhu and Dhillon, 2007; Dhillon *et al.*, 2010).

5.1.1 Weight and Volume growth

The significant differences in weight (kg/tree) and volume (m³/ tree) were observed among the poplar clones under this study (Table 10-14). The volume (m³/ tree) and weight (kg/tree) of different clones of poplar recorded at the age of seven years old in felling operation on farmer fields. The volume and weight for poplar clones were significantly influenced with spacings and clones. The clone WSL-39 gave maximum volume of 0.441, 0.403, 0.355, 0.328 and 0.298 m³ and weight of 392.7, 388.03, 385.22, 374.94 and 369.33 kg in different spacings such as 4.26 × 4.26 m, 3.96 × 3.96m, 3.65 × 3.65 m, 4.26 × 4.26 m and 3.65 × 2.13 m. Though, the weight and volume of clones WSL-22 and WSL-81 were at par with clone WSL-39 under 3.96 × 3.96 m spacing. The poplar clone G-3 had minimum weight and volume in closer spacing (3.65 × 2.13 m). The higher weight and volume of clones WSL-39 and WSL-22 may be attributed to their genetic potential. Field performance

of the clones of WSL -series have been found better in the Indo-gangetic plains of India with the volume production up to 0.132 m³ at the age of three years (Sidhu and Dhillon, 2007). High clonal variation in many clones of *Populus deltoides* species were also recorded by Dunlop *et al.*,1994; Singh *et al.*,2001; Dhillon, 2004.

Similar findings were also reported by Luna *et al.* (2012) who evaluated 12 clones of poplar for height, diameter growth and volume production at the age of 3 years in Punjab. Under this study, they observed that among the poplar clones, the clone WSL-39 achieved best growth and maximum volume production, attaining diameter of 14.74 cm, height 14.42 m and volume 0.104 m³/tree at the age of 3 years. The clone WSL-39 outperformed for growth and volume since the beginning. However, the volume production of clone Udai was at par with WSL-39 at 2 and 3 years of age.

The findings of present study are in agreement with the results of Rizvi *et al.* (2011) who reported that mean height and dbh of poplar tree were 14.23 m and 15.91 cm respectively, at the age of 3 years and reached up to 22.17 m and 24.39 cm respectively, at the age of 7 years. Estimated timber biomass and volume of poplar tree at the age of 3 years were 126.05 kg/tree and 0.091 m³/tree respectively, which became 267.34 kg and 0.279 m³ respectively at the age of 7 years. It was also found that the mean height and dbh of poplar tree were found to be 15.34 m and 15.77 cm respectively, at the age of 3 years, which reached up to 21.96 m and 21.38 cm respectively, at the age of 7 years. Timber biomass and volume were estimated to be 130.22 kg/tree and 0.104 m³/tree respectively, at the age of 3 years. These two values became 226.55 kg/tree and 0.237m³/tree respectively at the age of 7 years in agrisilviculture systems at Yamunanagar.

5.2 Economic return from poplar based agroforestry system

5.2.1 Poplar-sugarcane-wheat-crop rotation

The data in Table 15 depict the cost and return for growing poplar in intercropping with sugarcane and wheat under different spacings. Initially, sugarcane was taken as a major crop during first two years for poplar growth, while wheat crop was observed as a major crop during *rabi* season at the end of rotation. The plantations having sugarcane and wheat crops were selected because of adoption of these cropping rotations with poplar by the majority of the farmers in the state. The maximum input cost (Rs. 9, 05,522) for trees and crops were recorded under 3.65 × 2.13 m spacing, whereas the minimum input costs (Rs. 8, 58, 611) for trees and crops were recorded under wider spacing (4.26 × 4.26 m). The returns from trees were found to be maximum (Rs. 13, 42,500) under closed (3.65 × 3.65 m) spacing, which was closely followed by 4.87 × 2.74 m spacing with the returns (Rs. 13, 40,710) however, the returns from crops were recorded maximum (Rs. 4, 82,742) under 4.26 × 4.26 m spacing. This might be due to the fact that wider spacing provided maximum space for better growth and yield for agricultural crops. Whereas, the total returns from trees and crops were recorded

