Plantation Techniques of *Populus deltoides* Bartr for Problematic Sites in Temperate Region of North Western Himalayas

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Thesis

Submitted to

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in partial fulfilment of requirement for the award of the degree of

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Dedicated

to my beloved Parents

Sher-e-Kashmir
University of Agricultural Sciences and Technology of Kashmir
Faculty of Forestry, Benhama, Ganderbal (J & K)-191201

Certificate – I

This is to certify that the thesis entitled, **“Plantation Techniques of *Populus deltoides* Bartr. for Problematic Sites in Temperate Region of North Western Himalayas”** submitted in partial fulfilment of the requirements for the award of the degree of **Doctor of Philosophy in Forestry** to the **Faculty of Forestry, Sher-e-Kashmir University of Agricultural Sciences and Technology of Kashmir** is a record of bonafide research work carried out by **Mr. Tahir Mushtaq (Regd. No. 2012-430-D)** under my supervision and guidance. No part of the thesis has been submitted for any other degree or diploma.

It is further certified that information received during the course of investigation has duly been acknowledged.

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We, the members of the Advisory Committee of **Mr. Tahir Mushtaq (Regd. No. 2012-430-D),** a candidate for the degree of **Doctor of Philosophy in Forestry** have gone through the manuscript of the thesis entitled, **"Plantation Techniques of *Populus deltoides* Bartr. for Problematic Sites in Temperate Region of North Western Himalayas"** and recommend that it may be submitted by the student in partial fulfilment of the requirements for the award of the degree.

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Certificate – III

This is to certify that the thesis entitled, **"Plantation Techniques of *Populus deltoides* Bartr. for Problematic Sites in Temperate Region of North Western Himalayas"** submitted by **Mr. Tahir Mushtaq (Regd. No. 2012-430-D)** to the **Faculty of Forestry, Sher-e-Kashmir University of Agricultural Sciences and Technology of Kashmir** in partial fulfilment of the requirements for the award of the degree of **Doctor of Philosophy in Forestry** was examined and approved by the Advisory Committee and External Examiner on …………….. .

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ABSTRACT

The present study entitled “Plantation Techniques of *Populus deltoides* Bartr. for Problematic Sites in Temperate Region of North Western Himalayas” was conducted at Faculty of Forestry, Sher-e-Kashmir University of Agricultural Sciences and Technology of Kashmir, Benhama, Ganderbal, Jammu and Kashmir. The land of the experimental site was problematic pertaining to three types of problems namely: degraded underutilized (scrub dominated), degraded pastures/grazing lands, barren rocky/stony waste.

The investigations on planting seasons, intervals and nitrogen fertilizer levels were done to assess the establishment and growth of *Populus deltoides* plantations on problematic sites. The treatments included two planting seasons, three planting intervals and four nitrogen levels. The observations were recorded after the completion of one growing season i.e. onset of autumn season. Among the two seasons, autumn planting (S_1) was found best over the spring planting (S_2) under temperate conditions. Out of three planting intervals, Planting Interval I (PI_1) was proven to be best over Planting Interval II (PI_2) and Planting Interval III (PI_3), respectively. The nitrogen dosages N_2 (150 kg N/hectare) in the form of urea was found better as compared to other three nitrogen levels with respect to establishment and growth of poplar plantations. The interactional treatment combinations $S_1PI_1N_2$ (autumn planting × planting interval I × 150 kg nitrogen/ha) gave highest survival and growth over the rest of treatment combinations in both the planting seasons.

The study on planting seasons, pit shapes, sizes and moisture conservation measures (mulching) were done to assess the establishment & growth of *Populus deltoides* plantations on problematic sites. The treatments included two planting seasons, three pit types, three pit sizes and three mulching treatments including control. Autumn planting season (S_1) was observed to be the best over the spring planting season. Among the three pit types, PT_2 (Saucer Pit) gave highest survival with better growth parameters. It was also found that among three pit sizes, PS_3 (60×60 cm^3) observed to give higher survival and growth of plantations as compared to PS_2 (45×60 cm^3) and PS_1 (30×45 cm^3). Black polythene mulch (M_2) gave higher survival and growth over the paddy straw mulch (M_1). The treatment combinations $S_1M_2PT_2PS_3$ (autumn planting × black polythene mulch × pit type II × pit size III) gave better survival and higher value of growth parameters in poplar plantations. The moisture regime of soil was measured under three different moisture conservation measures. Moisture percentage under black polythene was more as compared to ordinary mulch (paddy grass) and control. Saucer pit gave highest percentage of moisture which was further followed by ring pit and ordinary pit. The highest moisture was found under 60×60 cm^3 followed by 45×60 cm^3 and 30×30 cm^3 in both the planting seasons.

