

**EFFECT OF POPLAR-BASED MICROCLIMATE ON
INTERCULTIVATION OF ONION**

Thesis

**Submitted to the Punjab Agricultural University
in partial fulfillment of the requirements
for the degree of**

**MASTER OF SCIENCE
in
FORESTRY
(Minor Subject: Vegetable Science)**

By

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(L-2016-A-79-M)**

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CERTIFICATE - I

This is to certify that the thesis entitled, "**Effect of poplar-based microclimate on intercultivation of onion**" submitted for the degree of **M.Sc.** in the subject of **Forestry** (Minor subject: **Vegetable Science**) of the Punjab Agricultural University, Ludhiana, is a bonafide research work carried out by **Jyoti Devi (L-2016-A-79-M)** under my supervision and that no part of this thesis 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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ABSTRACT

The present study entitled ‘Effect of poplar-based microclimate on intercultivation of onion’ was carried out at main research area of the Department of Forestry and Natural Resources, Punjab Agricultural University, Ludhiana during the year 2016-2017 and 2017-18. The study was carried out to optimize the planting time of different onion varieties under poplar plantation. An experiment was laid out during three planting times *viz.* end-December, mid-January and end-January with the four onion varieties *viz.* Pb-Naroya, PRO-6, PWO-35 and PRSC-10. The experiment was laid out in split-split plot design with the two environments as main plot, three times of planting as sub-plot and four onion varieties as sub-sub plot. Various growth and yield parameters were recorded for both trees and crops. The onion crop showed positive effect on the tree growth parameters such as tree height, diameter at breast height and crown spread. The average temperature was recorded higher under open conditions as compared to poplar plantation whereas relative humidity was recorded higher under poplar plantation as compared to under open conditions. The average total bulb yield was recorded higher under two-year-old plantation (188 q/ha) as compared to the bulb yield under three-year-old plantation (175.5 q/ha). The average total bulb yield was recorded higher under open conditions (222.5 q/ha) as compared to poplar plantation (128.5 q/ha). Under open conditions, the mean bulb yield of end-December planted crop (253.1 q/ha) was significantly higher than the mid-January (235.8 q/ha) and end-January (194.5 q/ha) planted crop. Among the varieties, the mean bulb yield was found maximum in PWO-35 (259.5 q/ha) which was followed by Pb-Naroya (235.8 q/ha), PRO-6 (223.6 q/ha) and PRSC-10 (192.4 q/ha). Under poplar plantation parameters *viz.* number of leaves, plant height, weight of plant before and after curing, average fresh bulb weight, dry matter content and TSS content was recorded maximum in the end-December planted crop which was followed by mid-January and end-January planted crop. Among the varieties, PWO-35 variety performed much better than the other three varieties. Overall, the best combination of planting time and variety in the present study was observed to be end-December planting time and PWO-35 variety.

Keywords: Poplar, Onion varieties, Bulb yield, Time of planting, Dry matter, TSS

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ਮੁੱਖ ਸ਼ਬਦ: ਵਣ-ਖੇਤੀ, ਪਾਪਲਰ, ਪਿਆਜ ਕਿਸਮਾਂ, ਗੰਢਿਆਂ ਦਾ ਝਾੜ, ਲਗਾਉਣ ਦਾ ਸਮਾਂ, TSS

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ABBREVIATIONS

%	:	Percent
/	:	Per
×	:	Multiply
C.D.	:	Critical Difference
cm	:	Centimeters
DBH	:	Diameter at Breast Height
<i>E.</i>	:	<i>Eucalyptus</i>
e.g.	:	For example
<i>et al</i>	:	others
<i>etc.</i>	:	Etcetera (and so on)
Fig.	:	Figure
FYM	:	Farm Yard Manure
g	:	Gram
i.e.	:	That is
m	:	Meter
mg	:	Milligram
q	:	Quintal
t ha ⁻¹	:	Tonne Per Hectare
<i>viz.</i>	:	Videlicet (Namely)
yrs	:	Years

CHAPTER-I

INTRODUCTION

Agriculture is a main land use system in Punjab where rice-wheat cropping system is intensively followed by farmers. The geographical area of State is 50,362 square kilometer which comes out to be 1.54 per cent of the total geographical area of country, out of this about 84 per cent land of Punjab comes under agriculture. Punjab contributes 24.2 and 41.5 per cent share of rice and wheat to the central pool of food grains (Anonymous 2017). This traditional crop rotation system is no longer ecologically sustainable although economically profitable. It has resulted in the loss of forest land, ecological imbalance and also lowering ground water table (Anonymous 2005). The monocropping and chemical-intensive agricultural practice would lead to barren land and weakened genetic pool (Chhetri 2007). The lesser availability of land and low productivity of natural forests widening the gap between demand and supply of forest products. To minimize this gap, there is a need to increase the land under tree cover by way of plantations and other afforestation works. But the horizontal expansion of land under tree cover is not feasible. In Punjab, forests occupy only 1,771 sq km (i.e. 6.49 per cent of the total geographical area as against the required 20 per cent as recommended by the National Forest Policy 1988). It is not possible to divert the fertile agriculture land to forests in view of prevailing agro-climatic and socio-economic conditions. Forest area of the Punjab has declined sharply due to heavy pressure of agriculture. There is no further land to increase the area under forest cover without sacrifices the area of cereals. In such a scenario, agroforestry is one of the feasible options to increase the area under tree cover. There are many sustainable agroforestry systems in vogue in several parts of the world. The component plant species like trees and crops in agroforestry system depends on the similar reserve of growth resources such as light, water, minerals and nutrients and hence there will be effect of one component of a system on the other components as well as on the system as a whole (Gill 2002). It requires optimized, judicious and sustained management of available growth resources in a given area rather than their over exploitation (Dhyani *et al* 2009).

The National Agriculture Policy 2000 has suggested that agroforestry is sustainable land use system that helps in improving organic matter, nutrient cycling and tree cover. The policy also stated that “farmers should also be encouraged to adopt the agroforestry to get the maximum benefits on the sustainable basis and to generate the high income by evolving advanced technology, extension and credit supporting systems and removing constraints for advancement of the agroforestry”. The National Agroforestry Policy 2014 states that agroforestry has the potential to reduce the poverty in rural India. Government estimates that policy will also help to increase the area from 25.32 million ha to 53 million ha. The policy suggests effective guidelines which will help farmers to get the maximum gain from the

suitable agroforestry system and to increase the production of food, fodder, fuel and other minor products.

Trees are one of the integral component of farming systems of the region. Traditionally, farmers used to retain different naturally growing trees like *Prosopis juliflora*, *Azadirachta indica*, *Acacia nilotica* and *Dalbergia sissoo* on their farming fields. But due to their highly spreading crown and slow growing nature they are incompatible with agriculture crops. Thus with commercialization of agriculture, farmers shifted towards fast growing tree species. Amongst the different fast growing tree species, poplar is an ideal tree in agroforestry.

Poplar based agroforestry system is playing an important role in the socio-economic life of farmers. It offers not only a sustained productivity, but also an increased productivity per unit area. It is neither a new concept nor is it new technology. It is an intensive land-management system that optimizes the benefits from the biological interactions when trees and/or shrubs are deliberately combined with crops and/or livestock (Garrett *et al* 1997). It is an emerging concept and technology that helps to increase yield, improve soil fertility, promote land sustainability and efficient use of natural resources. It helps to provide additional income to the marginal farmers and also act as a emergency cash crop system (Kaur *et al* 2010). Intercropping with 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). Fast growing trees species including poplars have an important role in capturing atmospheric carbon dioxide to ameliorate environment. Farmers are adopting the agroforestry system because of enhanced market demand of plywood, paper and furniture units from farm grown timber. Thus agroforestry based upon the sustainability in terms of economics (productivity and profitability) ecology (environmental and resource conservation) and social issues (food security, health and safety) makes it an unparallel land use system (Pandey 2007).

Populus deltoides which is an exotic, multipurpose, fast growing, short rotation tree with valuable timber emerged as one of the most suitable tree species for agroforestry system. Poplar is a winter deciduous tree which sheds its leaves during December and new leaves emerge during March. It was introduced in late 1950s in India and estimated that 60,000 ha equivalent plantations of poplar exist in India (Gill *et al* 2009). It is mostly planted in north-western states of India such as Haryana, Punjab and Uttar Pradesh (Chauhan and Mangat 2006). Poplar based agroforestry system is one of the big success in irrigated regions of north-western India. It can be successfully planted on farm boundaries as well as in block plantations. Due to its winter deciduous nature, it is more favorable for winter crops when shading is not a problem and sunlight is available to the understory crop. In northern India, productivity of poplar up to 50 m³ ha⁻¹yr⁻¹ was achieved through intensive management

practices as compared to $1.0 \text{ m}^3 \text{ ha}^{-1} \text{ yr}^{-1}$ of natural forests (Lal 2007). It is not suitable for water-logging conditions but can be grown as boundary plantations under traditional rice-wheat cropping systems (Gera *et al* 2006). It is most commonly found along the *Eucalyptus* plantations on agricultural fields in states of Punjab, Haryana, Uttar Pradesh and Uttranchal. It has become most suitable cash crops in the agroforestry system.

In addition to wheat, a number of agricultural crops such as mustard, turmeric, ginger, colocasia, cabbage, potato, spinach, garlic etc including fruit crops (citrus, guava, mango etc) can be profitably grown with poplar. Farmers choose to grow annual crops (turmeric, sugarcane etc.) or seasonal crops in *rabi* (wheat, oats, barley, berseem, mustard etc.) and *kharif* (cotton, sorghum, moong, pearl millet etc). The important factor to grow the number of agricultural crops under poplar is based on their compatibility and tree spacing. Reduction in the yield of different agricultural crops arises due to the non-compatibility and improper tree spacing. During first three years almost any crop except rice can be effectively grown under poplar. Therefore, there is a need to determine the compatibility of different crops under poplar based agroforestry system.

Onion (*Allium cepa* L.) is known as “queen of kitchen” and one of the important vegetable crops grown all over the world and becomes an essential part of daily diet. It is second after tomato in their importance as a vegetable in world. The demand of the onion is worldwide and due to genetic variability and congenial atmosphere it can be grown in varied agro climatic regions. It belongs to the family Alliaceae and native to Central Asia. It is largest item of export among the total export of fresh vegetables from India i.e. amounting to 76.18% export. Maharashtra is the leading state contributing 33% in production of the onion in the country. Other onion growing states are Karnataka, Gujarat, Orissa, Uttar Pradesh, Rajasthan and Tamilnadu etc.

Onion has many medicinal properties and used for the preparation of various ayurvedic, homeopathic and unani medicines. The main phenolic compound present in onion is Catechol which has high anti-fungal properties. It is mostly used as a spice and also consumed as a raw. By eating it as raw it kills most of the harmful bacteria present in mouth and stops tooth decay. It has number of benefits like helps in reducing blood pressure, plasma cholesterol and blood sugar etc. It is extensively used as condiment in the preparation of chutneys and pickles. Each 100 g of edible portion of onion contains energy 50 kilo calories, water 86.6 percent, calcium 47 mg, protein 1.2 g, ascorbic acid 11 mg, phosphorus 50 mg, riboflavin 0.01 mg, iron 0.7 mg, thiamine 0.08 mg etc.

In India, it is being cultivated as biennial crop for seed production and for bulb production. The edible portion bulb is of disc shape having succulent leaves and develop underground. In the plains of the India, it is grown in *rabi* season when temperature is favorable for the floral initiation. It is a long day plant and requires low temperature during

early stages of the growth. During harvesting, high temperature and low humidity is required. There is generally two methods of growing onion i.e. seed to seed method and bulb to seed method especially for seed production. Although onion is *rabi* season crop but now a day's production of onion in *kharif* season is in vogue due to the proven technologies developed by the ICAR institutes, NHRDF (National Horticultural Research and Development Foundation) and State agricultural universities (Singh and Sharma 2002). However *Kharif* crop is more profitable than the summer crop because in summer it is difficult to get onion bulbs due to high temperature and rainfall. Thus, Cultivation of onion under *Populus deltoides* could be one of the viable options for overall higher productivity of vegetable based agroforestry system and better economic returns of the small and marginal farmers.

Sustainability is an imperative element of any agricultural practice. Agroforestry with poplar tree is one of the viable option for maintaining sustainability. Sustainable agriculture gave maximum attention to high value crops because of economic opportunity they offer to low income farmers. Such farmers have several more opportunities to grow high value crops on small land holdings than they ever expect with commodity crops. Poplar is deciduous in nature and can be grown successfully with winter season crops when shading is not a problem. Therefore, by keeping this in mind, the present study is planned to evaluate the effect of poplar-based microclimate on the performance of different onion varieties with objectives-

- A. To study the microclimate variability under poplar plantation.
- B. To evaluate the effect of microclimate variability on growth and yield performance of different onion varieties.

CHAPTER-II

REVIEW OF LITERATURE

Cultivation of multipurpose trees on a farmland with agricultural/horticultural crops is an old age practice. The ultimate objective of the traditional farmer is to get maximum food production in a continuous manner. To get better quantify and enhance the aspect of agroforestry, more widely acceptable scientific definition was considered necessary to differentiate it from the other systems. Bene *et al* (1977) defined it as deliberate integration of silvicultural trees with agricultural crops and/or rearing of animals simultaneously and sequentially on the same piece of land in order to get diversified products such as food, fodder, timber, fuelwood, fibre, milk products etc. Agroforestry systems include both economic and ecological interaction among the different components of the system. During 1970s, the issues like deforestation, food hunger, environmental pollution and increasing gap between demand and supply gave importance to the agroforestry systems as an alternative land use system for crop diversification, to solve the problems of the food and hunger crisis. In agroforestry, poplar based agroforestry system is one among the others having important role in the socio-economic status of the farmers. Usually different crops like wheat, turmeric, potato, lentil, maize, soybean and fodder crops are successfully intercropped with it. It has been found that intercropping of different *rabi* and *kharif* crops in poplar based agroforestry systems significantly increases the different growth parameters of poplar as compare to poplar monoculture (Toky 1997, Dhanda and Kaur 2000).

In this chapter an attempt have been made to review the literature on different aspects of the study. The main emphasis has been given on the “STUDIES ON THE EFFECT OF POPLAR-BASED MICROCLIMATE ON INTERCULTIVATION OF ONION”. The literature is reviewed under the different sub categories:-

- 2.1 Soil and nutrient status under poplar based agroforestry system
- 2.2 Performance of different agronomic crops under farm grown trees
- 2.3 Performance of high value crops under poplar based agroforestry system
- 2.4 Onion: an important vegetable crop

2.1 Soil and nutrient status under poplar based agroforestry system

Agroforestry systems have a great potential to improve the soil physical, chemical and biological properties. Trees act as both source and sink of carbon and help to improve the organic fertilizers under soil by improving soil physical properties. Gupta *et al* (2009) studied that poplar based agroforestry system helps to improve soil physical properties like soil aggregation. The constant addition of the leaf litter increases organic matter content into the soil. It was also reported that the amount of biomass and soil carbon was significantly higher in the poplar based agroforestry systems as compare to the control (Singh and Lodhiyal

2009).

Several other studies have reported that soil fertility in terms of soil organic matter and exchangeable cations improved under the canopy of the trees as compare to field without trees (Campbell *et al* 1994). Soil under the canopy of *Faidherabia albida* had higher nutrient content than open soils. The organic carbon content, exchangeable N, Ca, P and K increased from 14-100%, 13-117%, 2-67%, 18-36% and 60-100% (Depommier *et al* 1992). Maximum improvement in the fertility was recorded in the top soil.

The soil organic carbon over different years of plantation was significantly higher in surface soils i.e. 61% more and in subsurface soils around 44% more than the control soils. According to Ralhan *et al* (1992) the poplar trees on an average adds 3.5 t/ha of litter fall every year. The amount of litter fall increases as the age of the poplar tree increases i.e. leaf litter under poplar trees of an age of 2-4 years significantly increased from two years 684.1 kg/ha to four year 831.9 kg/ha. Soil organic carbon was higher in surface layers because major litterfall takes place on the surface. Other than poplar, many forest trees help in improving the soil physical properties likewise Shukla and Misra (1993) observed that organic carbon was maximum in surface layers of *Acacia* based agroforestry systems (0.18–0.37%) than control (0.12–0.14%).

Sirohi and Bangarwa (2015) conducted an experiment during *rabi* season of 2013-2014 on plantation of *Populus deltoides* to evaluate the nutrient status under different spacing of poplar-based agroforestry system. The experiment was conducted at two stages of wheat i.e. before sowing of wheat in October and after harvest of wheat in April. Macro-nutrients i.e. N, P and K and organic carbon of surface soil (0-15 cm depths) was determined under different spacings 5 × 4 m, 10 × 2 m and 18 m × (2 × 2 m paired row) of poplar plantation. The organic carbon (0.61%), N (224.3 kg ha⁻¹), P (17.6 kg ha⁻¹) and K (231.3 kg ha⁻¹) contents were maximum under closer spacing at 5 m × 4 m of poplar based agroforestry system after the harvesting of wheat crop as compared to other spacing and sole crop. The macro-nutrients tended to increase with time due to higher inputs of organic matter with the age of tree. Khan and Choudhary (2007) reported linear relationship of crown development with tree spacing and it increase with the increase in spacing. Although wood production was higher under closer spacing as compared to the wider spacing. It was observed that wood volume contribution per tree was 31.4 per cent more in lower density of 230 trees per hectare as compared to higher density of 455 trees per hectare. While this difference was only 9.6 per cent under a density of 305 trees per hectare.