highest (Rs. 18, 03,154) under 4.87×2.74 m spacing, which was closely followed by 3.65×3.65 m spacing (Rs. 17, 98,484). The overall net returns from the rotation were also recorded highest (Rs. 9, 34,079) under 4.87×2.74 m spacing. The net present worth (Rs. 3,75,585) and IRR (48.51%) was recorded maximum under 4.87×2.74 m spacing, which was followed by 3.65×3.65 m spacing. The B: C ratio was also found to be maximum (1: 2.94) under 4.87×2.74 m spacing, which was closely followed by 3.65×3.65 m spacing (1:2.89). Both, 4.87×2.74 m and 3.65×3.65 m spacing, occupied equal number of trees, hence both spacing gave approx. same income from poplar –sugarcane-wheat crop rotation. The similar results were also found by Singh and Mavi (2016) in poplar based agroforestry system under Riparian wet land conditions of Punjab. They reported that maximum number of farmers adopted 6.0×1.5 m spacing, whereas, few of them adopted 5.5×2.0 m and 7.0×2.5 m. The cost and income analysis from intercrop as well as poplar plantation indicated that B: C ratio was 2.87, internal rate of return was 57.50 percent and net present worth was Rs. 12, 28, 162 ha⁻¹, which showed that poplar based agroforestry was economically viable in the study area. The B: C ratio, internal rate of return and net present worth were found to be higher for large poplar plantation followed by medium and small farms.

The lower growth of poplar with a sugarcane intercrop may be attributed to less application of fertilizers to sugarcane and higher competition for moisture between poplar and sugarcane. Poplar might have utilized lower amounts of nutrients applied to sugarcane, leading to its higher growth. This indicates that poplar intercropped with sugarcane during young age can recover the initial decline in growth rate during later years provided the favourable crop combinations are intercropped after cultivation of sugarcane.

5.2.2 Poplar-sugarcane-sorghum-wheat crop rotation

The data in Table 31-35 shows the cost and returns for growing of poplar in intercropping with sugarcane, sorghum and wheat under different spacing arrangements. Sugarcane was selected as a major crop initially during first two years of poplar age, while sorghum-wheat rotation was selected thereafter at the end of rotation. The plantations having above crops were selected because of adoption of these crop rotations with poplar by the majority of the farmers in the state. The highest cost (Rs. 9, 32,035) invested on trees and crops were found under 3.65×2.13 m spacing, while the lowest input cost (Rs. 8, 90,722) for trees and crops were observed under wider spacing (4.26×4.26 m). The returns from trees were recorded maximum (Rs. 13, 42,500) under 3.65×3.65 m spacing, which was closely followed by 4.87×2.74 m spacing (Rs. 13, 40,710) however, the highest returns from crops (Rs. 5,91,482) were observed under 4.26×4.26 m spacing. Whereas, the minimum returns from crops were recorded (Rs. 5, 41,345) under 3.65×2.13 m spacing. It might be due to the fact that more competition exists between tree and crop due to various aspects such as space, moisture, sun light and nutrient under closed spacing. However, the total returns from trees

and crops were found highest (Rs. 19, 08,606) under 4.87×2.74 m spacing, which was closely followed by 3.65×3.65 m spacing (Rs. 19, 02,447). The overall net returns from the rotation were also found highest (Rs. 10, 07, 420) under 4.87×2.74 m spacing. On the basis of net returns from the rotation, 4.87×2.74 m spacing was highly profitable for poplar + sugarcane + sorghum + wheat crop rotation than all other spacings in the study. The net present value (Rs. 4, 22,749) was found highest under 4.87×2.74 m, which was followed by 3.65×3.65 m spacing, however the highest internal rate of returns (51.24 %) from poplar-sugarcane- sorghum-wheat crop rotation was obtained under 4.87×2.74 m spacing, followed by 3.65×3.65 m while the lowest internal rate of return was recorded under closer spacing (3.65×2.13 m), as minimum growth and yield for both trees and crops were recorded under closed spacing. Similarly, the highest benefit-cost ratio (3.89) was recorded under wider spacing (4.87×2.74 m).

Present findings are in close agreement with the findings of Gaur and Pyare (2003) who reported that the annual net profit obtained from poplar + agricultural crops was Rs. 20, 590.00, while poplar alone had only Rs. 15, 000. The yield of sugarcane varies from 22.5 to 35.0 tha^{-1} , while the yield of ratoon crop decreased from 46 to 12% in block plantations. The average yield of wheat was 1.9 tha^{-1} . In boundary plantations, no effect on agricultural production was observed when tree line was at north-south direction, while negligible effect was observed at the east west direction. The profit of agroforestry was almost double of the agricultural crops.