The experiment on planting seasons, age of planting stock and hydrogel were done to assess the establishment & growth of *Populus deltoides* plantations done on problematic sites. The treatments included two planting seasons, two types of planting stocks and five hydrogel levels. Autumn planting was observed to be best over spring planting. Two years old planting stock (A_2) was better as compared to one year old planting stock (A_1). It was also recorded that among five levels of hydrogel H_3 (3.0 g/plant liquid application) was found better as compared to other four hydrogel levels applied. The interactional treatment combinations $S_1A_2H_3$ (autumn planting × planting stock II × hydrogel level @ 3 g/plant) gave highest survival and growth in *Populus deltoides* plantations.

The effect of different treatments on soil was also recorded under poplar plantations done on problematic sites. The soil physico-chemical parameters were found to vary with different treatments under temperate conditions. The economic valuation of poplar plantations done on problematic site in temperate conditions is beneficial venture as per the outcomes of the investigations. The B/C ratio was calculated by taking the 8 years rotation age of the poplar plantation and it was worked out to be 6.07.

Key words: Plantation, season, growth, site, hydrogel, pit, mulch, survival, moisture, soil, problematic.

Signature of Student	Signature of Major Advisor
Dated____________	Dated ____________________

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CONTENTS

LIST OF TABLES

LIST OF FIGURES

LIST OF PLATES

ABBREVIATIONS USED

g	Gram
kg	Kilogram
cm	Centimeter
m	Meter
mm	Millimeter
ha	Hectare
^{o}C	Degree Celsius
pH	Hydrogen ion concentration
C. $D_{0.05}$	Critical difference at 5% level of significance
C.D0.01	Critical difference at 1% level of significance
amsl	Above mean sea level
EC	Electrical conductivity
OC	Organic carbon
WHC	Water holding capacity
BD	Bulk density

Chapter-1

INTRODUCTION

Land is one of the most important resource on which human beings depend. The rate of soil degradation is continuously increasing with the advancement of science & technology, industrial expansion, urbanization and population explosion. The most important cause of land degradation is destruction of forests and other vegetation from sloping lands, river sides and other areas sensitive to damage (Pramod and Mohapatra, 2012). Anthropogenic activities like over grazing, wood cutting and burning have intensified land degradation results in soil deterioration all over the world (Jin, 2002). Vegetation acts as a protective cover against the forces of wind and water, protecting the soil from being washed or blown away and preserving the physical and hydrographic balance of nature (Jain and Singh, 1998). Plantations can conserve soil on degraded lands by reducing nutrient loss, increasing soil organic matter and improving the soil texture (Thapa, 2003). The plantation forestry is ecologically as well as economically viable option than traditional forestry. Plantation technology of fast growing species mainly Poplar and Eucalyptus have been taken up by farmers and institutions to boost wood production in the world. Plantation forestry has the potential to augment farmer’s income substantially. Tree plantations present an economically attractive alternative to natural forests and might also be a practical option for bringing the degraded lands to production option. Plantation forestry has been shown to contribute considerably in terms of carbon sequestration, increased soil organic carbon and conservation of biodiversity (Bremer and Farley, 2010).

In India, a major portion of the land is effected by different types of soil degradation (soil and water erosion, soil salinity, alkalinity, acidity, etc.). Large areas in the country have been rendered useless as a result of soil deterioration and problem of low productivity due to soil losses which is much larger as one can think. The problematic soils cover an area of 24 million hectare, accounts to be

7.30 percent to the total geographical area of the country. It presents a serious threat to achieve the target of higher crop productivity. The reclamation of problematic lands of India is becoming important because of increased demands for food, fodder, fuel and shelter (Banerjee and Raza, 1992). The National Wasteland Development Board (NWDP) was set up with the objectives of checking the good lands from further degradation, increasing tree and other green cover on the problematic lands, promoting fuelwood and fodder trees and to involve people in afforestation programmes. The most important way to reclaim problematic soils is to plant trees (Tomar *et al.*, 2003). There is growing concern in India about the degradation in the quality of forests and significant reduction of the forest tree cover.