Likewise Mishra *et al* (2006) reported that available nutrients like N, P and K increased significantly under poplar plantations than open conditions. Nutrient contents were maximum upto depth 0-20 cm and decreased as the depth increased. At depth 0-20 cm, the nutrient contents increased by 10% for N, 6% for P and 2% for K, respectively.

Das and Chaturvedi (2005) studied the concentration of nutrients in soil and plants and their cycling rates under poplar. Although the concentration of nutrients were more in the standing biomass of the crop as compared to the trees but nutrient contents showed overturn trend. Nutrients contents were accounted in soil, vegetation and litter as 80.3-99.5%, 0.4-14.7% and 0.1-5.0% respectively. Significant reduction in nutrient concentration from 40-54% was reported in leaves due to senescence. The annual transfer of litter nutrients by vegetation into the soil was 36.7-146.2% N, 5.6-17.9% P and 25-66% K kg ha⁻¹ yr⁻¹ in the mature plantations (9 yrs old).

Rivest *et al* (2010) observed that intercropping of hybrid poplar with soybean increased the soil microbial biomass, mineral N supply and tree growth. Soybean intercropping also improved nutrient turnover and supply for hybrid poplar trees, thereby increasing the land equivalent ratio (LER). But the grain and straw yield of different varieties of soybean were found less under poplar (3.94 percent) as compare to that control i.e. 9.86 percent (Singh *et al* 2015).

Poonia (2004) studied the impact of *Prosopis cineraria* locally known as Khejri on the soil fertility and yield of kharif season crops. It was reported that the soil underneath the Khejri tree was richer in organic matter, organic carbon and essential nutrients like N, P and K than open fields. Thus tree enhances the growth and yield attributes of the *kharif* season crops.

Sarvade *et al* (2014) evaluated the effect of tree species and their spacing on the yield of the intercrop wheat and soil parameters. Although the reduction in grain yield was recorded in the agroforestry system than control but maximum grain yield was observed in wider spacing of poplar followed by *Leucaena* and *Melia*. Crop growth and yield was highly affected by the competition for light, moisture and nutrient. Application of fertilizers NPK @ 180-60-40 kg ha⁻¹ had significant effect on crop growth and yield as compare to the open conditions.

Sharma *et al* (2005) conducted pot experiment for two years to determine the changes in the different growth parameters and yield of wheat due to occurrence of poplar leaf litter. Two levels of fertilizers (i.e. no fertilizers and full recommended dose of fertilizers, 120 kg ha⁻¹ N, 60 kg ha⁻¹ P and 40 kg ha⁻¹ K) were kept to observe the influence of mulch on performance of wheat in combinations with nutrients. Leaf litter was used as a source of mulch during first two years respectively. The response of fertilizer on the growth and yield of wheat was significantly higher than the treatment without fertilizers. Grain yield increased significantly when 15g per pot of 3 year old poplar leaves were incorporated into soil. Increase in the straw yield was significant when low dose of 10g per pot of 3 year old poplar leaves was used. Enhancement in growth and yield was reported when higher doses of the leaf litter was incorporated in the full combination of mineral fertilizers. The results showed

the higher yield was obtained when poplar leaf litter was applied in combination with the mineral fertilizers.

Kumar *et al* (2017) studied the effect of organic manures and fertilizers on the growth and yield attributes of paddy and wheat under *Casuarina equisetifolia* based agrisilviculture plantations and found that FYM @ 25t ha⁻¹ and fertilizers application of NPK @ 120:60:40 kg ha⁻¹ found effective on the growth of Casuarina, wheat and paddy in both under plantations and control. But the reduction in the yield of wheat and paddy was observed due to the competition for light, moisture, nutrients etc under plantation as compared to control. Significantly higher grain yield of wheat variety NW-1067 with NPK application @ 160:60:40 kg ha⁻¹ has been achieved in open area (29.20 q ha⁻¹) as compared to agri-silviculture system (27.6 q ha⁻¹) respectively, whereas significantly higher grain yield of paddy variety Sarjoo-52 with application of NPK @ 160:60:40 kg ha⁻¹ has been achieved in open conditions (40.70 q ha⁻¹) as compared to agri-silviculture system (38.40 q ha⁻¹), respectively.

Kumar *et al* (2003) studied the effect of three agroforestry systems on changes in soil chemical properties of maize-lentil cropping pattern including old mulberry and peach trees in the mid elevations of Western Himalayas. Measurements for different soil chemical properties upto 30 cm were made before sowing and after harvest of field crops. It was observed that the soil fertility status was higher under agri-horti-silviculture systems followed by agri-horticulture, agri-silviculture and monoculture system. Addition of nutrients like N, P and K was found higher in the agri-horticulture system followed by agri-horti-silviculture, sole cropping and agri-silviculture system. Whereas agrisilviculture systems resulted into more removal of nutrients than other agroforestry systems and monoculture removed minimum among the all three agroforestry systems. Availability of phosphorous declined in all the agroforestry systems although the level of N and K increased.

The compatibility of medicinal and aromatic herb species such as *Digitalis lanata*, *Matricaria chamomilla* and *Salvia sclaria* was studied under poplar plantation spacing 4 x 4 m (Thakur *et al* 2010). No adverse impact on the growth, herb yield and physiological parameters of the medicinal and aromatic plants was observed under poplar plantation. Further the application of fertilizers (N @ 100 kg ha⁻¹) and farmyard manure (FYM @ 4 t ha⁻¹) to the medicinal herbs was found effective in enhancing growth, production ability and photosynthetic efficiency of herbal plants. Growth with respect to height, leaf number, spread, flower number, branch number and leaf area index was significantly higher in fertilizer and FYM treated plots in comparison to control plots. Production increased with the use of fertilizers and FYM even under tree canopies.

2.2 Performance of different agronomic crops under farm grown trees

Poplar based agroforestry system is economically viable and more profitable than the

traditional crop rotation system. Intercropping of poplar with agricultural crops have positive effect on the growth parameters of the poplar. They showed better productivity and growing stock as compared to pure plantations. Mathur and Sharma (1983), Chaudhry *et al* (2003) noticed that production of poplar plantations increased significantly while intercropped with agricultural seasonal crops as compared to the pure plantations. The reason behind was that poplar plantations take advantage from the agricultural crops by drawing nutrients, fertilizers and water content from them.

Tree based microclimate also have pronounced effect on the different sowing time of crops. Gill *et al* (2009) studied the effect of poplar based microclimate on the different wheat varieties sown at different times. It was recorded that the highest grain yield was obtained in mid November as compared to late November and mid December although tiller height, number of tillers, 100 grain weight and spike length of wheat significantly contributed towards higher grain yield in early sown conditions i.e. mid November under poplar irrespective of its age of plantation. Chauhan *et al* (2012) revealed that growth and yield of wheat decreased significantly with the increase in poplar age. The values of micro-meteorological parameters i.e. light intensity and air temperature were also low under plantations than in open condition and decreased with increase in plantation age. The current and mean annual increments in biomass and carbon storage curves exhibited a sharp increase up to three years which thereafter increased with decreasing rate. Gill *et al* (2009) found that the number of tillers and tiller height of wheat was significantly more under open conditions than under poplar and gradually decreased with the delay in sowing time from early November to mid December. McMaster *et al* (1987) observed that greater tiller mortality resulting in fewer spikes per plant caused by the shading (50% of ambient light) after one week of anthesis. Similarly Kemp and Whingwiri (1980) found that shading around 20% of full sunlight before anthesis resulted in reduced tiller number in wheat as compared to control. Satish *et al* (2003) studied the effect of shading on different wheat varieties under *Eucalyptus* plantations and reported that grain yield of wheat decreased significantly with the increase in shading effect of *Eucalyptus* plantations on eastern side of the wheat field. Singh *et al* (1998) found that crop density, root and shoot length, biomass and grain yield of wheat were significantly lower in the fields sheltered by *P. deltoides* than in unsheltered one.

Inspite of reducing number of tillers and tiller height per plant due to shading effect, it was observed that germination, plant height and biomass of the crops reduced from 10 to 30% at 30 and 60 days interval of sowing in the poplar as compared to the one without the poplar (Singh *et al* 2001). The reduction in the different parameters of the crops i.e. plant height, grain yield, straw yield of different wheat varieties was increased significantly as the tree-crop competition increased for the light, moisture and nutrients with the advancement in the age of the poplar trees (Chauhan *et al* 2011). It was reduced up to 23.3% under poplar as

compared to the sole cropping (Rahlan *et al* 1992).

Chauhan *et al* (2011) studied the productivity and carbon sequestration potential of poplar-wheat agroforestry system. The grain and straw yield was reduced from 14 to 64% and 13 to 66% under poplar block plantation than open conditions. The annual productivity of poplar was increased from 1st yr to 4th yr and reached the maximum and then start decreasing from 42.4 m³/ha/yr to 35.6 m³ /ha/yr from 4thyr to up to 6th yr. But the organic matter and carbon storage potential was recorded maximum under poplar plantations as compared to the sole crop. Similarly, Sarvade *et al* (2014) evaluated the effect of different tree species such as Poplar, *Leucaena* and *Melia* and their spacing on soil properties and yield of intercrop wheat (variety PBW-502). The reduction in the grain yield of intercrop wheat was ranged from 16 to 62% under agroforestry systems as compared to control. The maximum yield was observed under open conditions. Among the different tree species, the highest grain yield and organic carbon was recorded under poplar followed by *Melia* and *Leucaena*.

Kumar *et al* (2013) studied the performance of two crops i.e. wheat and mustard under two and half years old plantation of *Eucalyptus tereticornis* planted at spacing 6×2m. The parameters such as spike length (7.7 cm), test weight (26.7 g) and grains per spike (37.7) were significantly higher under sole cropping than under *Eucalyptus tereticornis* plantation whereas the growth parameters like primary branches per plant and seeds per siliqua (in mustard) were significantly less under Eucalypt. The grain and straw/stover yields of both the crops (wheat and mustard) under *Eucalyptus* decreased significantly as compared to sole cropping. Reduced value of yield parameters of both crops may be attributed to struggle for light, moisture, nutrients and allelopathic effect of *Eucalyptus* tree plantation. Grain yield reduction was up to 63.2%. Net returns from crop grown with *Eucalyptus* and sole cropping revealed that higher income was recorded in sole cropping of wheat (Rs 46,620/ ha) than the wheat- *Eucalyptus* agroforestry system (Rs 1,890/ ha).

Kiran and Agnihotri (2001) observed that biological and grain yield of wheat was reduced significantly under the canopy of *Dalbergia sissoo* and it ranged between 69.24 to 79.86 and 71.58 to 88.90 percent respectively than control. Likewise Kiran (2001) studied the reduction in biological and grain yield of wheat under canopy of *Eucalyptus tereticornis* and observed reduction of 69.13 to 57.17 percent where biological and grain yield under control was 71.54 to 49.16 percent. Kumar and Nandal (2004) observed that performance of all the test crops including wheat sown in the interspaces of *E. tereticornis* based agrisilviculture showed reduced plant vigour in terms of plant height, number of branches, stem diameter and yield attributes as compared to crop sown in control. The yield of the wheat was decreased up to 62.3 percent under *Eucalyptus* as compare to that in control.

Kumar and Tewari (2004) studied the effect of different poplar spacings on the grain yield of the wheat. The effect of different spacings of poplar was also seen on the growth

parameters of poplar. Tree volume, diameter at breast height and tree height was recorded maximum under spacing 5×4 m and with the increase in the density of poplar plantation, tree height was also increases. Likewise, grain yield of wheat was recorded maximum under spacing of 5×2 m and it increased under spacing 5×10 m followed by 5×4 m spacing.

As the crop distance increased from the tree lines the effect of tree based microclimate decreased significantly. Singh *et al* (1998) revealed that the as the distance of the crop from the poplar tree line increased, the crop density, root and shoot length, biomass and grain yield of wheat were improved effectively and beyond 12 m it was similar to that in the unsheltered fields. Similarly Kohli *et al* (1990) observed that root and shoot growth, plant density, biomass and economic yield of different wheat varieties was depressing up to 11 m and beyond 11 m no influence of *Eucalyptus* was recorded. Rao *et al* (2016) also revealed that plant height and straw yield of different varieties of wheat and rice were found significantly higher as the crop were grown 1m away from the *Dalbergia sissoo* tree base line. The concentration of different nutrients i.e. N, P and K as well as their uptake in wheat plants was observed minimum near the tree line (0-3 m) and increased subsequently with increase in distance from tree line (Sharma *et al* 2012).

Chauhan *et al* (2008) studied the performance of different maize varieties under various tree spacing of Poplar. As the distance between the rows of trees increased, growth parameters of maize and tree also increased. A significant increase in the DBH, plant height, crown height and crown diameter of poplar and grain yield of maize was recorded. The growth parameters of poplar and maize gradually decreased as spacing between the tree rows decreased. This decrease was recorded maximum at spacing 4m×6m. Reduction in grain yield of different maize varieties was found in ranged from 35.22 percent to 21.66 percent grown under 4m×6m spacing of poplar.

Chauhan *et al* (2012) studied the wheat and paddy (rice) yield with respect to aspect as well as distance from the base of poplar tree lines in all the four directions. The results showed that wheat and paddy yield was maximum on Southern aspect as compared to Northern aspect. Distance from tree base also played a significant role on the yield of grain crops. The yield of wheat as well as paddy increased with the increase in distance from the boundary tree lines. However, in control conditions wheat and paddy yield was 4.47 t ha⁻¹ and 6.96 t ha⁻¹, respectively. There was a decrease of 33.75 per cent and 36.15 per cent in paddy and 26.68 and 25.69 per cent in wheat respectively under 5th and 6th year old poplar boundary plantation than the control.

2.3 Performance of high value crops under agroforestry systems

The diversification of crops under poplar canopy itself is essential to harness higher income than poplar-wheat model. It is important to explore the possibilities of low volume high value crops for the economic betterment. Therefore, crops other than wheat have equally

been advocated excepting rice to ensure regular/enhanced income and indirect benefits. Sharma (1996) studied that almost any crop (cereals, pulses, vegetables, forage, fruit/vegetable crops etc) can be grown successfully under agroforestry systems. Dinssa (1993) studied the growth and yield of soybean, black gram, horse gram and cowpea under intercropping with *Morus alba*. It was observed that growth and yield of legumes reduced as intercrops as compared to their performance as sole crop. The yield of wheat was also significantly reduced under *Paulownia*.

Chauhan and Dhiman (2003) studied the yield and quality of sugarcane under poplar based rainfed agroforestry systems and revealed that significant differences in growth rate of different poplar clones grown with sugarcane were observed. Sugarcane varieties Coj 64 and Co 7717 proved to be superior for cane yield having yield around 116.5 t ha⁻¹ and 116.9 t ha⁻¹ respectively. Although PD 3294 clone of poplar was inferior in tree height (13.1 m) and diameter at breast height (13.6 cm) as compare to other clones such as PD G 3, PD G48 and PD 1/56 at 4 year age.

Singh *et al* (2014) studied combination of different silvicultural species i.e. *Ailanthus excelsa*, *Prosopis cineraria* and *Colophospermum mopane* with horticultural crops namely *Ziziphus mauritiana*, *Cordia myxa* and *Embllica officinalis* and intercropped with wheat (*Triticum aestivum*). The combination of *Z. mauritiana* + *P. cineraria* produced greater fruit, fodder, fuel wood and imposed less competition to the wheat crop. But crop yield was reduced significantly from 5% to 23% under agroforestry system than sole crop. The lowest yield was observed in the *Colophospermum mopane* + *Cordia myxa* combination. Fodder yield was reduced from 0.53, 0.20 and 0.07 t ha⁻¹ from *C. mopane*, *P. cineraria* and *A. excelsa*, respectively, whereas the highest exploitable biomass was obtained from *C. myxa* + *P. cineraria* (2.63 t ha⁻¹) followed by *C. myxa* + *C. mopane* (2.21 t ha⁻¹) and *Z. mauritiana* + *P. cineraria* (2.18 t ha⁻¹) combinations. Availability of Soil organic carbon and NH₄-N increased from 7% and 8% respectively in the sole crops whereas PO₄-P and NO₃-N decreased in agroforestry. *Z. mauritiana* + *P. cineraria* were the best arrangement with minimum yield reduction and were found to be valuable in enhancing soil fertility.