Similar findings were also reported by Dwivedi *et al.* (2007) who observed that the tree species like *Azadirachta indica*, *Acacia nilotica*, *Dalbergia sissoo* and *Eucalyptus spp.* were dominant species in traditional system whereas, *Populus deltoides* and *Eucalyptus spp.* were the main species of commercial agroforestry. Fuel wood (50.6 %) was major driving force for agroforestry adoption followed by additional income (24.4 %) and shade (17.5 %) in traditional agroforestry region while, additional income (71.3 %) was the major factor in commercial agroforestry region. They found that the net return from tree produce ha^{-1} annum⁻¹ in traditional system was Rs. 989, 541 and 440 for marginal, small and medium farmers, respectively. In commercial region, B: C ratio has been found higher (3.00) for poplar based agrisilviculture than poplar (2.84) and eucalyptus (2.68) based bund system. Although traditional agroforestry seems less promising as compared to commercial agroforestry, but it is also relevant to the farmers livelihood.

5.2.3 Poplar-sorghum-berseem crop rotation

The data presented in Table 47 to 51 shows the cost and return from poplar–sorghum–berseem based crop rotation among different spacings of poplar. During initial first three year, sorghum was taken as a major crop during *Kharif* season, while berseem was taken during the *rabi* season. The highest input cost (Rs. 8, 40,110) for trees and crops was recorded

under 3.65×2.13 m spacing, however the lowest input cost (Rs. 8, 08,594) for trees and crops was found in wider spacing (4.26×4.26 m). Because in wider spacing, the cost for planting material, cost of labour for different cultural and management operation were minimum. The returns from trees were recorded maximum (Rs. 13, 42,500) under 3.65×3.65 m spacing, which was closely followed by 4.87×2.74 m spacing (Rs. 13, 40,710) however, the maximum returns (Rs. 4, 01, 437) from crops were observed under 4.26×4.26 m spacing. The reason behind this could be that the wider spacing provided maximum space for better growth and yield for agricultural crops as compared to closed spacing. However, the total returns from trees and crops were found highest (Rs. 17, 25,947) under 3.65×3.65 m spacing, which was closely followed by 4.87×2.74 m spacing (Rs. 17, 21, 070). The overall net returns from the rotation were also found highest (Rs. 9, 05,587) under 3.65×3.65 m spacing, which was closely followed by 4.87×2.74 m spacing (Rs. 9, 01,172). The highest net present value (Rs. 3, 47,939) and internal rate of return (43.64 %) were recorded under 3.65×3.65 m spacing. The highest benefit –cost ratio (2.65) was also obtained under 3.65×3.65 m spacing. On the basis of the above results it can be delineated that 3.65×3.65 m spacing gave higher benefit from poplar+ sorghum+ berseem crop rotation. Similarly, Kumar *et al.* (2004) also reported that Poplar-Sugarcane-potato-berseem chari block plantation models adopted by the farmers in Haryana and Uttaranchal state. They found that NPV for this model on six year rotation at 12%, 9% and 6% discount rates came to Rs. 49384, 57338 and $66,902 \text{ ha}^{-1} \text{ yr}^{-1}$ with Benefit –Cost (B : C) ratio as 2.83, 3.01 and 3.22, respectively and IRR as 97 %.

5.2.5 Poplar-sorghum-wheat crop rotation

The data presented in Table 64 to 68 shows the cost and return from poplar- sorghum-wheat crop rotation in different spacings. During initial first three year, sorghum was taken in *Kharif* season while wheat was taken as major *Rabi* season crop during the end of rotation. The data depict that the highest input cost (Rs. 6, 57,943) for trees and crops was recorded under 3.65×2.13 m spacing, whereas the lowest input cost (Rs. 5, 72,505) for trees and crops was recorded under wider spacing (4.26×4.26 m). The returns from trees were found highest (Rs. 9, 94,000) under 3.65×3.65 m spacing, which was closely followed by 4.87×2.74 m spacing (Rs. 9, 52,728). However, the returns from crops were recorded highest (Rs. 3, 63,876) under 4.26×4.26 m spacing and lowest (Rs. 2, 95,784) were recorded under 3.65×2.13 m spacing. The total returns were obtained maximum (Rs. 12, 73, 75) under 4.87×2.74 m spacing, which was closely followed by 3.65×3.65 m spacing (Rs. 12, 72,854). The net returns from the rotation were observed highest (Rs. 6, 92,276) under 3.65×3.65 m spacing. The highest internal rate of return (48.55 %) and B: C ratio (3.12) was recorded under 3.65×3.65 m spacing. On the basis of the above results it can be revealed that 3.65×3.65 m spacing gave maximum benefit from poplar + sorghum + wheat crop rotation.