Mishra *et al* (2006) evaluated the productivity of soybean and wheat under five promising clones of *Populus deltoides* in agri-silviculture system. Soybean grain and straw yield was reduced significantly with the increase in the age of poplar tree. The yield reduced was from 1.3 to 14.2 percent within 4th and 5th yr plantation as compared to sole crop. Maximum grain yield reduction was found in the clone G3 followed by G48, 65/27, D121 and S7C1. In contrary soybean, wheat yield increased by 4.1 to 10.3% as the age of the poplar clones increased from 5th to 6th yr. The wheat yield was recorded maximum under clones G3 and S7C1, whereas it was lowest under clone G48. It was reduced from 15 to 30.3 percent under different clones. The straw yield also showed similar decreasing trend. The decreasing

trend in the grain and straw yield of wheat in clones was found in order G3 < S7C1 < D121 < 65/27 < G48. The content of available nutrients improved by 14.9 to 24.1% for N, 17.2 to 23.3% for P and 3.1 to 5.1% for K under different clones. The growth parameters of poplar also increased as the age increased. It was recorded that tree height increased from 11.1 to 14.5 cm and diameter at breast height (dbh) increased from 13.3 to 21.6 cm in 6 year-old clones. Both dbh and tree height were maximum in 65/27 and minimum in clone S7C1.

Kumar and Nandal (2004) studied the effect of Eucalyptus based agroforestry system on the different winter season crops such as wheat, berseem, potato, mustard and lentil grown as inter-crop. It was found that the vigour and yield of all intercrops reduced under plantations as compared to monocrop. There was least reduction in the lentil yield as compared to the other intercrops. From the economical point of yield, wheat was found to be the most efficient crop under *Eucalyptus* based agroforestry system.

Vanlalngurzauza *et al* (2010) conducted the experiment on different intercrops grown under *Gmelina arborea*. It was observed that yield of different intercrops i.e. rice, cowpea, groundnut and black gram under gamhar (*G. arborea*) based agroforestry system has been increased. Further the growth parameters i.e. height, DBH, volume of trees was the highest when grown with black gram and the lowest with cowpea. Singh and Singh (2001) observed the effect of three tree species such as *Eucalyptus tereticornis*, *Acacia nilotica* and *Populus deltoides* on the performance of turmeric (*Curcuma longa*). The mean germination count of turmeric was maximum when grown in association with *Acacia* and minimum in the open conditions. The mean height attained by turmeric was the highest under *Eucalyptus* and the lowest under poplar. The yield of turmeric was the highest in *Eucalyptus* as compared to poplar and *Acacia*.

Babu (2012) studied the growth and yield of two winter vegetables i.e. chilli and sweet gourd under different spacing of *Eucalyptus* tree. It was observed that yield of vegetable crops increased as the distance from *Eucalyptus* tree increased gradually. Thus the boundary plantation of *Eucalyptus* was observed to have a negative impact on the growth of vegetable crops.

Bisht *et al* (2000) studied the performance of ginger (*Zinger officinale*) and turmeric (*Curcuma longa*) under different fodder tree species such as *Grewia optiva*, *Celtis australis*, *Quercus leucotrichophora* and *Bauhinia variegata*. Different yield of turmeric and ginger was observed under different fodder tree species. The results showed that the yield of turmeric and ginger was significantly high under the *Q. leucotrichophora* i.e. 12.04 t ha⁻¹ and 7.98 t ha⁻¹. Negative correlation between the light intercepted by the trees and yield of ginger and turmeric was observed. Thus, *Q. leucotrichophora* was found to be the most suitable intercropping tree species with turmeric and ginger. LAI (leaf area index) acts as indicator of biomass productivity. It is an important determinant of biomass production and yield of short

rotation bio-energy plantation. An accurate measurement of LAI is critical for quantifying light interception and penetration within the canopy and subsequently understanding its influence on the stand carbon and energy balance. The specific leaf area was maximum in uncoppiced ($38.9 \text{ cm}^2\text{g}^{-1}$) as compared to coppiced ($126.9 \text{ cm}^2\text{g}^{-1}$) plantation (Tripathi *et al* 2016).

Rahman (2004) studied different morphological characters i.e. number of branches, number of fruits, fruit length, fruit diameter of different vegetable crops viz. tomato, brinjal and chilli. Among the different agroforestry systems, the highest yield was obtained in *Terminalia chebula*-lemon-vegetable based agroforestry system. An experiment was laid out to evaluate the varietal differences in onion and garlic yield when grown with or without mulch in three year old poplar plantation at spacing 5 x 5 m (Dhiman and Gandhi 2010). Garlic was sown in 48 beds of 10m x 2m and onion was sown in 32 beds of same size. In the replicated experiment, no significant difference in the yield of garlic between the plots under poplar and in open condition was observed. However there was significant difference in case of onion yield showing a decrease from $48.37 \text{ q acre}^{-1}$ under open condition to $38.42 \text{ q acre}^{-1}$ under poplar plantation.

Krishna *et al* (2011) conducted an experiment on performance of vegetable cowpea in Jatropha based cropping system during *kharif* season. Among the three different Jatropha tree spacings, growth and yield of cowpea was higher when grown in the interspaces of Jatropha trees spaced at 4m x 3m. Plant height, number of leaves per plant, vegetable pod yield, net returns and B.C ratio (Benefit cost ratio) were found maximum with application of 30 kg N ha^{-1} + azotobactor followed by 20 kg N ha^{-1} + azotobactor when compared to other nutritional treatments.

Gill *et al* (2008) studied the performance of different crops such as turmeric, *Tagetes minuta*, celery, *Tagetes minuta*, coriander, fennel, fenugreek, *Mentha arvensis*, sarson (*Brassica napus* L.), wheat and *Mentha spicata* in compact poplar plantation (clone 'Udai') with spacing 5m x 4m. Results showed that with increase in the age of poplar the yield of the inter- crops decreased. The decline in yield was more in crops like *M. spicata* (65%), *Mentha arvensis* (64.9%), coriander (26.7%) and *Tagetes minuta* (16%) but minimum loss was in dillseed (12.6%), fennel (6.8%), fenugreek (7.1%), wheat (4.75%), lemongrass (2.6%), sarson (1.84%) and turmeric (1.1%). During 2nd yr, the decrease in the yield of *Mentha arvensis* (60.5), *M. spicata* (50.0), fennel (43.9), turmeric rhizome (40.6), fenugreek (37.4), sarson (34.4), wheat (32.7%), seed of coriander (28.1), dillseed (27.6), *Tagetes minuta* (7.50) and lemongrass (6.55) was observed in dense poplar plantation.

2.4 Onion: an important vegetable crop

Onion (*Allium cepa* L.) is an important bulbous crop belongs to the Alliaceae family. It is grown throughout the world for its nutritive value and pungency. In India, it is grown

from the ancient time. The crop is grown for both green vegetable and mature bulbs. It is grown as an annual for bulb production and biennial for seed production. It is popular as salad crop and widely used in cooking of vegetables, as flavoring agent in many dishes. The outstanding characteristics of onion is its pungency i.e. due to the presence of "Allyl-propyl disulphide". Because of its importance in culinary it is known as "queen of the kitchen" by Germans.

It is a generally a photo-thermo sensitive crop is extensively affected by climate aberrations. Being a cool season crop, it perform well during winter season followed by early part of summer season. In onion, bulb initiation takes place at 20-25°C day and 10-15°C night temperatures. Best range of temperature for bulb development is around 15-20°C night and 25-30°C day temperatures. For maturity, day temperature ranged between 35-38°C is required. High night temperature above the critical level during bulb initiation leads to poor bulb development. Very low temperature (< 10°C) during bulb development caused bolting in onion. Excessive high temperature (> 42°C) at the time of maturity (April-May) results into the heavy reduction in bulb size and reduces its storage life. In onion, warmer temperature also affects growth rate.

In general, it was observed that increase in average temperature by 1°C results into decreased bulb yield by 3.5-15% while an increase in CO₂ levels from current ambient levels to 530 ppm, results into increase in bulb yield by 30-50%. In addition to temperature, clear sunshine, optimum humidity also play an important role in productivity of onion. Clear sunshine about 12-13 hours during bulb development and maturity, 500-600 mm well distributed rainfall and humidity between 65-75% ensures good crop growth. Cloudy weather and excessive rainfall in *kharif* and late *kharif* season cause heavy crop failures up to 60-70%. The fungal and soil borne diseases are also very high during *kharif* season.

2.4.1 Performance of onion under open conditions

Gadge and Lawande (2012) conducted a survey to study the effect of climate change on the onion in the Ahmednagar and Pune districts of Maharashtra. It was observed that the major constraints faced by 73 percent farmers of the area was erratic rainfall at the time of the harvesting of *kharif* onion and nursery preparation of the *rabi* onion. The *kharif* onion was affected by 30-40% which was ready for harvest, late *kharif* affected by 15-20% which was planted in Sept-Oct and *rabi* nursery damaged by near 20-25%. It has also been found that the *kharif* crop planted in flat beds gets damaged by *Anthraco* disease due to water stagnation. Foliage damage by *Colletotrichum* and bulb development was affected due to soil borne diseases like bulb rot.

Lal *et al* (2018) assessed the impact of climate change on the seed yield of the onion crop in the Himachal Pradesh. The onion seed yield data for 26 years and meteorological data for 30 years were collected; regression and correlation analysis among different weather

parameters (temperature, RH and rainfall) and onion seed productivity was prepared for productivity trend analysis. Climate based crop yield forecast model equation was constructed and maximum accuracy of 69 per cent of crop yield was predicted. It was revealed that over the last 26 years, onion seed productivity showed a variable pattern with which as a whole decreasing trend at the rate of $2.58 \text{ kg ha}^{-1} \text{ yr}^{-1}$. Weather variability analysis indicated decrease in total rainfall (57.02 mm and 183.14 mm) and increase in average temperature (0.60°C and 0.46°C) during 1995-2004 (decade-1) and 2005-2014 (decade-2), respectively over the baseline (1985-1994). While, an increase of 0.03% in relative humidity (RH) showed during first decade and decrease of 3.39% during second decade over the baseline. It is concluded that the variable climatic conditions negatively affected the onion seed production in the mid Himalayan region of the Himachal Pradesh.

Khokhar (2017) studied effect of environment and genotype on the bulb development of onion. Various environmental and genetic factors influence growth and development of onions by affecting their physiology. Photoperiodism plays an important role in development of bulb. It also helps to determine the suitability of a particular cultivar for a specific region. Bulb development promotes by the long day and high temperature and it is more regulated by temperature than photoperiodism, as Far-red light stimulates bulb development most efficiently. Storage of sets at high temperature ($> 20\text{--}25^\circ\text{C}$) results into better total bulb yields, while very high temperature ($25.5\text{--}31^\circ\text{C}$) or lower temperature ($< 0^\circ\text{C}$) results into decreased yield. Plant density also affects the bulb size. An inverse relationship was observed i.e. the higher the plant density the smaller will be the size of bulb. Onion is very sensitive to water stress conditions during bulb formation than the vegetative stage. Nitrogen helps to improve bulb development, but excessive use of nitrogen promotes vegetative growth and delays maturity. Gibberellins and ethrel growth hormones promote the growth and bulb development.

2.4.2 Effect of planting dates on the growth and yield of onion

The growth and yield of cultivated crop plants mainly depends upon two principle factors *viz.*, genetical and cultural/ management factor. Genetical factors includes various breeding techniques for the perfection in different crop varieties. The second one deals with cultural practices *viz.*, spacing, planting date, planting techniques, irrigation, fertilizer, plant protection, cultivation, weed control etc.

Planting date is one of the main factor which affects the growth, quality and yield of the crop as a climatic factor. Various climatic factors such as atmospheric temperature, day length and humidity influence the yield of onion bulbs. Sowing of seeds and transplanting time of onion seedlings is vary from region to region. In Punjab, nursery is sown in month of October to the mid of November and transplanted in mid of December to January. In various parts of Maharashtra, October is the best sowing time of nursery and transplanting in the

month of November for *rabi* season. Khokhar *et al* (2002) studied the effect of planting and seedling times on quality and bulb yield of onion cultivar Phulkara during autumn season in 2000. The sets and bulb of seedlings were graded in three sizes of 7.5 mm, 12.5 mm and 17.5 mm diameter and 2.5 mm, 3.5 mm and 4.5 mm diameter, respectively sown on two different dates 1st September and 15th August 2000. The highest mean saleable bulb yield (21.2 t ha^{-1}) was observed using diameter set size 17.5 mm and seedling with 4.5 mm diameter bulbs. However, the crop sown on 1st September 2000 with 17.5 mm diameter seedling produced significantly highest profitable bulb yield of 24.6 t ha^{-1} .

Nayee *et al* (2009) studied the influence of various type of planting materials and different planting dates on growth and bolting of *Kharif* onion (*Allium cepa* L.) cv. Agri Found Dark Red. There were 12 treatments consists of four planting materials *viz.*, seedling, 1.5 – 2.0 cm, 2.0 – 2.5 cm, 2.5 – 3.0 cm and 3.0 – 3.5 cm size onion sets and three planting dates *viz.*, 10th, 20th and 30th July. On the basis of collective data, relationship between different growth characters, various planting materials and different planting dates showed that the maximum plant population was found in planting date 30th July and planting material 3.0-3.5 cm size onion sets, while maximum neck thickness and plant height of plant was found with planting date 20th July and planting material 2.5-3.0 cm size onion sets. Number of leaves per plant and bolting percent remain unaffected with combination of various planting materials and different planting dates.

Jilani *et al* (2010) studied the performance of two onion cultivars *viz.*; Phulkara and Naurang Local at different plant spacing (10, 15, 20 and 25 cm). The data on number of leaves/plant, leaf length, bulb weight, bulb diameter, bulb yield/plot, plant height and total yield (t ha^{-1}) were recorded. Significant variations were found for two onion cultivars and different plant spacing for all the parameters studied. Phulkara cultivar showed better results in all the parameters against Naurang Local as it produced bulb weight (56.40 g), plant height (52.98 cm), maximum leaves per plant (9.63), bulb diameter (5.25 cm), bulb yield per plot (2.89 kg), leaf length (46.32 cm) and total yield (10.78 t ha^{-1}). Amongst plant spacing, the widest plant spacing (25 cm) produced the maximum plant height, leaves per plant, bulb diameter, and bulb weight but it reduced the total yield and yield/plot. However, closest plant spacing (10 cm) gave significantly higher total yield and yield/plot and. Overall the better yield, cultivar Phulkara with closer plant spacing (10 cm) is recommended.

Kandil *et al* (2013) assessed the effect of different transplanting dates on vegetative growth, yield and quality of some local cultivars of onion during two seasons 2010-11 and 2011-12. Results indicated that onion seedlings transplanted on 15th December resulted into the highest total yield, average bulb weight, average of foliage fresh weight/plant at 90 and 120 days from transplanting, marketable yield, dry matter, total soluble solids and total weight loss percentage of onion bulbs. Highest bulbing ratio after 90 and 120 days from

transplanting, total yield, total cull, marketable yield and bulb weight as well as total weight loss percentage of onion bulbs were produced from Texas Early Yellow Grano X Giza 20 cultivar. A significant interaction was observed between transplanting dates of some onion cultivars in foliage fresh weight/plant at 90 days from transplanting, total culls and marketable yield. It can be concluded that, seedlings of Texas Early Yellow Grano X Giza 20 cultivar transplanting on 15th December or 1st January showed maximum productivity and bulb quality under the environmental conditions of Egypt.

2.4.3 Variety evaluation

Dawar *et al* (2007) evaluated the effect of three planting densities viz; 40, 60 and 80 plants/4m² on varieties of onion namely Terich-02, Swat-1 and Gilassi Local. The results showed that lower planting density (40 plants/ 4m²) had significant effect on the number of leaves per plant (14.80) and large bulbs weight (720.29 g), while medium planting density (60 plants/ 4m²) had significant effect only on weight of double bulbs (609.39 g). Higher planting density had significantly improved the weight of small bulbs (738.11 g), single bulbs weight (1774.00 g), leaf length (52.51 cm), weight of medium bulbs (958.50 g) and total yield of bulbs (7072 kg ha⁻¹). The results indicated that Terich-02 had shown good performance over the Swat-1 and Gilassi Local with regard to single bulbs (1515.44 g), higher weight of medium bulbs (995.00 g), double bulbs (552.00 g) and large bulbs (742.39 g). Higher weight of small bulbs (483.67 g) and greater leaf length (51.87 cm) were observed in Swat-1, while Gilassi Local showed poor performance for all the growth parameters except for number of leaves per plant which were significantly higher (15.22) among the other varieties. The significant interaction between planting density and varieties was only for bulb yield. Maximum yield was produced by Terich-02 (7958 kg ha⁻¹) at a maximum plant density (80 plants/4m²).

Gautam *et al* (2006) evaluated the performance of different varieties of onion namely N-53, LR-241, Red Creole and Nasik Red with four transplanting dates 25 July, 5 August, 15 August, and 25 August for the off season production in the mid hills of Nepal. Data was recorded for the different parameters viz. neck thickness, plant height, diameter and length of bulbs, plant stand at maturity, yield of green bulbs and green tops. The varieties showed the significant variation only among the fresh bulb weight. Transplanting dates showed a significant variance on the plant stand at maturity, plant height and marketable bulb production. The highest fresh bulb yield was obtained from variety N-53 (16.63 t ha⁻¹). Likewise, transplanting date (August 15) produced the maximum bulb yield (15.31 t ha⁻¹) amongst four different transplanting dates.

Demisie and Tolessa (2018) studied the effect of four onion varieties (Nafis, Adama Red, Nasik Red and Melkam), intra-row spacing (7, 10 and 13 cm) and their possible interaction on growth and yield of onion in Jimma, South Western Ethiopia. The results of the

study showed that different varieties and intra-row spacing had a significant effect ($P < 0.05$) on all parameters of onion, except for the leaf diameter i.e. affected by intra-row spacing. Number of leaves per plant was considerably influenced by interaction between variety and intra-row spacing. The highest leaf number (13.9) with intra-row spacing 13 cm achieved from variety Nafis. Overall, number of leaves per plant, plant height, leaf length and leaf diameter were maximum at wider intra-row spacing (13 cm). Variety Nafis showed the higher results in terms of number of leaves per plant (13.9), average bulb weight (74.50g), bulb diameter (5.67 cm), marketable yield (36.26 t ha^{-1}) and total bulb yield (36.28 t ha^{-1}). Onion seedlings grown at closer intra-row spacing (7 cm) showed higher average bulb weight, marketable yield and total tuber yield.

Sharma *et al* (2014) evaluated ten varieties of onion to identify the most promising varieties to be grown under low hill conditions of Himachal Pradesh. Data was recorded for different parameters such as number of leaves per plant, bulb diameter, plant height, neck thickness, number days to harvest, bulb weight, TSS and total yield. In addition, all the varieties were also tested for resistance against purple blotch disease which is most common fungal diseases of onion. It was observed that variety Holland Louis took maximum number of days to harvest (129.33 days) while variety Agrifound Rose exhibited minimum number of days to harvest (109 days). Varieties Palam Lohit (275.00 q ha^{-1}), Nasik Red (240.67 q ha^{-1}), N-53 (239.25 q ha^{-1}) and Agrifound Dark Red (232.37 q/ha) recorded significantly higher bulb yield than the other varieties evaluated. None of the varieties was showed complete resistance against the disease, however, 'Agrifound Dark Red' resulted into moderately resistant, showing just 13.78% disease incidence. Varieties Nasik Red, Palam Lohit and Agrifound Dark Red had shown medium bulb size and higher yield.

Hirave *et al* (2015) studied the performance of eight red onion varieties namely Agrifound Dark Red, Phule Samarth, Baswant-780, N-53, Pune Red, Bhima Super, Bhima Raj and Bhima Red replicated three times in *khariif* season under Akola conditions of Maharashtra. Varieties of red onion showed significant variation for morphological characteristics. Results showed that the variety N-53 produced the maximum plant height (66.87 cm) while varieties Bhima Red and Phule Samarth were at par in terms of bulb diameter (6.61 and 6.36 cm), number of leaves per plant (14.33 and 14.20 cm), fresh bulb weight (110.95 and 106.28 g) and cured bulb weight (99.53 and 95.30 g). Whereas the variety Pune Red showed the minimum (0.87 cm) neck thickness which was at par with varieties N-53 (0.93 cm), Baswant-780 (1.03 cm) and Bhima Super (0.97 cm). The maximum marketable yield per hectare ($328.57 \text{ quintal ha}^{-1}$) was recorded in cultivar Bhima Red which was at par with two cultivars Bhima Super ($269.83 \text{ quintal ha}^{-1}$) and Bhima Raj ($298.41 \text{ quintal ha}^{-1}$). Agrifound Dark Red showed the highest TSS ($11.47 \text{ }^\circ\text{Brix}$) content which was at par with Phule Samarth ($10.50 \text{ }^\circ\text{Brix}$). The highest bolting percentage was recorded in Bhima Red

variety Thus, it was concluded that cultivar Bhima Red and Bhima Raj performed better under Akola region in *kharif* season.

Dwivedi *et al* (2012) studied eight improved cultivars of onion Arka Niketan, Pusa Hybrid 107, VL-1, Pusa Red, VL-3, Arka Kalyan, Pusa White flat and Pusa Hybrid 102 to determine their growth, yield and quality under agro-climatic conditions of Kymore plateau region of Madhya Pradesh in the year 2011. The study revealed that variety Pusa Hybrid 102 showed significantly maximum yield along with the highest plant height, maximum number of leaves per plant, bulb diameter, bulb weight and dry matter content followed by variety Pusa White flat, Pusa Red, VL-3, Arka Niketan, Pusa Hybrid 107, VL-1 and Arka Kalyan.

Sarada *et al* (2009) studied the performance of eight different cultivars of onion. During the *rabi* season of 2000-03, Agrifound Dark Red, Agrifound Light Red, Arka Niketan, Arka Kalyan, Arka Pragati, Pusa Red, N 53 and Nasik Red in black soils in the Krishna-Godavari zone of Andhra Pradesh, India, was evaluated. The cultivars significantly varied in growth and yield parameters. Arka Kalyan produced the tallest plants (61.14 cm). Arka Niketan and Arka Kalyan were superior in terms of number of leaves per plant (16.7 and 15.4 respectively), bulb diameter (5.78 cm and 5.52 cm) and yield (25.49 t ha⁻¹ and 24.27 t ha⁻¹). Bulb length was greatest in Arka Niketan (6.0 cm) and Arka Pragati (5.9 cm). The highest bulb weight was recorded for Arka Niketan, Arka Kalyan and Arka Pragati (75.01, 71.91 and 67.02 g). The results indicated that Arka Niketan and Arka Kalyan were the most suitable for cultivation in the Krishna-Godavari Zone under *rabi* season.

Sarkar *et al* (2015) studied the behaviour of seven onion hybrids namely Nasik Red, Pusa Red, Agrifound Dark Red, Mathahari (H), N-53, Red Gold (H) and Lucifer (H) against the local cultivar namely Local Red during *Rabi* season for two years under agro-climatic conditions of West Bengal. The results showed that the hybrid Red Gold showed the maximum plant height, bulb diameter, number of leaves per plant, average bulb weight, TSS and dry matter content of bulb along with maximum bulb yield (22.45 t ha⁻¹) followed by Mathahari (19.58 t ha⁻¹) placed at next to it and Lucifer (18.94 t ha⁻¹) while Agrifound Dark Red (17.93 t ha⁻¹), N-53 (17.75 t ha⁻¹), Nasik Red (16.62 t ha⁻¹) and Pusa Red (16.12 t ha⁻¹) showed moderately high yield, respectively. The cultivar Local Red produced the lowest bulb yield of 12.40 t ha⁻¹. On the basis of bulb size, dry matter and bulb yield along with the genetically superior genotypes and storage qualities the cultivars Red Gold and Mathahari were recognized as promising ones for commercial cultivation of onion in *rabi* season under agro-climatic conditions of West Bengal.

Mustaq *et al* (2013) studied the productive and quality parameters of nineteen cultivars of onion under agro-climatic conditions of Faisalabad, Pakistan. Variety Desi Red showed the maximum bolting percentage (46.67%) that means it requires less vernalization followed by minimum bolting percentage was noticed in Faisal Red and VRIO-6 (13.33%).

The cultivar Phulkara produced larger bulb size (73.22 mm diameter) as well as maximum bulb yield (21.90 t ha⁻¹) and bulb to neck diameter ratio (6.75). Similarly, maximum weight loss during curing was noticed in VRIO-6 (6%) followed by Phulkara (4.83%), Pusa Red (4.76%) and Desi Red (4.64%). Therefore, overall results indicated that both Desi Red and Phulkara are outstanding for processing purposes while Dark Red for cooking purposes under agro-climatic conditions of Faisalabad.

CHAPTER-III

MATERIAL AND METHODS

The present investigation entitled, “Effect of poplar based microclimate on intercultivation of onion” was carried out at the experimental area of the Department of Forestry and Natural Resources, College of Agriculture, Punjab Agricultural University, Ludhiana during the year 2016-17 and 2017-18. The details related to experimental site, material used, methodology adopted and observations recorded during the course of investigations are described in this chapter.

3.1 Experimental site

3.1.1 Location

The experimental site was located in the main Research Area of Department of Forestry and Natural Resources, Punjab Agricultural University, Ludhiana. It is situated at an elevation of 247 m above the mean sea level and lies at 30⁰54' latitude and 75⁰40' longitude, which represent the central agro climatic zone of the state.

3.1.2 Climate

The climate of the region is typical subtropical to tropical with long dry season from late September to early June and wet season from July to early September with hot desiccating winds in summer (May-June) and severe cold in winter with occasional ground frost (December-January). May and June are the hottest months with intensive evapo-transpiration losses whereas December and January are the coldest months. Generally from October to July, dry conditions prevail in the region of the experimental site, except for few light showers received from north- western depressions during the winters.

3.2 Experimental layout

The experiment was conducted in the field during December 2016 to May 2017 and December 2017 to May 2018 with the following details:

Poplar clone: L-47/88, Age: 2 and 3 years, Spacing: 8×2.5 m (N-S direction row spacing)

There were 36 treatment combinations of following three factors:

Main-Environment

- i) Poplar
- ii) Open (sole crop)

Sub- Planting time

- i) End-December
- ii) Mid-January
- iii) End-January

Sub-sub: four varieties

- i) PUNJAB NAROYA

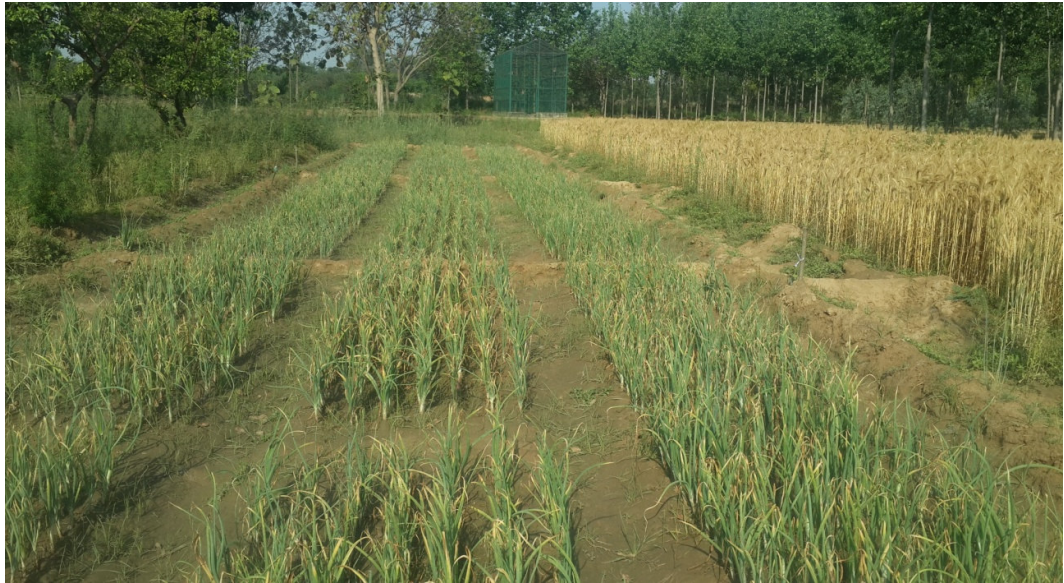


Plate 1 : General view of an experimental site

- ii) PRO-6
- iii) PWO-35
- iv) PRSC-10

Experimental plot size- 2.7×2.5 m (in-between tree rows)

No. of plots- 36

Design- Split-Split plot design

Replications- Three

3.3 Observations recorded

3.3.1 Soil characteristics

Before sowing the experimental crop, composite soil samples were taken from the randomly selected sites of the experimental field at depth 0-15cm. After sun drying, sample were ground, sieved through 2 mm size of sieve and analyzed for the determination of pH, Electrical Conductivity (EC), Organic Carbon (OC) and available N, P and K of the soil. The physical properties indicated that the soil of the experimental field was loamy sand in texture. Chemical analysis of the soil along with method used for the determination are presented in Table 3.2.

3.3.1.1 Soil physical and chemical properties

Table 3.1 Soil texture of the experimental field

Soil particles	Percentage
Sand	82.8
Silt	11.4
Clay	5.8
Textural class	Loamy sand

Table 3.2 Chemical properties of experimental field

Soil property	Soil depth (0-15cm)	Rating	Method used
pH	8.3	Slightly saline	1:2 soil-water suspension (Jackson 1967)
Electrical conductivity (ds/m)	0.18	Normal	1:2 soil-water suspension with solubridge conductivity metyer (Jackson 1967)
Organic Carbon (%)	0.15	Low	Walkey and Black's rapid titration method (Walkley and Black 1934)
Available N (kg/ha)	285	Medium	Alkaline potassium permanganate method

			(Subbiah and Asija 1965)
Available P (Kg/ha)	28.8	Medium	0.5 N Sodium bicarbonate method (Olsen <i>et al</i> 1954)
Available K (kg/ha)	270	Medium	1 N Ammonium acetate method (Jackson 1967)

3.3.2 Tree growth parameters

Various tree growth parameters such as tree height, tree diameter, crown spread and leaf fall pattern were recorded using the basic methodology as explained below.

3.3.2.1 Tree height (m)

Height of the trees was measured in metres (m) from ground level to the tip of the main shoot of the trees with the help of Ravi's multimeter. The height of all of the trees from two tree rows, in which the onion crop intercultivated studied, was recorded. Height was recorded during the time period when the trees were leafless to avoid errors.

3.3.2.2 Diameter at breast height (cm)

The diameter at breast height (dbh) was measured in centimetres (cm) with the help of digital caliper at 1.37 m above the ground level, both at the start as well as near the termination of the experiment. The measurements of dbh were taken in two different directions perpendicular to each other and average dbh was calculated. Precautions were taken that the point of measurement was clean and clear. Knots and other such abnormalities were avoided at the point of measurement, and if present, the observations were recorded at slightly higher or lower point.

3.3.2.3 Crown spread (m²)

Crown spread was measured by cross method in square meters (m²) with the help of measuring tape. It is determined by multiplying lengths of longest spread from edge to edge across the crown and the longest spread perpendicular to the first cross-section through the central mass of the crown.

3.3.2.4 Leaf fall pattern (%)

The time period between the leaf fall and leaf emergence was recorded in the poplar plantation. The leaves fallen from the trees were recorded on the basis of visual observations, at a fortnightly interval and the leaf fall was expressed in percentage.

3.3.3 Cultural practices

3.3.3.1 Nursery sowing and transplanting

Onion nursery was sown in the mid-October to mid-November and transplanted after 6 to 8 weeks of sowing.

3.3.3.2 Preparation of the field

The experimental site was prepared by cultivating twice with tractor mounted

cultivator followed by planking.

3.3.3.3 Manures and fertilizers application

Fertilizers as recommended by the package and practices (2017) of PAU were applied at the rate of 20 t FYM/acre, 40 kg of N/acre, 20 kg P₂O₅/acre and 20 kg of K₂O/acre. Whole of FYM, P₂O₅, K₂O and half of N was applied before transplanting and remaining dose of N was applied after 4-6 weeks of transplanting.

3.3.3.4 Weed control

Weeds were controlled by spraying Stomp 30 EC (pendimethalin) @ 1 litre/acre followed by one hoeing.

3.3.3.5 Spacing

Plants were sown at spacing 15 cm between rows and 7.5 cm between plants.

3.3.3.6 Irrigation

Irrigation was applied as per recommendation.

3.3.3.7 Harvesting

Harvesting was done when tops dried and neck fall takes place. After harvesting bulb cured under well- ventilated and dry place.

3.3.4 Crop Parameters

Various important parameters for crop were recorded as explained below:

3.3.4.1 Leaves per plant (no.)

The number of leaves were counted at full maturity from five plants in each plot randomly and then averages were worked out.

3.3.4.2 Neck thickness (cm)

Neck thickness was measured at the time of full maturity from five plants in each plot randomly. The neck thickness was measured in centimetres with the help of vernier calliper and then averages were worked out.

3.3.4.3 Plant height (cm)

Observations were recorded on plant height at the time of full maturity. The height of five randomly selected plants was measured in centimetres from the ground to the tip of the larger leaf with the help of meter tape and then means plant height was calculated.

3.3.4.4 Weight of the whole plant before and after curing (g)

Observations regarding weight of the whole plant before curing was recorded by selecting five plants at random from each plot and taken at the field itself whereas weight of whole plant after curing was taken after drying the samples in shaded and open well-ventilated room for 10-15 days.

3.3.4.5 Days to bulb initiation (no.)

Five onions were selected randomly and labelled. The neck bulb diameter was measured with vernier calliper after weekly interval. Diameters were measured only when

they were greater than 2 mm.

3.3.4.6 Bulb diameter (cm)

For this parameter, bulbs were selected randomly at the time of harvesting. The bulb diameter was measured in centimeters with the help of vernier calliper and then average worked out.

3.3.4.7 Average bulb weight (g)

Observations regarding this parameter were recorded by weighing the ten bulbs random selected from each plot and then average worked out.

3.3.4.8 Bolting percentage

The bolting percentage was calculated by using formula

Number of bolters/total number of plants × 100

3.3.4.9 Bulb yield (q/ha)

The observation regarding this parameter was recorded at the time of harvest as bulb yield per plot and then bulb yield (q/ha) was calculated.

3.3.4.10 Days to maturity (no.)

The number of days taken by plants from transplanting to maturity was counted. The maturity indices observed for recording days to maturity were – complete drying of leaves and neck fall.