The retarded growth of poplar with a sugarcane intercrop may be attributed to less application of fertilizers to sugarcane than sorghum-wheat rotation (Anonymous 2002) and higher competition for moisture between poplar and sugarcane than poplar and sorghum-wheat rotation. Conversely, poplar might have utilized higher amounts of nutrients applied to sorghum-wheat rotation than sugarcane as intercrops, leading to its higher growth. April to June is the most critical period for the growth of sugarcane and poplar as the biomass of both crops increases phenomenally during this period. At the same time, these are also the hottest months of the year and it is probable that the growth of poplar reduces during these months because of reduced water availability. It has been also reported by Reddy, (2004) that the water requirement of sugarcane is higher (150–250 cm) than fodder-wheat rotation (90–130 cm). Similarly, Singh *et al.* (1997) also observed that poplar gained maximum height, girth and woody biomass in 6 years when it was intercropped with crops irrigated with high amounts of water (rice-wheat/ guinea grass-oats, about 492 cm and rice-berseem/ cowpea-berseem, about 636 cm) as compared to those receiving less water (pigeon pea/sorghum-mustard/ turmeric, about 258 cm). On the other hand, growth characteristics and volume did not differ significantly between the two crop rotations under 4 year old plantations. This indicates that poplar intercropped with sugarcane during young age can recover the initial decline in growth rate during later years provided the favourable crop combinations are intercropped after cultivation of sugarcane.

The similar findings were also recorded by Singh *et al.*, (2016) who observed that the tree species like *Populus deltoides*, *Eucalyptus spp.*, *Mangifera indica* and *Dalbergia sissoo*, are dominant species for commercial agroforestry. The net return from block plantation (Rs.1, 96, 950 ha⁻¹ annum⁻¹) was found higher than the bund plantation (Rs.1, 02, 249 ha⁻¹ annum⁻¹) in agrisilviculture system. The net return from tree produce (Rs.1, 48,076 ha⁻¹ annum⁻¹) in block plantation was also higher than the bund plantation (Rs. 48,883 ha⁻¹ annum⁻¹). In both the systems, B:C ratio was found highest for poplar based block planting (3.85) as compared to poplar based bund plantation (2.22).

Similarly, Kumar *et al.* (2004) also reported that agroforestry models adopted by the farmers in Haryana and Uttaranchal state of the India are highly lucrative, therefore, attracting farmers in a big way. It was showed that NPV for different models on six year rotation varies from Rs. 26,626 to Rs.72, 705 ha⁻¹ yr⁻¹ whereas Benefit Cost ratio and Internal Rate of Return vary from 2.35 to 3.73 and 94 % to 389 % respectively. This showed that agroforestry has not only uplifted socioeconomic status of the farmers but has also contributed towards overall development of the region.

The cost of plant material accounted to maximum; *i.e.*, 34 per cent of total establishment cost was analyzed by Dhillon *et al.* (2001). They reported that the operational cost was Rs. 2,800 annum⁻¹ acre⁻¹ during first six years. The total annual cost also did not

vary much with age of trees. The discounted cash flow of poplar plantation results in constant annual net returns per acre over the entire rotation was Rs. 22,156 and Rs.29, 332 without intercropping and within intercropping, respectively.

5.3 Periodic changes in plant height and collar diameter of different poplar clones under nursery condition:

The data presented in Table 80 to 81 revealed that the plant height and collar diameter of different poplar clones were significantly influenced by different spatial arrangement during the different periodic stage under nursery condition. The performance of poplar clones for plant height and collar diameter were found best with wider spacing (80 × 60 cm) followed by 60 × 50 cm, 65 × 45 cm, 70 × 35 cm and 60 × 40 cm spacing. Poplar clone WSL-109 was observed to have maximum height and collar diameter at different stages of growth under various spacings followed by WSL-110, WSL-39, WSL-22, WSL-81, G-48 and G-3 during both the years of study. However, poplar clone G-3 was observed to possess minimum plant height and collar diameter at different stages of growth under various spacings during both the years of study.