3.3.4.11 Days to harvesting (no.)

The numbers of days taken by plants from date of transplanting to date of harvesting were counted.

3.3.5 Quality Parameters

3.3.5.1 Total soluble solids (%)

Total soluble solids percentage of fresh bulbs were estimated by using hand refractometer.

3.3.5.2 Dry matter content (g)

Twenty five grams of fresh bulbs were cut into small pieces and placed in petri- plates in hot air oven for drying at $65^{\circ} \pm 2^{\circ}$ C for 48 hours or till constant weight was obtained. The petri-plates were cooled in desiccator, reweighed and dry matter content was computed.

3.3.6 Micrometeorological observations

3.3.6.1 Maximum and minimum temperature (°C)

Data on maximum and minimum temperature were recorded under poplar plantation with help of maximum and minimum thermometer placed on poplar tree at height of 1.2 m from ground level. Data for open was taken from meteorological observatory installed in PAU, Ludhiana. The temperature recorded twice a day, at 8:30 am and 2:30 pm in onion crop season. Then monthly mean were calculated from the data taken daily.

3.3.6.2 Relative humidity (%)

Data for relative humidity were recorded under poplar and open with the help of

psychrometer. The relative humidity was measured twice a day, at 11 am and 3 pm during growing season of onion crop at fifteen days interval. The average for relative humidity was calculated.

3.3.6.3 Photosynthetically active radiation ($\mu\text{mol/s/m}^2$)

Data for PAR were recorded at 15 days interval at 12:00-2:00 pm starting from the 30 days after the transplanting during the growth period of onion crop using digital canopy analyser. The PAR was recorded under poplar-onion conditions and sole crop in open conditions.

3.3.6.4 Leaf area index

The data for leaf area index was recorded under poplar plantations with the help of digital canopy analyser during growing season of the crop.

3.4 Statistical analysis

Statistical analysis of data was performed as the procedure given by Panse and Sukhatme (1967) and using CPCS-1 software developed by Department of Mathematics and Statistics, PAU Ludhiana.

Analysis of Variance

Source of variation	Degree of freedom
Replication	2
Environment	1
error a	2
Planting time	2
Environment \times Planting time	2
error b	8
Varieties	3
Environment \times Varieties	3
Planting time \times Varieties	6
Environment \times Planting time \times Varieties	6
error c	36
Total	71

CHAPTER-IV

RESULTS AND DISCUSSION

The present investigation entitled “Effect of poplar-based microclimate on the intercultivation of onion” was carried out in the experimental area of Department of Forestry and Natural Resources, Punjab Agricultural University, Ludhiana during two consecutive years 2016-17 and 2017-18. The results were recorded for different parameters under the study and discussed below under following sub headings-

4.1 Tree parameters

4.2 Crop parameters

4.3 Quality parameters

4.4 Meteorological data

4.1 Tree parameters

Tree growth refers to an irreversible increase in the size and shape of the trees which is influenced by both the genetic and environmental factors such as climatic (temperature, light, relative humidity, rainfall), edaphic (soil characteristics) and physiographic factors (slope and aspect). In the present study, different tree growth factors like tree height (m), diameter at breast height (cm), crown spread (m²) and leaf fall pattern (%) were recorded for the two years of experimentation and discussed as below. It was observed that all trees present in the field were uniform in the height and diameter. Thus, all the plots under which onion crop grown experienced almost similar micro-environmental conditions.

4.1.1 Tree height

The tree height was measured in month of February for the years 2016-17 and 2017-18 when the tree is completely leafless to avoid any type of error in the measurement. The average height of trees was 9.7 m and it varied from 9.0 m to 10.3 m while in the next year, the average height of trees was recorded 12.8 m during February 2017 and it varied from 12.0 m to 13.5 m.

4.1.2 Diameter at breast height

The tree diameter was recorded at breast height with the help of vernier calliper during the month of February 2016 and February 2017. The increment in the diameter was recorded for both the years. The average diameter recorded during May 2016 was 11.2 cm and varied from 9.3 cm to 13.0 cm. During May 2017, the average diameter recorded was 13.1 cm and varied from 12.0 cm to 15.0 cm.

4.1.3 Crown spread

Crown spread is the horizontal and vertical spread of the tree crown. Mean data for the crown spread was recorded in the month of May 2017 and May 2018. The average crown was ranged between 17.2 m² and 20.2 m² during both the growing season, respectively.

4.1.4 Leaf fall pattern

The leaf fall pattern was observed for both the years of experiment and given in the below Fig 4.1. It was noticed that the leaf fall started from the mid-November and up to the mid-December, 50% of leaf fall took place. Likewise in earlier studies, similar leaf fall pattern was observed (Bhandari *et al* 2015). The new flush of leaves start appearing from the mid-March. Poplar is a deciduous tree which shed its leaves during the winter. Leaf fall is affected by environmental factors such as temperature, wind and rainfall.

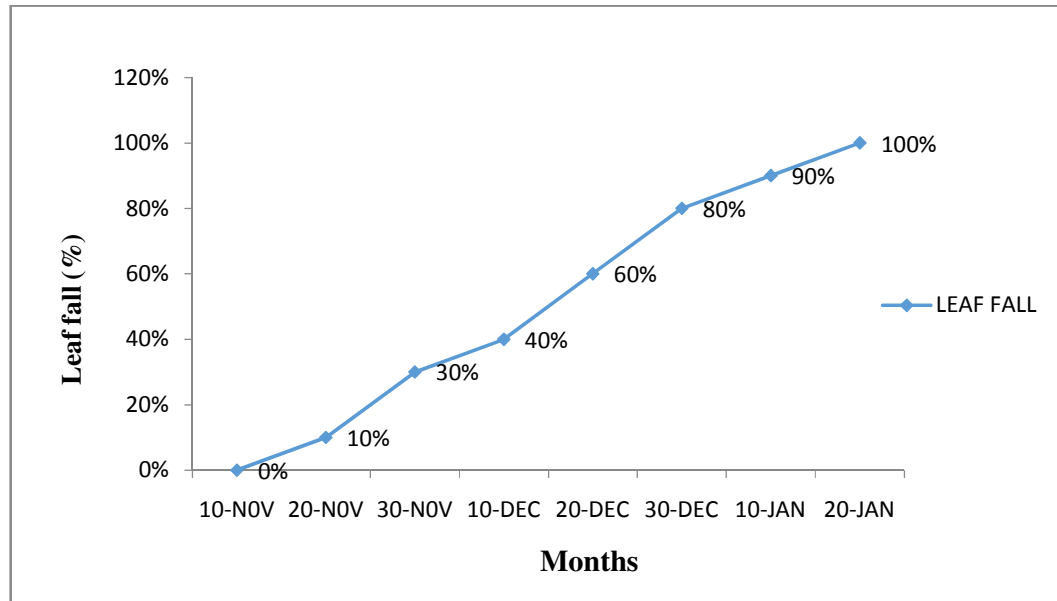


Fig 4.1 Leaf fall pattern of *Populus deltoides* during growing season of interplanted onion crop

4.2 Crop parameters

The results for different parameters of onion crop were obtained under two factors; three times of planting as main plot and four onion varieties as sub-plot factor. The interaction between these two factors was also analysed. The results obtained under the poplar trees for various crop parameters are discussed below section wise.

4.2.1 Neck thickness

Neck thickness is one of the important character in onion crop which determines its bulb storability. The onion with the thin neck thickness stores better than the thick neck. The data for neck thickness for four onion varieties during three planting time for the two consecutive years 2016-17 and 2017-18 is given in the Table 4.1. Neck thickness was found non-significant for both the factors such as time of planting and varieties furthermore interaction between them was also found non-significant. Among planting times, during both the experimental years, end of December (1.52 cm and 1.30 cm) planted crop recorded the highest neck thickness followed by mid of January (1.48 cm and 1.29 cm) and end of January

(1.41 cm and 1.19 cm). Among the varieties, PWO-35 showed the highest value for the neck thickness (1.51 cm and 1.29 cm) followed by Pb-Naroya (1.48 cm and 1.28 cm), PRO-6 (1.47 cm and 1.26 cm) and PRSC-10 (1.43 cm and 1.21 cm).

In general neck thickness was recorded maximum in the end of December planted crop and it decreased with the delayed transplanting dates and also with the age of the poplar trees.

Table 4.1 Neck thickness of four different onion varieties planted under poplar at different planting times

Planting time	Varieties									
	2016-17					2017-18				
	Pb-Naroya	PRO-6	PWO-35	PRSC-10	Mean	Pb-Naroya	PRO-6	PWO-35	PRSC-10	Mean
End-Dec	1.48	1.57	1.58	1.43	1.52	1.36	1.27	1.36	1.21	1.30
Mid-Jan	1.57	1.42	1.49	1.46	1.48	1.31	1.35	1.27	1.24	1.29
End-Jan	1.41	1.40	1.45	1.39	1.41	1.19	1.16	1.24	1.18	1.19
Mean	1.48	1.47	1.51	1.43		1.28	1.26	1.29	1.21	
CD (p = 0.05) Time of planting= NS Varieties = NS Time of planting × Varieties = NS					CD (p = 0.05) Time of planting= NS Varieties = NS Time of planting × Varieties = NS					

4.2.2 Leaves per plant (no.)

A perusal of data for number of leaves per plant for different onion varieties presented in the Table 4.2 depicted that during the first year of study, significant differences were obtained for both times of planting and onion varieties. Significantly higher number of leaves per plant was obtained when crop planted in end of December (7.9 leaves per plant) followed by mid of January (7.4) and the later was statistically at par with the end of January (7.4). Among the varieties, significantly higher number of leaves per plant was obtained in variety PWO-35 (7.9) followed by Pb-Naroya (7.6). However, time of planting and varieties produced non-significant effect on the number of leaves of four different onion varieties.

During the second year of study, non-significant differences were obtained with planting time and onion varieties with respect to number of leaves. Among the time of planting, end of December planted crop recorded the maximum number of leaves (7.3) while end of January planted crop showed minimum number of leaves (6.7). Among the varieties, PWO-35 showed the maximum number of leaves per plant (7.2) and PRSC-10 showed the minimum number of leaves per plant (6.6).

It is obvious from the data in Table 4.2 that number of leaves per plant decreased as the transplanting dates and age of poplar increased from the one season to the second season. Likewise reported by Hama (2013) that early transplanted crops had more number of days to complete both their growth and developmental stages than late planted crops which results more accumulation of the photosynthates, lead to the more vegetative growth such as number

of leaves per plant, plant height etc. The decrease in the number of leaves with the increase in the poplar age might be due to shade effect, above and below ground competition for resources and phytotoxic interference with the trees (Singh *et al* 1998). It was reported that shading of i.e. 50% of ambient light one week after anthesis resulted into the greater tiller mortality in wheat (Mcmaster *et al* 1987). Similar findings were recorded by Kemp and Whingwiri (1980) who observed that shading (20% of full sunlight) before anthesis resulted in reduced tiller number in wheat.

Table 4.2 Effect of different planting times on the leaves per plant of four onion varieties planted under poplar

Planting time	Varieties									
	2016-17					2017-18				
	Pb-Naroya	PRO-6	PWO-35	PRSC-10	Mean	Pb-Naroya	PRO-6	PWO-35	PRSC-10	Mean
End-Dec	7.9	7.7	8.3	7.7	7.9	7.3	7.3	7.6	7.2	7.3
Mid-Jan	7.5	7.4	7.7	7.3	7.4	7.0	6.5	7.2	6.3	6.8
End – Jan	7.5	7.2	7.6	7.1	7.4	6.8	6.6	7.0	6.2	6.7
Mean	7.6	7.4	7.9	7.4		7.1	6.8	7.2	6.6	
	CD (p = 0.05) Time of planting = 0.40 Varieties = 0.23 Time of planting × Varieties = NS					CD (p = 0.05) Time of planting = NS Varieties = NS Time of planting × Varieties = NS				

4.2.3 Plant height

A perusal of data (Table 4.3) revealed that during the first season 2016-17, plant height was significantly influenced with time of planting but showed non-significant effect on varieties. The interaction effect between both the factors was non-significant. Significantly higher plant height was observed when crop planted in end-December with the mean of 63.9 cm followed by mid-January planted crop with the mean of 56.8 cm which was significantly at par with plant height of end-January planted crop with the mean of 54.6 cm. Among the four varieties, the maximum plant height was attained by PWO-35 (59.3 cm) followed by Pb-Naroya (58.5 cm), PRO-6 (58.0 cm) and PRSC-10 (57.8 cm). While in second season 2017-18, plant height was also significantly influenced with the time of planting. The maximum plant height was observed when crop was planted in end-December with the mean 50.8 cm which was significantly at par with the plant height of mid-January planted crop (46.4 cm) and minimum plant height was observed in end-January (40.8 cm) planted crop. The plant height showed non-significant difference among varieties, the maximum plant height was recorded in PWO-35 (48.1 cm) while minimum plant height was recorded in PRSC-10 (44.7

cm). The effect of interaction between the time of planting and varieties was found to be non-significant.

Plant height is one of the important growth contributing factor for onion which determines its vigour. The vegetative growth is important pre- requisite for the higher bulb yield. Recorded data revealed that maximum plant height was attained in the end-December planted crop and decreased towards the end-January planting time. It was reported by Ralhan *et al* (1992) that tiller height in wheat decreased from 84.9 cm to 67.3 cm with the delay in sowing time from early November to mid-December. Likewise, among the two years of experimentation, the plant height decreased from first season to the second season. This might be due to the fact that tree-crop interaction changes with the increase in the age of poplar such as different level of competition for light, nutrients and minerals under different aged plantations (Mcmaster *et al* 1987; Kemp and Whingwiri 1980).

Table 4.3 Effect of different planting times on plant height of four onion varieties planted under poplar

Planting times	Varieties									
	2016-17					2017-18				
	Pb-Naroya	PRO-6	PWO-35	PRSC-10	Mean	Pb-Naroya	PRO-6	PWO-35	PRSC-10	Mean
End-Dec	66.2	65.7	62.8	61.0	63.9	48.7	49.0	55.3	50.5	50.8
Mid-Jan	55.6	55.4	58.5	55.0	56.8	47.4	46.0	48.3	44.2	46.4
End – Jan	53.8	52.9	56.6	57.8	54.6	41.5	41.5	40.7	39.4	40.8
Mean	58.5	58.0	59.3	57.8		45.9	45.5	48.1	44.7	
CD (p = 0.05) Time of planting = 3.73 Varieties = NS Time of planting × Varieties = NS					CD (p = 0.05) Time of planting = 6.87 Varieties = NS Time of planting × Varieties = NS					

2.4.2 Weight of whole plant before curing

The data pertaining to the weight of plant before curing presented in the Table 4.4. It was taken by weighing the freshly harvested plants from all the plots in the field.

In the first season 2016-17, weight of plant before curing exhibited significant effect on the time of planting. The maximum plant weight was obtained when crop planted at the end of December (69.9 g) which was significantly higher than rest of the two planting times. Amongst the varieties, the mean data showed non-significant influence on plant weight of four onion varieties. The maximum and minimum plant weight before curing was attained by variety PWO-35 (61.0 g) and PRSC-10 (55.0 g). The interaction between the time of planting and varieties of onion crop exhibited non-significant effect on the fresh weight of the plant.

During the second season 2017-18, weight of plant was significantly influenced with

time of planting and varieties but interaction effect between both the factors was found to be non-significant. Likewise previous year of study, planting on end-December showed significantly higher plant weight (54.6 g) whereas planting on end-January showed minimum plant weight (42.5 g) before curing. Among the varieties, the maximum weight of plant was recorded by the variety PWO-35 (52.1 g) which was significantly at par with the Pb-Naroya (49.1 g) followed by PRO-6 (47.5 g) which was at par with the PRSC-10 (45.5 g).

It is inferred from the Table 4.4 that delayed planting time resulted in decrease of plant fresh weight. It was reported by Misu *et al* (2018) that total weight of the onion plant was found maximum in the early transplanted crop as compared to the late transplanted crops. This might be due to the favorable weather conditions during vegetative period. It was also revealed that as the age of poplar increased, the fresh weight of the plant decreased as shown in the table 4.4. Gill *et al* (2009) reported that availability of light, nutrients and moisture become the limiting factors with the increase in the intensity of competition between the shallow rooted crop and deep rooted trees with the age of the poplar which resulted into the decreased yield contributing factors.

Table 4.4 Weight of whole plant before curing of four different onion varieties planted under poplar at different planting times

Plantingtime	Varieties									
	2016-17					2017-18				
	Pb-Naroya	PRO-6	PWO-35	PRSC-10	Mean	Pb-Naroya	PRO-6	PWO-35	PRSC-10	Mean
End-Dec	69.5	68.6	74.6	66.9	69.9	55.3	53.0	58.1	52.0	54.6
Mid-Jan	56.1	53.9	57.1	53.2	55.1	49.6	48.0	52.4	44.0	48.5
End -Jan	50.2	48.4	51.4	45.0	48.8	42.4	41.5	46.0	40.5	42.5
Mean	58.6	57.0	61.0	55.0		49.1	47.5	52.1	45.5	
	CD (p = 0.05) Time of planting = 3.42 Varieties = NS Time of planting × Varieties = NS					CD (p = 0.05) Time of planting = 4.15 Varieties = 3.62 Time of planting × Varieties = NS				

4.2.5 Weight of the whole plant after curing

Mean observations pertaining to the weight of plant after curing was furnished in Table 4.5.

In the year 2016-17, the weight of plant after curing was found significant with time of planting and non-significant with onion varieties. The maximum plant weight was recorded

in the end of December planted crop (62.0 g) which was significantly higher than the rest of planting times followed by mid of January planted crop (44.5 g) which was significantly at par with weight of plant obtained in the end of January (40.5 g). Among the varieties, the highest plant weight was recorded in the variety PWO-35 (52.9 g) while the lowest plant weight was recorded in variety PRSC-10 (45.8 g). The interaction between time of planting and onion varieties exerted non-significant effect.

In the second year 2017-18, data presented in Table 4.5 exerted significant effect of planting times and varieties on the weight of whole plant after curing. Planting of onion on end-December recorded significantly maximum weight of the plant after curing (46.0 g) than the other planting times followed by mid of January planted crop (42.1 g) and end of January planted crop (37.2 g). Among the varieties, significantly maximum weight of plant after curing was recorded in variety PWO-35 (46.2 g) followed by Pb-Naroya (41.8 g) which was significantly at par with both the varieties PRO-6 (40.6 g) and PRSC-10 (38.3 g). For the weight of the plant after curing, the interaction effect among the two factors i.e. time of planting and varieties was found non-significant.

Mean data indicated that the weight of the plant after curing decreased with the delay in the planting dates and with the enhancement in the age of poplar as shown in Table 4.5.

Table 4.5 Weight of plants after curing of four different onion varieties planted under poplar at different planting times

Planting time	Varieties									
	2016-17					2017-18				
	Pb-Naroya	PRO-6	PWO-35	PRSC-10	Mean	Pb-Naroya	PRO-6	PWO-35	PRSC-10	Mean
End-Dec	62.0	61.9	66.6	57.7	62.0	46.2	45.3	50.2	42.2	46.0
Mid-Jan	44.1	43.6	48.1	42.4	44.5	41.6	40.7	47.6	38.4	42.1
End – Jan	40.7	40.0	44.1	37.2	40.5	37.5	36.0	42.0	34.4	37.2
Mean	48.9	48.5	52.9	45.8		41.8	40.6	46.2	38.3	
	CD (p = 0.05) Time of planting = 5.15 Varieties = NS Time of planting × Varieties = NS					CD (p = 0.05) Time of planting = 3.08 Varieties = 4.02 Time of planting × Varieties = NS				

This might be due to the reason that late planted crops had less vegetative phase than the early planted crops that adversely affected the various growth parameters. It was also reported that dry weight of bulbs negatively correlated with the temperature (Caruso *et al* 2014). Chauhan *et al* (2012) observed that number of factors responsible for the reduction in the yield

contributing parameters such as loss of original land to the trees i.e. only possible to grow crop on 90% of the original area which resulted into the decreased crop density and half of reduction in the yield contributing parameters was the age of poplar. As the age increased, competition for resources such as light, nutrients and minerals below and above ground increased which resulted into decreased crop yield.

4.2.6 Bulb diameter

From the Table 4.6 it infers that bulb diameter was found significant for both the factors i.e. time of planting and varieties during the first growing season 2016-17 while the interaction among them was found to be non-significant. Among the planting times, significantly higher bulb diameter (5.3) was recorded with the planting of crop in end-December followed by planting of crop in mid-January (4.5 cm) which was significantly at par with the planting of crop in end-January planted crop (4.3 cm). Among the four varieties, PWO-35 had significantly higher bulb diameter (5.0 cm) than the other three varieties and followed by Pb-Naroya (4.7 cm) which was significantly at par with the PRO-6 (4.6 cm) and PRSC-10 (4.5 cm).

Table 4.6 Bulb diameter of four onion varieties planted under poplar at different planting times

Planting time	Varieties									
	2016-17					2017-18				
	Pb-Naroya	PRO-6	PWO-35	PRSC-10	Mean	Pb-Naroya	PRO-6	PWO-35	PRSC-10	Mean
End-Dec	5.3	5.2	5.5	5.2	5.3	4.7	4.5	4.8	4.2	4.6
Mid-Jan	4.6	4.3	4.9	4.2	4.5	4.4	4.2	4.6	4.1	4.3
End – Jan	4.4	4.1	4.6	4.1	4.3	4.1	4.0	4.5	4.0	4.1
Mean	4.7	4.6	5.0	4.5		4.4	4.2	4.6	4.1	
	CD (p = 0.05) Time of planting = 0.33 Varieties = 0.28 Time of planting × Varieties = NS					CD (p = 0.05) Time of planting = 0.28 Varieties = 0.39 Time of planting × Varieties = NS				

Similar results were observed during second season 2017-18, end-December crop gave significantly higher bulb diameter (4.6 cm) than the other three varieties and End-January planted crop recorded the minimum bulb diameter (4.1 cm). Among the varieties, PWO-35 gave the maximum bulb diameter (4.6 cm) which was statistically at par with Pb-Naroya (4.4 cm) but significantly higher than PRO-6 (4.2 cm) and PRSC-10 (4.1 cm).

The presented mean data indicated that bulb diameter of four different onion varieties showed the similar trend with the transplanting dates. Khadrah *et al* (2017) reported that onion transplanted on first transplanting date i.e. 15th December gave the highest value of

bulb diameter while last transplanting date gave the lowest value of bulb diameter. This might be due to the favourable weather conditions and the longer period to accumulate more food material which resulted into the increase in growth and yield characteristics.

It was also found that as the age of poplar increased, the bulb diameter decreased. Chauhan *et al* (2012) revealed that reduction in yield contributing factors of wheat under poplar of age (1-5 years old) might be due to modifications in the micro-environmental conditions and competition between trees and crop increase with the age that affects the availability of light, moisture and nutrients etc.

4.2.7 Average fresh bulb weight

The data for the average fresh bulb weight was recorded in 2016-17 and 2017-18 and presented in the Table 4.7. During the first year 2016-17, the average fresh bulb weight was found significant for the planting times and varieties. End-December planted crop showed the maximum average fresh bulb weight (54.1 g) followed by mid-January planted crop (42.8 g) which was significantly at par with the end-January planted crop (37.1 g), although end-January planted crop remain at the bottom in list. Among the four varieties, PWO-35 showed the maximum average fresh bulb weight (47.5 g) which was significantly at par with the Pb-Naroya (45.7 g) followed by PRO-6 (43.6 g) and PRSC-10 (41.9 g). During the second year 2017-18, the average fresh bulb weight was found significant for both the factors such as time of planting and four onion varieties. End-December planted crop recorded the maximum average fresh bulb weight (43.4 g) which was significantly higher than the other planting times while, end-January planted crop recorded the minimum average fresh bulb weight (31.2 g). Among the varieties, PWO-35 gave the highest average fresh bulb weight (40.7 g) which was significantly at par with the average fresh bulb weight of Pb-Naroya (38.0 g) followed by PRO-6 (36.6 g) and PRSC-10 (34.3 g). The interaction effect between the time of planting and varieties was found non-significant for both the experimental years.

Observations recorded (Table 4.7) revealed that the average fresh bulb weight of four onion varieties decreased with the delay in transplanting time. The crop planted in the end of December showed the highest average fresh bulb weight whereas end of January planted crop showed the minimum average fresh weight. Joshi *et al* (1975) reported that early transplanted crop showed high value for average fresh bulb weight of onion as compared to late transplanted crop. This might be because of fact that the early planted crops provides low temperature for more number of days than the late planted crops which is favorable for the bulb development. Another reason might be due to the time period required for the synthesis and storage of the metabolites in to the bulb shortened at late planted crops due to the reduction in the crop cycle and resulted into the lower average bulb weight into the late planted crops. It was also reported that dry weight of bulbs negatively correlated with the temperature (Caruso *et al* 2014).

It was also observed that the crop planted in the first year gave comparatively higher average fresh bulb weight than the second year planted crop. This might be because of less availability of light, moisture and nutrients under old age plantations for the proper growth and development of the crop. The agricultural crops are generally shallow rooted crops but trees have deep tap root system so the trees can exploit more soil volume than the agricultural crops. That is why the effects of moisture and nutrient competition are generally more with increase in density and age of the trees, it was reported that shading effect up to 28 and 54 % of full light resulted into the decrease in number of grains and grain weight per ear in the wheat crop (Willey and Holliday 1971).

Table 4.7 Effect of different planting times on average fresh bulb weight of four onion varieties planted under poplar

Planting time	Varieties									
	2016-17					2017-18				
	Pb-Naroya	PRO-6	PWO-35	PRSC-10	Mean	Pb-Naroya	PRO-6	PWO-35	PRSC-10	Mean
End-Dec	54.7	53.3	56.2	52.4	54.1	43.5	42.5	47.7	40.2	43.4
Mid-Jan	43.8	41.2	45.7	40.3	42.8	37.8	37.0	40.1	35.7	37.6
End – Jan	38.7	36.2	40.7	33.0	37.1	32.8	30.4	34.5	27.1	31.2
Mean	45.7	43.6	47.5	41.9		38.0	36.6	40.7	34.3	
	CD (p = 0.05) Time of planting = 6.00 Varieties = 3.71 Time of planting × Varieties = NS					CD (p = 0.05) Time of planting = 5.71 Varieties = 2.97 Time of planting × Varieties = NS				

4.2.8 Days to bulb initiation (no.)

The data presented in the Table 4.8 depicted that number of days to bulb initiation was found significant for the planting times and varieties while the interaction between them was found to be non-significant. Among the planting times, end-December planted crop took maximum number of days to bulb initiation (89.9 and 92.0) which was significantly at par with the mid-January planted crop (85.3 and 87.3) and end-January planted crop took minimum number of days to bulb initiation (81.3 and 83.6). Among the varieties, PRO-6 took minimum number of days to bulb initiation (75.4 and 77.8) whereas PRSC-10 took maximum number of days to bulb initiation (90.8 and 92.9).

Lancaster (1996) reported that bulb formation and subsequent growth were influenced by photoperiod and temperature. Bulb formation required long days and high temperature. Increasing air temperature from 6 to 20°C increased bulbing ratio and reduce the time to bulb maturity. The relative growth rate of bulbs were linearly related to accumulated thermal time.

Table 4.8 Total number of days to bulb initiation taken by onion varieties under poplar plantation

Planting time	Days to bulb initiation	
	2016-17	2017-18
End-December	89.9	92.0
Mid-January	85.3	87.3
End-January	81.3	83.6
CD (p = 0.05)	6.05	5.93
Varieties		
Pb-Naroya	86.8	88.9
PRO-6	75.4	77.8
PWO-35	89.1	91.0
PRSC-10	90.8	92.9
CD (p = 0.05)	4.40	4.49
CD (p = 0.05)	Planting time × Varieties=NS	

4.2.9 Days to maturity (no.)

Maturity indicates the end of reproductive phase. The mean data with respect to the days to maturity taken by four onion varieties is illustrated in the Table 4.9. The number of days to maturity ranged from 95.8 to 121.9 and 98.4 to 124.9 in 2016-17 and 2017-18. Data with respect to the mean values, number of days to maturity was found significant for the planting times and varieties while the interaction between them was found non-significant. It was noticed that crop planted in the end of December took more days to maturity (121.9 and 124.9) while crop planted in the end of January took less number of days to maturity (103.2 and 105.1). Among the varieties, PRSC-10 took maximum number of days to maturity (119.8 and 122.7) whereas PRO-6 took minimum number of days to maturity (95.8 and 98.4).

Khokhar (2008) and Caruso *et al* (2014) revealed that crop cycle get shortened with the delayed transplanting times. This might be due to the seasonal variation in the environmental factors such as air temperature, photoperiod and light intensity increased as the summer approached, thus accelerating the end of the vegetative phase earlier in the case of late planted crops.

4.2.10 Days to harvesting (no.)

Data regarding the number of days to harvesting taken by four onion varieties presented in the Table 4.9. The number of days to harvesting ranged from 106.0 to 134.8 and 108.0 to 136.7 during both the growing seasons. Significant difference was recorded among

the four onion varieties and three planting times but the interaction between them was found to be non-significant. Among the varieties, PRSC-10 took maximum days to harvesting (130.8 and 132.8) while, PRO-6 took minimum number of days to harvesting (106.0 and 108.0).

It was reported that crop cycle shortened with the delayed transplanting times. This might be due to the seasonal variation in the environmental factors such as air temperature, photoperiod and light intensity increased as the summer approached, thus accelerating the end of the vegetative phase earlier in the case of late planted crops (Caruso *et al* 2014 and Khokhar 2008).

PRO-6 is an early maturing variety, it took 120 days to harvest from transplanting while, Pb-Naroya took 145 days to harvest from transplanting (Anonymous 2016).

Table 4.9 Total number of days to maturity and harvesting taken by different onion varieties

Planting time	Days to maturity		Days to harvesting	
	2016-17	2017-18	2016-17	2017-18
End- December	121.9	124.9	134.8	136.7
Mid-January	113.0	115.2	123.0	124.8
End-January	103.2	105.1	112.2	114.2
CD (p = 0.05)	4.32	4.55	3.58	3.73
Varieties				
Pb-Naroya	115.8	118.6	126.9	128.8
PRO-6	95.8	98.4	106.0	108.0
PWO-35	118.1	120.6	129.6	131.2
PRSC-10	119.8	122.7	130.8	132.8
CD (p = 0.05)	5.25	5.13	4.29	4.22

4.2.11 Bolting percentage

Bolting is an undesirable character. It occurs when the plants have sufficient number of leaves for the evolution to the reproductive stage and the temperature < 10°C (Brewster 1994). Mean data with regard to the bolting percentage given in the Fig 4.2. It was noticed that during both the years, end of December planted crop showed the maximum bolting percentage (0.11% and 0.07%) and end of January planted crop showed the least bolting percentage (0.025% and 0.002%). Among the varieties, during the year 2016-17, variety PRO-6 showed the maximum bolting percentage (0.15%). However PRSC-10 showed the least bolting percentage (0.02%). During the next successive year, maximum and minimum

bolting percentage was noticed in the varieties PRSC-10 (0.013%) and Pb-Naroya (0.002%). Khokhar (2008) reported that the bolting percentage tended to decrease from early planting (5 December) to later planting of sets (5 March). This could be due to the fact that in late plantings, the plants are too small when the flower-inducing temperature prevails and the tendency to bolt is therefore retarded. Maximum bolting was noticed in the earliest planting (5 December) which was probably an effect of low temperatures during winter and early spring season. Varieties vary noticeably in their susceptibility to bolting percentage.

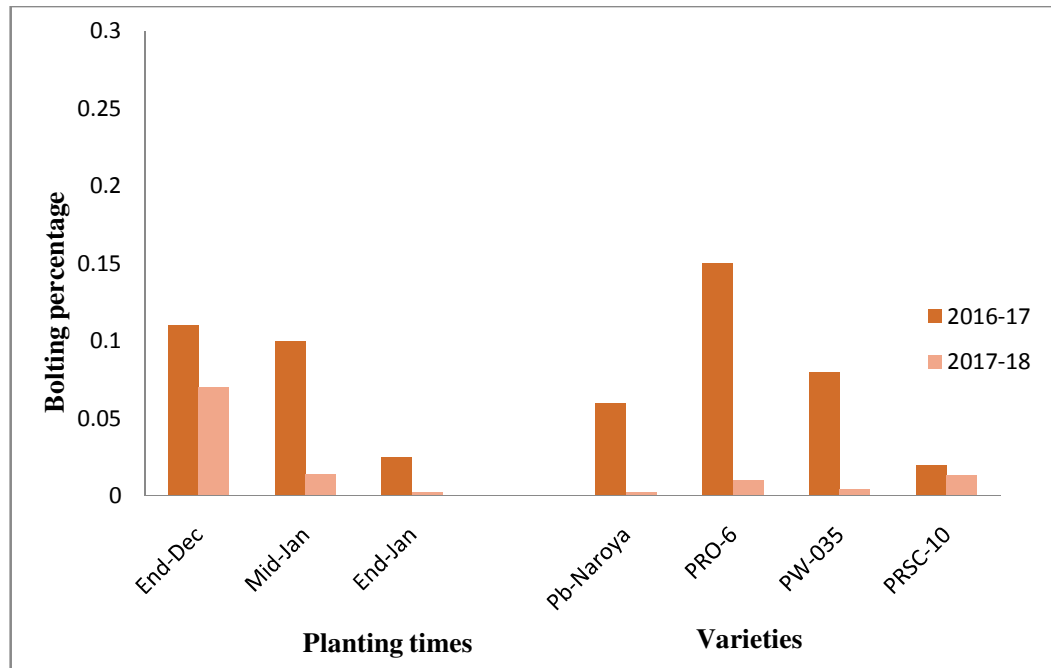


Fig 4.2 Bolting percentage of onion varieties planted under poplar at different planting times

4.2.12 Bulb yield (q/ha)

Bulb yield is the product of number of factors enacted upon plant such as number of leaves, plant height, bulb diameter, average bulb weight etc. The mean data pertaining to the bulb yield (q/ha) was recorded in two consecutive years (May 2016 and May 2017) illustrated in the Table 4.10. There were three planting times and four onion varieties. During the first experimental year 2016-17, the average bulb yield was found significant for growing environments, planting times and varieties. The end-December planted crop mean bulb yield (216.9 q/ha) was significantly higher than the other two planting times. However among the varieties, PWO-35 produced the significantly highest mean bulb yield (212.7 q/ha) followed by Pb-Naroya (192.1 q/ha) which was significantly at par with the variety PRO-6 (182.4 q/ha) and PRSC-10 produced the lowest mean bulb yield (164.8 q/ha). The effect of interaction between growing environment, planting times and varieties was found non-significant.