Spacing had significant influence on plant height and collar diameter and it was observed that as the spacing increases, the collar diameter and height of the plant also increases. This may be due to the fact that the competition among plants for space and nutrients decreases under wider spacing. Singh (2001) also reported that in *P. deltoides* collar diameter of seedlings decreased as the seedling density increased. It was also stated that the growth characters of *Populus deltoides* are influenced by the genetic constitution of the clone, site quality and different cultural operation carried out during growing period. Similarly, Luna *et al.*, (2012) also reported that the growth performance of the WSL-series have been found better in Indo-gangetic plains. This may be ascribed to the difference in the genetic potential among the different clones as the treatment given to all clones was the same. These results are also in close conformity with the earlier findings of Verma and Bangarwa, 2003; Dhillon, 2004; Dhillon *et al.*, 2010.

5.4 Economic of nursery:

The data presented in Table 82 to 83 shows that the cost and return (Rs. /acre) from poplar nursery at different spacings during the year 2015-16 and 2016-17. The maximum input cost for nursery raising was recorded in 60 × 40 cm spacing due to higher cost for planting material and labours for various cultural and management operation, while the minimum cost were recorded under wider spacing (80 × 60 cm) during both the years. During 2015-16, the highest income (Rs. 3, 13,040) was obtained in 60 × 40 cm spacing, which was closely followed by 70 × 35 cm spacing (Rs. 3, 00,000). The net benefit (Rs. 2, 11,532) and benefit cost ratio (1: 3.08) were also recorded maximum under 60 × 40 cm spacing. However, during 2016-17 the highest income (Rs. 2, 83,333) was recorded in 70 × 35 cm spacing,

which was closely followed by 60×40 cm spacing (Rs. 2, 78, 261). Similarly, the maximum net benefit (Rs. 1, 82,983) and B: C ratio (1: 2.82) was also recorded in 70×35 cm spacing. The possible reason for the above result would be that during the 1st year, the 10% entire transplants (ETPs) were culled during the selling time, however, during the 2nd year under 60×40 cm spacing 20% entire transplants (ETPs) was culled due to unhealthy ETPs for transplants. These results are in broad agreement with the findings of Kumar (2004) who reported that plants grown at wider spacing of 90×90 cm recorded maximum height and diameter growth. However, closer spacing of 30×30 cm had minimum plant growth. In general, wider spacing resulted in more plant height and diameter, whereas narrower spacing reduced the plant growth.

Singh and Vashista (2001) further revealed that the cost and return from poplar nursery grown in 60×60 cm spacing gave net return was Rs. 33, 571 $\text{acre}^{-1} \text{yr}^{-1}$.

CHAPTER-VI

SUMMARY AND CONCLUSION

The present investigation entitled “Evaluation of poplar (*Populus deltoides*) for spacing under nursery and field plantation” was carried out at Yamunanagar district of Haryana, during 2015-16 and 2016-17. The present study resolved into two broad experiments as per the objectives of the study. Accordingly, salient findings are summarized herewith:

6.1 Growth of poplar under different spatial arrangements

After seven years of age, poplar has been found to attain significantly more height and dbh at 4.26×4.26 m and 3.96×3.96 m spacings in comparison of closer spacing (3.65×2.13 m). The significant variation was observed between the spacings and clones for dbh and height. The Current annual increment (CAI) for both total height and basal diameter were significant from first to seven years in all spacings and clones. However, the mean annual increment (MAI) for both the attributes in seven year old plantation was also found significant under different spacing and clones at the harvesting stage.

6.1.1 Weight and Volume

Among all the different spacings of poplar based agroforestry system, the maximum volume ($0.441 \text{ m}^3/\text{tree}$) and weight ($392.70 \text{ kg}/\text{tree}$) were recorded significantly higher in poplar clone WSL-39 in 4.26×4.26 m spacing, which was closely followed by poplar clone WSL-22 at the stage of harvesting during this study. However, in poplar clone G-3, the minimum volume ($0.198 \text{ m}^3/\text{tree}$) and weight ($328.90 \text{ kg}/\text{tree}$) was obtained under 3.26×2.13 m spacing.

6.2 Economic return from poplar based agroforestry system

6.2.1 Poplar-Sugarcane- Wheat crop rotation

In poplar-sugarcane- wheat crop rotation, the total returns from trees and crops were recorded highest (Rs. 18, 03,154) under 4.87×2.74 m spacing, which was followed by 3.65×3.65 m spacing (Rs. 17, 98,484). The overall net returns from the rotation were also recorded higher (Rs. 9, 34,079) under 4.87×2.74 m spacing. The highest NPV at 12% discount rate came to Rs.3, 75,584 under 4.87×2.74 m, which was followed by 3.65×3.65 m spacing (Rs. 3, 71,842). The highest internal rate of return (48.51%) and Benefit- Cost ratio (2.94) was also found in 4.87×2.74 m spacing.