While during the second experimental year 2017-18, the mean data of bulb yield was

found significant for growing environments, planting times and varieties. The end-December planted crop produced the highest mean bulb yield (200.0 q/ha) which was at par with the mid of January planted crop mean bulb yield (176.8 q/ha) and end of January planted crop produced the minimum mean bulb yield (149.7 q/ha). Among the varieties, PWO-35 produced the significantly maximum mean bulb yield (198.0 q/ha) than the other three varieties and followed by variety Pb-Naroya (179.8 q/ha) which was significantly at par with the mean bulb yield of variety PRO-6 (171.5 q/ha). While PRSC-10 produced the minimum mean bulb yield (152.6 q/ha). Looking to the statistical analysis, the interaction between growing environment and varieties was found to be significant presented in the Table 4.10. However, the interaction between the environment, planting times and varieties was found to be non-significant.

The statistical analysis showed that the highest average bulb yield was recorded in the early transplanted crops than the late transplanted crops. Kandil *et al* (2013) revealed that onion seedlings transplanted on 15th December recorded the highest average bulb weight, total yield and marketable yield. This might be due to the favourable weather conditions during the vegetative growth which increase the production of photosynthates and resulted into the increase in the growth and yield characteristics. This finding is also in accordance with the Misu *et al* (2018), Hamma (2013) and Khadrah *et al* (2017). It was noticed that the average bulb yield was comparatively higher during the first year (188.0 q/ha) as compared to the second year (175.5 q/ha). Gill *et al* (2007) reported the gradual decrease (10-46%) in the grain yield of wheat with the increase in the age of trees (1st - 6th year). But the yield reduction is often compensated by the economic returns from the sale of poplar wood at the end of rotation. It was also observed that average bulb yield was higher under open conditions as compared to under poplar plantations.

Mean data with regard to the interaction between the growing environment and varieties illustrated in the Table 4.10 (a). The presented mean data indicated that the average bulb yield under open conditions (222.5 q/ha) was comparatively higher than the under poplar plantations (128.5 q/ha). Under open conditions, variety PWO-35 (252.4 q/ha) produced the significantly highest mean bulb yield followed by mean bulb yield of variety Pb-Naroya (231.4 q/ha), PRO-6 (219.6 q/ha) and variety PRSC-10 which produced the minimum mean bulb yield (186.78 q/ha). Likewise under poplar plantations, variety PWO-35 produced the significantly highest mean bulb yield (143.7 q/ha) followed by variety Pb-Naroya (128.2 q/ha) which was significantly at par with the mean bulb yield of PRO-6 (123.4 q/ha) and PRSC-10 (118.5 q/ha).

Table 4.10 Bulb yield (q/ha) of four different onion varieties sown under poplar and in open (control) conditions at different planting times

Varieties	Environment	Time of planting							
		2016-17				2017-18			
		End dec	Mid-Jan	End-Jan	Mean (varieties)	End dec	Mid-Jan	End-Jan	Mean (varieties)
Pb-Naroya	Poplar	177.0	138.8	116.5	192.1	152.9	121.3	110.3	179.8
	Open	273.5	247.1	199.7		253.2	245.5	195.7	
PRO-6	Poplar	165.7	135.3	110.0	182.4	145.3	117.6	107.3	171.5
	Open	259.4	229.1	194.8		250.5	217.2	191.0	
PWO-35	Poplar	187.3	166.5	122.9	212.7	181.3	130.0	119.7	198.0
	Open	287.1	277.0	235.5		274.0	264.0	219.1	
PRSC-10	Poplar	163.0	127.5	104.7	164.8	137.5	116.7	101.3	152.6
	Open	222.2	204.7	166.9		204.9	202.0	153.4	
	Mean (Planting time)	216.9	190.7	156.4		200.0	176.8	149.7	
		CD (p = 0.05) Environment = 8.32 Time of planting = 14.03 Varieties = 14.70 Environment × Time of planting = NS Environment × Varieties = NS Time of planting × Varieties = NS Environment × Time of planting × Varieties = NS				CD (p = 0.05) Environment = 14.78 Time of planting = 23.35 Varieties = 10.09 Environment × Time of planting = NS Environment × Varieties = 14.28 Time of planting × Varieties = NS Environment × Time of planting × Varieties = NS			

Singh *et al* (1998) reported that the grain yield of wheat under the poplar canopy was only 58.76% of the unsheltered crop. The experiment witnessed that this might be due to the factors like competition, shade effect and allelopathic interference of trees.

Table 4.10 (a) The mean bulb yield (q/ha) of different onion varieties under different environment during growing season 2017-18

Environment	Varieties				
	Pb-Naroya	PRO-6	PWO-35	PRSC-10	Mean
Poplar	128.2	123.4	143.7	118.5	128.5
Open	231.4	219.6	252.4	186.8	222.5
Mean	179.8	171.5	198.0	152.4	
	CD (p = 0.05) Environment = 14.78 ; Varieties = 10.09 Environment × Varieties = 14.28				

Looking to the pooled analysis (Table 4.10(b)), the bulb yield (q/ha) of four onion varieties was found non-significant for the years, interaction between years, growing environment, planting times and varieties whereas the interaction between the growing environment, planting times and varieties, time of planting and varieties was found to be significant. The interaction for bulb yield (q/ha) of four onion varieties of growing environments, planting time and varieties was presented in the Table 4.10 (b). Under poplar, end of December planted variety PWO-35 produced the highest mean bulb yield (184.3 q/ha) which was significantly at par with the end of December planted variety Pb-Naroya (165.0 q/ha). Likewise, under open conditions end of December planted variety PWO-35 produced the maximum mean bulb yield (280.6 q/ha) which was significantly at par with the mid of January planted variety PWO-35 (270.5 q/ha) and end of December planted variety Pb-Naroya (263.3 q/ha). End of January planted variety PRSC-10 produced the minimum mean bulb yield (160.2 q/ha). The interaction between the time of planting and varieties was given in Table 4.10 (c). Variety PWO-35 planted in the end of December recorded the significantly highest mean bulb yield (232.5 q/ha) and variety PRSC-10 planted in the end of January recorded the lowest mean bulb yield (131.6 q/ha).

Table 4.10 (b) Growing environments × Times of planting × Varieties interaction means for bulb yield (kg/ha) of different onion varieties (pooled data)

Environment	Varieties	Time of planting			Mean
		End December	Mid January	End January	
Poplar	Pb-Naroya	165.0	130.0	113.4	136.1
	PRO-6	155.5	126.5	108.7	130.2
	PWO-35	184.3	148.3	121.3	151.3
	PRSC-10	150.2	122.1	103.0	125.1
	Mean	163.8	131.7	111.6	
Open	Pb-Naroya	263.3	246.3	197.7	235.8
	PRO-6	254.9	223.1	192.9	223.6
	PWO-35	280.6	270.5	227.3	259.5
	PRSC-10	213.6	203.4	160.2	192.4
	Mean	253.1	235.8	194.5	227.8
CD (p = 0.05) Environment × Time of planting × Varieties = 24.14					

Table 4.10 (c) Times of planting × Varieties interaction means for bulb yield (q/ha) of different onion varieties

Varieties	Time of planting			Mean
	End December	Mid January	End January	
Pb-Naroya	214.2	187.7	155.5	185.8
PRO-6	205.2	174.8	151.8	177.3
PWO-35	232.5	209.4	174.3	205.4
PRSC-10	182.0	162.7	131.6	158.8
Mean	208.5	183.7	153.3	
CD (p = 0.05) Time of planting × Varieties = 17.07				

The percent reduction in the bulb yield (q/ha) of four onion varieties under poplar canopy over open conditions is illustrated in the Table 4.10 (d). Significant reduction in the bulb yield of four onion varieties was recorded under poplar plantation as compared to the open conditions. This difference was mainly due to the competition between the trees and crop which affects the availability of resources such as light, moisture and nutrients. Under open condition, it was noticed that all three planting times and four onion varieties produced maximum bulb yield than the bulb yield under poplar canopy. During the year 2016-17, the maximum percent reduction in the bulb yield of onion was recorded in the end-January

planted variety PWO-35 (47.8%) whereas minimum reduction was found in end-December planted variety PRSC-10 (26.6%). During the next consecutive year 2017-18, the maximum percent reduction was recorded in the mid of January planted variety PWO-35 (50.8%) and minimum reduction was recorded in the end of December planted PRSC-10 (32.9%). Sreekala and Jayachandran (2002) reported that the yield of ginger was reduced 60-80% due to the heavy shades levels. Gill *et al* (2009) observed that trees ameliorates the micro-environmental conditions under poplar canopy by reducing the air temperature, photosynthetic active radiation (PAR) and by increasing the relative humidity. It depends upon the choice of agroforestry system and type of intercrop. During the first two years, any crop can be grown without much decrease in yield (10-15%) of summer and winter season. According to the report given by Dhillon *et al* (2010) that modification in the micro-environmental conditions under poplar had resultant effects on the crop physiology and yield of turmeric grown under the poplar. Under open conditions, higher values for all the physiological parameters such as net photosynthesis, water use efficiency, transpiration and carboxylation efficiency etc. were recorded than under poplar canopy whereas crop under two year old canopy yielded the least values. An increase in the crop yield was recorded under open conditions rather than under the poplar canopy. Singh *et al* (1998) found that crop density, root and shoot length, biomass and grain yield of wheat were significantly lower in the fields sheltered by *P. deltoides* than in unsheltered one. In spite of reducing number of tillers and tiller height per plant due to shading effect, it was observed that germination, plant height and biomass of the crops reduced from 10 to 30% at 30 and 60 days interval of sowing in the poplar as compared to the one without the poplar (Singh *et al* 2001). The reduction in the different parameters of the crops i.e. plant height, grain yield and straw yield of different wheat varieties increased significantly as the age of the poplar trees increased (Chauhan *et al* 2011). It was reduced up to 23.3% under poplar as compared to the sole cropping (Ralhan *et al* 1992). A decline in the wheat yield up to 50-60% was also recorded by the Puri and Bangarwa (1992). Light is one of the limiting factor which affects the growth and development of the crop. Fischer (1985) studied the influence of solar radiations and temperature on the wheat crop. It was observed that shading shortened crop development rate nearly in direct proportion to the reduction in captivated radiations.

The reduction in the bulb yield of four onion varieties might be due to the shading effect on the morphology of crop. In onion, best range of temperature for bulb development is around 15-20 °C night and 25-30°C day temperatures. For maturity, day temperature ranged between 35-38°C is required. Variety PRO-6 took 120 days to harvest from transplanting while variety Pb-Naroya took 145 days to harvest from the transplanting. Excessive high temperature (> 42°C) at the time of maturity (April-May) results into the heavy reduction in bulb size and reduces its storage life. In onion, warmer temperature also affects growth rate.

Table 4.10 (d) Percent reduction in bulb yield (q/ha) of onion varieties planted at different times under poplar canopy and open conditions during 2016-17 and 2017-18

Varieties	Bulb Yield (q/ha)		% Reduction
	Open	Poplar	
2016-17			
	End December planted crop		
Pb-Naroya	273.5	177.0	35.3
PRO-6	259.4	165.7	36.1
PWO-35	287.1	187.3	34.8
PRSC-10	222.2	163.0	26.6
	Mid January planted crop		
Pb-Naroya	247.1	138.8	43.8
PRO-6	229.1	135.3	40.9
PWO-35	277.0	166.5	39.9
PRSC-10	204.7	127.5	37.7
	End January planted crop		
Pb-Naroya	199.7	116.5	41.7
PRO-6	194.8	110.0	43.5
PWO-35	235.5	122.9	47.8
PRSC-10	166.9	104.7	37.3
2017-18			
	End December planted crop		
Pb-Naroya	253.2	152.9	39.6
PRO-6	250.5	145.3	41.9
PWO-35	274.0	181.3	33.8
PRSC-10	204.9	137.5	32.9
	Mid January planted crop		
Pb-Naroya	245.5	121.3	50.6
PRO-6	217.2	117.6	45.9
PWO-35	264.0	130.0	50.8
PRSC-10	202.0	116.7	42.2
	End January planted crop		
Pb-Naroya	195.7	110.3	43.6
PRO-6	191.0	107.3	43.8
PWO-35	219.1	119.7	45.4
PRSC-10	153.4	101.3	34.6

4.3 Quality Parameters

4.3.1 Dry matter content (g)

Dry matter content of four different onion varieties presented in the Table 4.11. Presented data indicate that the dry matter content of onion varied from 6.4 to 7.2 in both the experimental years. However, during the first year 2016-17, it was observed that the dry matter content was significant for the four onion varieties but non-significant for the three planting times. The crop planted in the end-December produced the highest dry matter content (7.2 g) whereas the crop planted in the end-January produced the lowest dry matter content (6.4 g). Among the varieties, PWO-35 gave the highest dry matter content (7.1 g) which was significantly at par with the PRSC-10 (6.9 g). Variety PRSC-10 was significantly at par with the PRO-6 (6.7 g) and Pb-Naroya (6.6 g). The interaction effect was found significant between planting times and onion varieties. Variety PWO-35 planted at the end-December produced the highest dry matter content (7.5 g) which was significantly at par with the varieties Pb-Naroya (7.3 g) planted at the end-December, PRSC-10 (7.3 g) planted at the mid-January, PRSC-10 (7.2 g) planted at the end-December, PWO-35 (7.2 g) planted at the end-January and PRO-6 (7.1 g) planted at the mid-January while variety PRSC-10 planted at the end of January produced the lowest dry matter content (6.1 g).

During the second year 2017-18, the mean data revealed that the dry matter content was found significant for planting times, varieties and their combination. The crop planted at the end of December and mid of January produced the highest dry matter content (7.1 g) and end of January planted crop produced lowest dry matter content (6.4 g). Among the varieties, PWO-35 produced the highest dry matter content (7.2 g) which was significantly at par with the PRSC-10 (6.9 g). PRO-6 (6.7 g) and Pb-Naroya (6.7 g) produced lowest dry matter content.

The interaction between the planting times and varieties was found significant. Variety PWO-35 planted at the end of December produced the highest dry matter content (7.4 g) which was significantly at par with the Pb-Naroya (7.3 g) planted at the end-December, PRO-6 (7.3 g) and PRSC-10 (7.3 g) planted at the mid-January, PWO-35 (7.2 g) planted at the end-January and PRSC-10 (7.1 g) planted at the end-December. Whereas, PRSC-10 (6.2 g) planted at end-January produced the lowest dry matter content.

The presented data in the Table 4.11 indicate that early planting showed comparatively highest dry matter content than the late planting. This might be due to the favorable weather conditions and more vegetative phase for early transplanting to complete their growth and developmental stages which increased the production of photosynthates and resulted into the increase in growth and yield characteristics of onion. These findings were in accordance with the Bardisi *et al* (2013), Bharti and Ram (2014) and Mishra *et al* (2014).

Table 4.11 Dry matter of four onion varieties planted under poplar at different planting times

Planting time	Varieties									
	2016-17					2017-18				
	Pb-Naroya	PRO-6	PWO-35	PRSC-10	Mean	Pb-Naroya	PRO-6	PWO-35	PRSC-10	Mean
End-Dec	7.3	6.6	7.5	7.2	7.2	7.3	6.6	7.4	7.1	7.1
Mid-Jan	6.6	7.1	6.6	7.3	6.9	6.8	7.3	7.0	7.3	7.1
End – Jan	5.9	6.3	7.2	6.1	6.4	6.0	6.3	7.2	6.2	6.4
Mean	6.6	6.7	7.1	6.9		6.7	6.7	7.2	6.9	
	CD (p = 0.05) Time of planting = NS Varieties = 0.34 Time of planting × Varieties = 0.59					CD (p = 0.05) Time of planting = 0.31 Varieties = 0.28 Time of planting × Varieties = 0.49				

4.3.2 Total soluble solids (%)

The mean data pertaining to the total soluble solids given in the Table 4.12. During the first year of study, significant differences were recorded in the four onion varieties and their interaction but the times of planting was found to be non-significant. Among the planting times, it was observed that the crop planted at the end-December showed highest TSS content (13.6 %) while the lowest TSS content (12.8 %) was recorded in the crop planted at the end-January. Among the varieties, PWO-35 showed the significantly highest TSS content (13.7%) than the other three varieties and PRO-6 showed the lowest TSS content (12.8%). The interaction between the planting times and varieties indicated that mid-January planted Pb-Naroya (12.4%) and end-January planted PWO-35 (12.4%) showed minimum TSS content. End-December planted PWO-35 and mid-January planted PWO-35 (14.3%) showed highest TSS content (14.3%) which was significantly at par with the mid-January planted PRSC-10 (14.0%), end-December planted Pb-Naroya (13.9%) and end-January planted Pb-Naroya (13.4%).