6.2.2 Poplar- Sugarcane-Sorghum –Wheat crop rotation

The total returns from trees and crops were found highest (Rs. 19, 08,606) in 4.87×2.74 m spacing, which was closely followed by 3.65×3.65 m spacing (Rs. 19, 02,447). The overall net return from the rotation was also recorded highest (Rs. 10, 07, 420) under $4.87 \times$

2.74 m spacing in Poplar- Sugarcane- Sorghum -Wheat crop rotation. For this crop rotation, the Net Present value at 12% discount rates came to Rs.4,22,749 under 4.87×2.74 m spacing, which was closely followed by 3.65×3.65 m spacing (Rs. 4,18,057). The highest internal rate of return (51.24 %) and Benefit- Cost ratio (3.89) was also found under 4.87×2.74 m spacing, which was followed by 3.65×3.65 m spacing.

6.2.3 Poplar –sorghum –berseem crop rotation

In poplar-sorghum- berseem crop rotation, total returns from trees and crops were found higher (Rs. 17, 25,947) in 3.65×3.65 m spacing, which was closely followed by 4.87×2.74 m spacing (Rs. 17, 21, 070). The overall net return from the rotation was also found highest (Rs. 9, 05,587) in 3.65×3.65 m spacing, which was followed by 4.87×2.74 m spacing (Rs. 9, 01, 172). The Net Present value for this crop rotation at 12% discount rates came to Rs. 3,47,939 under 3.65×3.65 m spacing, which was closely followed by 4.87×2.74 m spacing. The highest IRR (43.64 %) found under 3.65×3.65 m spacing, which was followed by 4.87×2.74 m spacing (43.58), While the highest B:C ratio (2.65) was also found under 3.65×3.65 m spacing, which was followed by 4.87×2.74 m spacing (2.64).

6.2.4 Poplar-sorghum-Wheat crop rotation

The total returns from trees and crops were found highest (Rs. 12, 73,751) in 4.87×2.74 m spacing, which was closely followed by 3.65×3.65 m spacing (Rs. 12, 72,854). The overall net return from the rotation was also recorded highest (Rs. 6, 92,276) under 4.87×2.74 m spacing in Poplar- Sorghum-Wheat crop rotation. For this crop rotation, the Net Present value at 12% discount rates came to Rs. 2,76, 283 under 3.65×3.65 m spacing, which was closely followed by 4.87×2.74 m spacing. The highest IRR (48.55 %) was found under 4.26×4.26 m spacing, which was 3.65×3.65 m spacing. The highest Benefit-Cost ratio (3.12) was recorded under 3.65×3.65 m spacing, which was followed by 4.26×4.26 m spacing (3.06).

6.3. Growth attributes of poplar in nursery stage

The plant height and collar diameter of different poplar clones were significantly influenced by different spatial arrangement during the different periodic stage under nursery condition. The performance of poplar clones for plant height and collar diameter were found best with wider spacing (80×60 cm) followed by 60×50 cm, 65×45 cm, 70×35 cm and 60×40 cm spacing. Poplar clone WSL-109 was observed to have maximum height and collar diameter at different stages of growth under various spacings followed by WSL-110, WSL-39, WSL-22, WSL-81, G-48 and G-3 during both the years of study.

6.4. Economics of poplar nursery

The highest net benefit (Rs. 2, 11,532) and benefit cost ratio (1:3.08) was recorded under 60×40 cm spacing during the year 2015-16. However, during 2016-17, the higher net benefits (Rs.1, 82,983) and B: C ratio (1:2.82) was recorded under 70×35 cm spacing.

Conclusion

- Under field plantation, growth of poplar was significantly higher in 4.26×4.26 m spacing as compared to other spacings of poplar.
- Different clones of poplar showed significant variation for growth parameters (height and dbh). Poplar clone WSL-39 out yielded the rest of poplar clones under different spacings of poplar plantation and it was closely followed by poplar clone WSL-22.
- Volume and weight of poplar wood was increased with the increase in poplar age as well as spacing. In poplar clone WSL-39 the volume and weight with the spacing of 4.26×4.26 m was $0.441 \text{ m}^3/\text{tree}$ and $392.70 \text{ kg}/\text{tree}$ respectively at the age of seven year old plantation.
- Poplar + sugarcane + sorghum + wheat based agroforestry system with 4.87×2.74 m spacing were found more economical (with benefit cost ratio of 3.89) than the other crop rotation with poplar.
- In nursery condition, 80×60 cm spacing has been found to attain significantly more plant height and collar diameter and it was closely followed by 70×50 cm spacing.
- Among the six poplar clones screened under different spacings in nursery condition, maximum plant height and collar diameter was observed in clone WSL-109 and minimum plant height and collar diameter was observed in G-3 clone.