During the second year of study, significant differences were recorded among three planting times, four onion varieties and their interaction. Mean data revealed that the crop planted at the end December showed significantly highest TSS content (13.5%) as compared to other two planting times and end-January planted crop showed the lowest TSS content (12.4%). Among the varieties, PWO-35 showed highest TSS content (13.3%) which was significantly at par with the PRSC-10 (13.2%), Pb-Naroya (13.0%) and PRO-6 showed the lowest TSS content (12.2%). The interaction between the planting times and varieties showed

end-January planted Pb-Naroya showed the highest TSS content (14.2%) which was significantly at par with the end-December planted PWO-35 (13.9%), end-January planted PRSC-10 (13.9%), end-January planted PWO-35 (13.8%) and mid-January planted Pb-Naroya (13.4%) while end-January planted PRO-6 showed the lowest TSS content (10.6%). The decrease in the TSS content from the end-December to end-January due to delayed transplanting is in accordance with Coolong and Randle (2003) who reported the negative linear response of soluble solid content of mature onion bulbs to the increasing temperature. These findings are also in agreement with the findings of Kanwar and Akbar (2013), Kandil *et al* (2013) and Bharti and Ram (2014).

Table 4.12 TSS of four onion varieties planted under poplar at different planting times

Planting time	Varieties									
	2016-17					2017-18				
	Pb-Naroya	PRO-6	PWO-35	PRSC-10	Mean	Pb-Naroya	PRO-6	PWO-35	PRSC-10	Mean
End-Dec	13.9	13.1	14.3	13.1	13.6	14.2	13.0	13.9	12.7	13.5
Mid-Jan	12.4	12.6	14.3	14.0	13.3	13.4	13.0	12.2	13.0	12.9
End – Jan	13.4	12.8	12.4	12.7	12.8	11.3	10.6	13.8	13.9	12.4
Mean	13.2	12.8	13.7	13.3		13.0	12.2	13.3	13.2	
	CD (p = 0.05) Time of planting = NS Varieties = 0.57 Time of planting × Varieties = 0.98					CD (p = 0.05) Times of planting = 0.59 Varieties = 0.54 Time of planting × Varieties = 0.93				

4.4 Meteorological parameters

4.4.1 Temperature (°C)

The temperature data was recorded under poplar plantations and in open conditions during the growing period of onion varieties shown in Table 4.13. It was observed that the average temperature was relatively higher under open conditions than under poplar plantations. The minimum and maximum temperature under poplar plantations varied from 7.9°C to 19.2°C in December and in May varied from 23.1°C to 37.8°C while in open conditions, the minimum and maximum temperature ranged from 7.6°C to 20.6°C in December and 22.7°C to 38.7°C in May. Trees help to ameliorate the microclimate by lowering the air temperature in the understory (Gill *et al* 2009). It was also reported that agroforestry system helps in retaining the productivity of agriculture crops by ameliorating the understory air temperature (Sehgal *et al* 2008).

Table 4.13 Monthly mean minimum and maximum temperature under poplar and in open conditions

Treatment	Under Poplar		Under Open	
	T min(°C)	T max(°C)	T min(°C)	T max(°C)
December	7.9	19.2	7.6	20.6
January	6.2	17.3	5.7	18.0
February	8.1	20.6	7.8	21.2
March	12.3	25.6	12.0	26.7
April	17.8	33.3	17.4	34.6
May	23.1	37.8	22.7	38.7
Mean	12.6	25.6	12.2	26.6

4.4.2 Relative humidity (%)

The average data of relative humidity recorded during the growth season of onion is presented in the Fig 4.3. The relative humidity was significantly higher under poplar canopy than under open conditions. Overall, under the poplar canopy, the maximum relative humidity was recorded in the January (79%) and minimum in May (44%). Breman and Kessler (1995) noticed that relative humidity remain higher under poplar canopy than in open conditions.

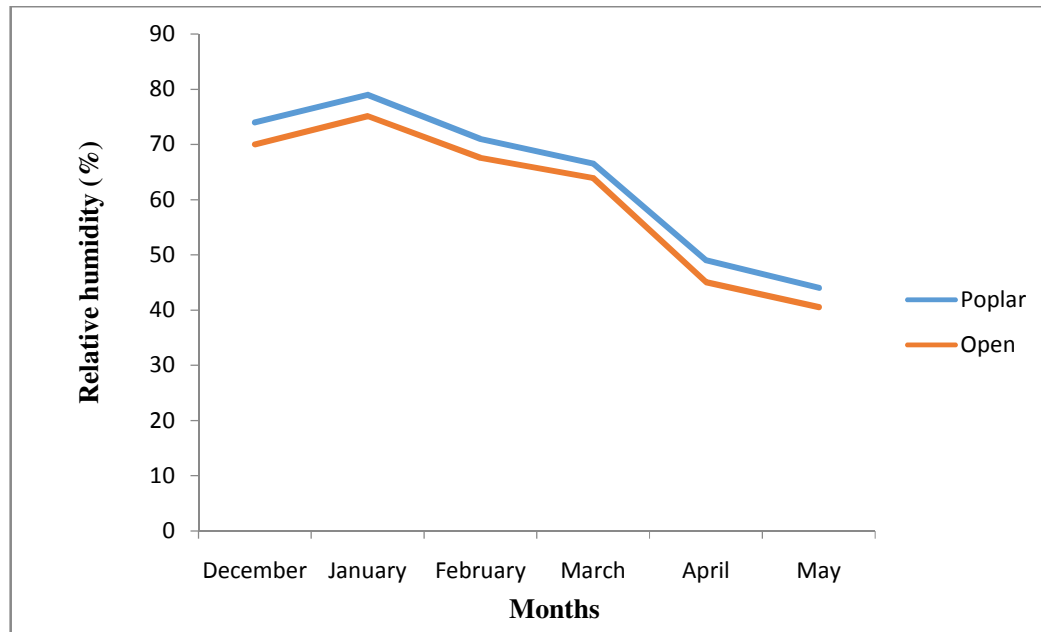


Fig 4.3 Relative humidity (%) recorded under poplar canopy and open conditions during growing season of onion

4.2.4 Photosynthetic active radiation (PAR)

PAR is micromoles of light energy per square meter per second that is available for

photosynthesis and lies in the range of 400-700 nm. Higher value of PAR leads to higher photosynthetic activity. Under poplar, maximum value of PAR was observed in the month of March and then decreased (Fig 4.4). Whereas under open conditions, value of PAR increased from the month of January to May.

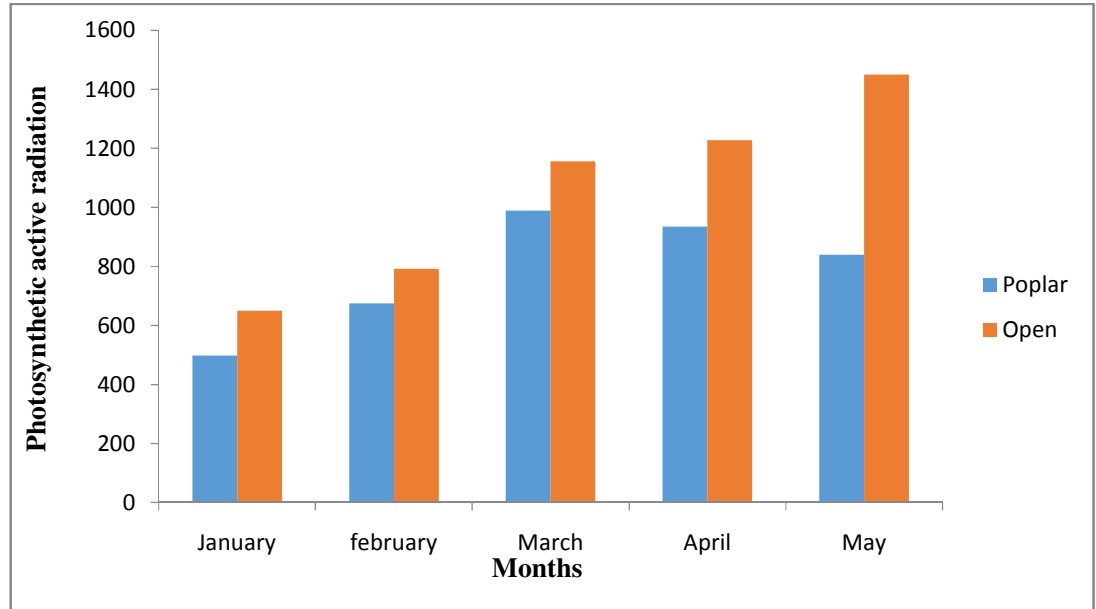


Fig 4.4 Comparison of photosynthetic active radiation (PAR: $\mu\text{mol m}^{-2}\text{s}^{-1}$) under poplar and in open

4.2.5 Leaf area index

Leaf area index is a dimensionless quantity that characterizes plant canopies. Leaf area index of poplar was recorded during the growing season of onion given in the Fig 4.5. It was recorded minimum in the month of January 0.29 and maximum in the month of May 0.9.

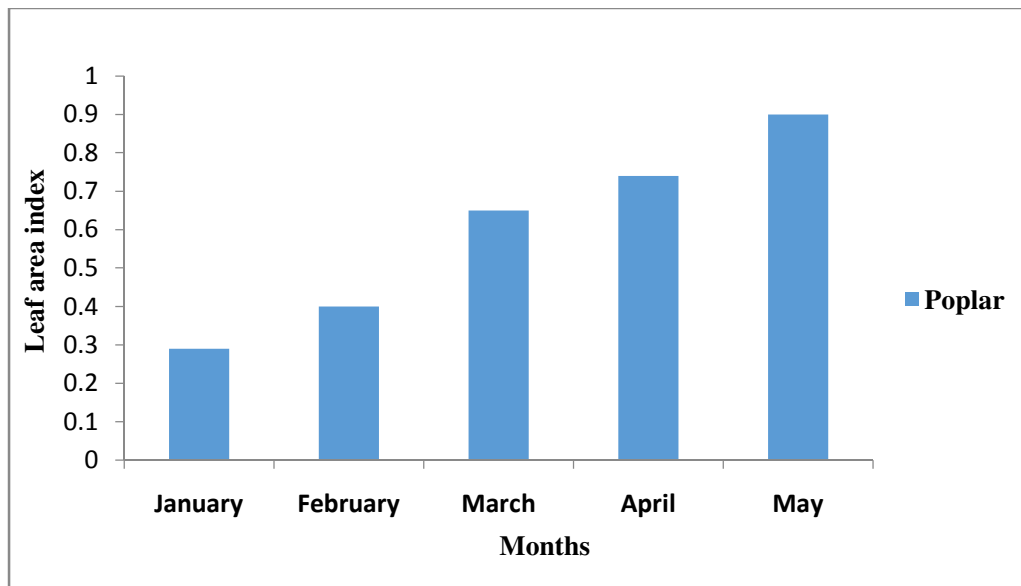


Fig 4.5 Leaf area index of poplar during the growing season of inter-planted onion crop

CHAPTER-V

SUMMARY

Agroforestry is a deliberate integration of trees with agricultural crops and/or livestock on the same piece of land in an order to obtain diversified products such as food, fodder, fruit, fuel and timber. It helps to improve the socio-economic status of the farmer by providing them an additional income. There are many sustainable agroforestry systems in approach in several parts of the world. Among them poplar based agroforestry system is one of the ecological and economical viable system that offers not only a sustained productivity, but also an increased productivity per unit area. *Populus deltoides* mostly planted in north-western parts of India such as Punjab, Haryana and Uttar Pradesh (Chauhan and Mangat 2006). Due to its winter deciduous nature, it is more complimentary for winter season crops when shading is not an issue and sunlight is accessible to the understory crop. In addition to wheat, number of agricultural crops such as turmeric, ginger, mustard, colocasia, potato, cabbage, garlic, spinach etc including fruit crops (citrus, mango, guava etc) can be profitably grown with poplar. Farmers choose to grow annual crops (turmeric, sugarcane etc) or seasonal crops in *rabi* (wheat, oats, barley, berseem, mustard etc) and *kharif* (cotton, sorghum, moong, pearl millet etc) crops with poplar.

Onion (*Allium cepa* L.) is known as “queen of kitchen” and one of the important vegetable crops grown all over the world which becomes an essential part of daily diet. The demand of the onion is worldwide and due to genetic variability and congenial atmosphere it can be grown in varied agro climatic regions. Present study was conducted to study the effect of microclimate on the growth and yield of onion varieties grown under the poplar plantation. Experiment was conducted in the main experimental area of Department of Forestry and Natural Resources, Punjab Agricultural University, Ludhiana in the year 2016-17 and 2017-18. The experiment was laid out in split-split plot design with three planting times i.e. end-December, mid-January and end-January; varieties viz. Pb-Naroya, PRO-6, PWO-35 and PRSC-10 with three replications. The onion varieties were also planted in open conditions for comparison of growth and yield parameters. The observations were recorded for various tree parameters viz. tree height (cm), dbh (cm), crown spread (m²) and leaf fall pattern (%); crop parameters viz. neck thickness, plant height, leaves per plant, weight of plant before and after curing, average fresh bulb weight, Days to bulb initiation, maturity and harvesting, bulb yield (q/ha), dry matter content and TSS (total soluble solids); meteorological parameters viz. minimum and maximum temperature, relative humidity and leaf area index. Following are the outcomes of the present study:

- Average tree height was recorded 9.7 m and 12.8 m in 2016-17 and 2017-18. Average diameter at breast height recorded during both the years was 11.2 cm to 13.1 cm. Poplar

started leaf shedding in the month of October and become completely leafless in the month of January. Average crown spread was 17.2 m² and 20.2 m² during both the growing seasons, respectively.

- Maximum neck thickness was recorded in the end-December planted crop followed by mid- January and end- January planted crop. Among the varieties, PWO-35 and PRSC-10 showed the maximum and minimum neck thickness during both the growing seasons.
- During the year 2016-17 and 2017-18, maximum and minimum number of leaves per plant was recorded in the end-December planted variety PWO-35 and end-January planted variety PRSC-10.
- Onion plant height was found maximum in the end-December planted crop as compared to other planting times followed by mid-January and end-January. Among the varieties, maximum plant height was recorded in the variety PWO-35 followed by Pb-Naroya, PRO-6 and PRSC-10.
- Bulb diameter of onion was recorded for both the growing seasons 2016-17 and 2017-18, maximum and minimum bulb diameter was recorded in the end December planted variety PWO-34 and end January planted variety PRSC-10, respectively.
- Weight of whole plant before curing and after curing was observed maximum in the end-December planted crops followed by mid-January and end-January during both the years of study. Among the varieties, PWO-35 attained the maximum weight of plant before and after curing followed by Pb-Naroya, PRO-6 and PRSC-10.
- Variety PRO-6 took minimum number of days to bulb initiation, maturity and harvesting followed by Pb-Naroya, PWO-35 and PRSC-10. Among the planting times, end-December planted crop and end-January planted crop took maximum and minimum number of days to bulb initiation, maturity and harvesting, respectively.
- Bolting percentage was found to be more in the end-December planted crop and less in the end-January planted crop during both the years. While, during the year 2016-17, variety PRO-6 showed the maximum bolting percentage followed by PWO-35, Pb-Naroya and PRSC-10 whereas in the next successive year 2017-18, maximum bolting percentage was recorded in PRSC-10, followed by PRO-6, PWO-35 and PRSC-10.
- Bulb yield during both the years was higher under open conditions as compared to poplar trees. Under open, it was higher in variety PWO-35 followed by Pb-Naroya, PRO-6 and PRSC-10. Likewise, under poplar, it was higher in PWO-35 and PRSC-10 recorded the minimum bulb yield. Among the growing seasons, bulb yield was higher in the first growing season; 2016-17 under both the open and poplar plantations as compared to the second growing season 2017-18.
- Dry matter content and TSS was recorded maximum in the end-December planted variety

PWO-35 and minimum in the end-January planted variety PRSC-10 for both the growing seasons.

- The average temperature was relatively higher under open conditions than under poplar plantations whereas relative humidity was observed significantly higher under poplar canopy than under open conditions.
- The value of PAR was observed maximum in the month of March and then decreased whereas under open conditions, value of PAR increased from the month of January to May. LAI was recorded minimum and maximum in the month of January and May.

Conclusion

1. End-December planting time was better than the other planting times for higher growth and bulb yield of onion under poplar trees.
2. Onion variety PWO-35 performed significantly better than rest of varieties followed by Pb-Naroya, PRO-6 and PRSC-10.
3. Onion varieties namely PWO-35, Pb-Naroya, PRO-6 and PRSC-10 could be successfully grown under the poplar plantations in the end-December planting time.
4. Onion crop showed positive effect on the tree growth parameters such as tree height, diameter at breast height and crown spread.

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