The maximum benefit cost ratio (3.08) was recorded with a spacing of 60×40 cm under nursery condition.

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APPENDIX

Schedule

CCS HARYANA AGRICULTURAL UNIVERSITY

COLLEGE OF AGRICULTURE, HISAR

DEPT. OF FORESTRY

Title of Research Problem: - Evaluation of Poplar (*Populus deltoides*) for spacing under nursery and field plantation

(A) General information: -

(a) Name of farmer _____ Father's Name _____

(b) Village _____ Tehsil _____ Nearest Market _____

- i. **Year of Establishment of Poplar plantation**
- ii. **Name of clone**
- iii. **Establishment time**
- iv. **Spacings**
- v. **Input use**
- vi. **Time of different management operation**
- vii. **Crop grown**
- viii. **Crop rotation**
- ix. **Crop production potential**
- x. **Cost price**
- xi. **Sale price**
- xii. **Economic return**

(A) Establishment cost of Poplar based Block Plantation

S.No.	Particulars	Rs. / Hectare
1.	Preparation of land	
2.	Layout	
3.	Digging of pits	
4.	Filling of pits	
5.	FYM	
6.	Fertilizers a) SSP/ DAP b) Znso4 c) Chloripyriphous d) Any other	
7.	Cost of plant	
8.	Transportation of plant	
9.	Plantation cost	
10.	Cost of irrigation	
11.	Intercultural operation and Hoeing	
12.	Pruning and cutting	
13.	Insecticide, fungicide and Nutrient spray	
14.	Watch and ward/fencing	
15.	Land Rent	
16.	Miscellaneous	
	Total cost	

(B) Operational Cost of Poplar based Block Plantation

S.No.	Particulars	Rs/hec.
1.	Intercultural Operation and Hoeing	
2.	FYM cost	
3.	Fertilizers	
4.	Irrigation	
5.	Pruning and cutting	
6.	Insecticides and Fungicides	
7.	Watch and ward	
8.	Picking cost	
9.	Miscellaneous	
	*Sub Total	
10.	Interest on working capitals	
11.	Variable cost	
12.	Transportation	
13.	Management charges	
14.	Risk factor	
15.	Rental value of land	
16.	Total cost	
17.	Productions	
18.	Gross Return	
19.	Return of variable cost	
20.	Net Return	
21.	Cost of production / qtls	

(C) Cropping Pattern

Kharif Crop	Rabi Crop
1.	1.
2.	2.
3.	3.

ABSTRACT

Title of Thesis	Evaluation of poplar (<i>Populus deltoides</i>) for spacing under nursery and field plantation
Name of degree holder	Pradyuman Singh
Admission No.	2013A63D
Title of degree	Doctor of Philosophy
Name and Address of Major Advisor	Dr. K.S. Bangarwa Major Advisor (Professor & Head) Department of Forestry CCS Haryana Agricultural University, Hisar
Degree awarding University/ Institute	CCS Haryana Agricultural University, Hisar-125004 (Haryana), India.
Year of award of degree	2017
Major Subject	Forestry
Total No. of Pages in the Thesis	80 + v + II
No. of words in the abstract	Approx. 421

Key words: *Populus deltoides*, poplar clones, different spacings, growth attributes, economics

The present investigation entitled “Evaluation of poplar (*Populus deltoides*) for spacing under nursery and field plantation” was carried out at Yamunangar district, Haryana during 2015-16 and 2016-17 to study the effect of different spatial arrangements (4.26 × 4.26 m, 3.96 × 3.96 m, 3.65 × 3.65 m, 4.87 × 2.74 m and 3.65 × 2.13 m spacings) and different clones (WSL-39, WSL-22, WSL-8, G-48 and G-3) up to 7 years old poplar plantation in farmers fields. The growth attributes (height and dbh) were significantly influenced in association with all the five spatial arrangements of poplar. Wider spacing (4.26 × 4.26 m) of poplar was found best for growth characters (height and dbh) of poplar followed by 3.96 × 3.96 m, 3.65 × 3.65 m, 4.87 × 2.74 m and 3.65 × 2.13 m spacings. However, among different poplar clones, the height and dbh were recorded significantly higher in poplar clone WSL-39 which was followed by WSL-22, WSL-81, G-48 and G-3 in wider spacing (4.26 × 4.26 m) up to a seven year. The poplar clone WSL-39 gave maximum volume and weight in all the spacings such as 4.26 × 4.26 m, 3.96 × 3.96 m, 3.65 × 3.65 m, 4.26 × 4.26 m and 3.65 × 2.13 m. Though the weight and volume of poplar clones WSL-22 and WSL-81 was at par with clone WSL-39 at the spacing of 4.26 × 4.26 m spacing. The cost and income analysis for growing poplar in intercropping with sugarcane and wheat under different spacings indicated that highest B-C ratio (2.94), internal rate of return (48.51%) and net present worth (Rs. 3, 75,584.9 hectare⁻¹) was obtained under 4.87 × 2.74 m spacing. However, highest B-C ratio (3.89), internal rate of return (51.24 %) and net present worth (Rs. 4,22,749.30 hectare⁻¹) was recorded from Poplar- Sugarcane- Sorghum-wheat crop rotation under 4.87 × 2.74 m spacing. In poplar-Sorghum- berseem crop rotation, highest net present worth (Rs. 3, 47,939.6 hectare⁻¹), B-C ratio (2.65) and internal rate of return (43.64 %) was found in 3.65 × 3.65 m spacing. In 3.65 × 3.65 m spacing, the highest B-C ratio ((3.12), internal rate of return (48.55 %) and net present worth (Rs. 2, 76, 283.32 hectare⁻¹) was also recorded from Poplar- Sorghum-wheat crop rotation. On the other hand, under different spacings of poplar nursery the highest net benefit (Rs. 2, 11,532) was recorded under 60 × 40 cm spacing during the year 2015-16. However, during 2016-17, the higher net benefit (Rs.1, 82,983) was recorded under 70×35 cm spacing.

MAJOR ADVISOR

DEGREE HOLDER

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Degree	University/Board	Year of Passing	Percentage	Subjects
High-School	U.P. Board	2003	58.83.%	Hindi, Eng., Science, Maths, social science & Drawing
Intermediate	U.P. Board	2005	65.6.%	Gen. Hindi, Eng., Physics, Chemistry & Math
B.Sc. (Agriculture)	Bundelkhand university Jhansi, U.P.	2011	71.58%	Agriculture
M.Sc. Forestry (Agroforestry)	N.D.U.A &T. Faizabad, U.P.	2013	79.69%	Major- Forestry Minor- Agronomy
Ph.D. Forestry	CCS HAU, Hisar, Haryana	2017	71.60%	Major- Forestry Minor- Agronomy

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- i. Vice Chancellor's Gold Medal for obtaining highest marks/ OGPA (7.969) in the discipline of M.Sc. Forestry with specialization in Agroforestry at Narendra Deva University of Agriculture & Technology, Kumarganj, Faizabad, Uttar Pradesh.
- ii. Recipient of DST (Department on Science and Technology) Inspire fellow during Ph.D. programme.

(k) List of Publications :

Abstract published in National/International seminar and conferences

- i. **Singh, P.** and Bangarwa, K.S. (2017). Optimum spacing of poplar for maximum growth and Higher Economic Return under Poplar based agroforestry system in Yamunanagar (Haryana) In: International Conference on "Sustainable Natural Resource Management: from Science to Practice" Department of Farm Engineering Institute of Agricultural Sciences, Varanasi From 12-13 January, 2017, pp.173.
- ii. **Singh, P.** and Bangarwa, K.S. (2015). Survey on various spacings of *Populus deltoides* grown in farmers field in northern Haryana. In: Jammu and Kashmir Agricultural Science Congress entitled "Technological Innovations, Opportunities and Challenges for sustainable rainfed agriculture for food and livelihood security". Organized by SKUAST, Jammu, pp:176.

UNDERTAKING OF COPY RIGHT

I, **Pradyuman Singh Admn. No. 2013A63D** undertakes that I give copy right to the CCS Haryana Agricultural University, Hisar of my thesis entitled, “**Evaluation of poplar (*Populus deltoides*) for spacing under nursery and field plantation**”.

I also undertake the patent if any, arising out of the research work conducted during the programme shall be filed by only with due permission of the competent authority of CCS Haryana Agricultural University, Hisar.

SIGNATURE OF THE STUDENT