Jammu and Kashmir is predominantly a hilly state with forest cover of 20,230 km^2 accounting for 19.95 percent of the total geographical area of 1,01,387 km^2. About ⅔rd of the states' total area is under recorded forest and the substantial part of this is non-conducive for the growth, being under permanent snow, glaciers and cold deserts (Digest of Forest Statistics, 2012). The total problematic area of the state is about 45.70 per cent. This area is prone to soil erosion and other forms of degradation leaving behind the denuded and degraded soils with poor service for mankind. The degradation of forest resources in Jammu and Kashmir has been accelerating, owing to the rapid growth of population which is coupled with the development of agriculture and urban construction. The situation is further aggravated by faulty forest management practices in vogue. As a result of forest degradation, environmental problems including soil erosion and loss of biodiversity are being experienced and natural hazards are occurring with increasing frequency. Now the government of Jammu and Kashmir is focusing on conservation of forests and restoration of problematic areas existing in the state.

To maintain the fertility of degraded soils. It is essential that the lost nutrients are made equally good by artificial means. Fertilizers play a vital role in boosting the initial growth and development of plants (Moscatelli *et al.*, 2008).

However, the optimum requirement for the different fertilizers varies with the species as well as the prevailing soil fertility status. In the developed countries, the conventional tool used by foresters for maintaining higher productivity is fertilization. Whereas, the application of chemical fertilizers in plantations is not very common in developing countries like India. It is well documented that too much or too little N, P and K may result in poor establishment and growth of the stands. Optimum fertilization extended the fast growing period of the tree as well as the survival percentage of the out planting (Jagger and Pender, 2003). Among the various nutrients, nitrogen is the major element required for the growth of all plant species which is always available in limited quantity in the soil. Nitrogen being a major plant growth nutrient plays a pivotal role in the plant growth systems. It is an integral part of protein, enzymes and nucleic acids which are responsible for the development of chlorophyll. Thus, nitrogen supply to plants is of utmost importance in all the crops.

Populus deltoides locally called as '*Fras'* make a striking and important contribution to the landscape and economy of Jammu and Kashmir. Poplars in the state have gained considerable importance in farm and plantation forestry like other neighbouring states of Uttrakhand, Haryana and Punjab. Poplars are fast growing trees; they recycle nutrients fast due to their shedding of a large quantity of leaves which decompose early. Poplar timber is being used for making apple boxes, interior wood work, beams, poles and fuelwood. Poplar is one of the few forest species which is considered ideal for successful inter cultivation with agricultural crops. Poplars are known for their fast growth, easy vegetative propagation and enriching the soil with litter and provide high production (10-30 m^3/ha/year) on a short rotation of 8-12 years (Chandra, 1986). Food and Agriculture organization (FAO) has recommended the introduction of poplars to meet the increasing timber requirement of the world. The poplars have the potential for narrowing down the gap between demand and supply of wood. Therefore, various attempts have been made in the past for raising this economically important species on problematic lands in different parts of the world.

In temperate region particularly in Kashmir valley, farmers possess small land holding which is mostly under the cultivation of agricultural crops. Therefore, farmers are left with only option to plant trees on degraded lands. As the availability of land for tree plantation is insufficient, people have to grow short rotation crops. Short rotation species are seen as an option to have better income and biomass in a short time and in a sustainable way (Bentsen and Felby, 2012). Poplars are cultivated not only on arable lands but also on problematic soils. The most important exotic species used for this purpose in the region is *Populus deltoides*. It is the most commonly observed species in community and household woodlots. In an environment suffering from land degradation and deterioration, fast growing and resilient *Populus deltoides* perform better than most indigenous tree species. Small holders show a clear preference for this poplar which is multiple in use (Jagger and Pender, 2003). Therefore, an attempt was made to utilize degraded lands for poplar plantations to address the problem of land degradation with social commitment.

The current emphasis on plantation has regularly been confined to merely achieving the targets without taking the cognizance of the success of the plantations. Greening of degraded and problematic landscapes is the most important task of all the afforestation activities. It is common sights in hills and plains to see the same area is being planted and replanted year after year with a little or negligible success. A big reason behind the fiasco is lack of technical knowhow. The common practice prevailing for out planting results in seedling moisture stress and competition with weeds for light, moisture, nutrients and space. Moisture conservation is the quintessence of any plantation strategy on problematic sites to have the success. The use of appropriate soil working techniques and management ensures more infiltration and higher moisture retention in the soil.

Faulty landuse systems and inflated human population have led to land degradation in the hills and plains. The efforts of the planners, foresters and scientists have brought heavy chunk of areas under plantation but success is heading to low year after year. The reason is being the age old practice and poor physico-chemical attributes of such soils (problematic lands). In order to restore the productive potential of such lands, soil working and use of suitable trees with other measures like fertilizer application, moisture conservation etc. are the alternatives for ameliorating these problematic lands. At present the knowledge about the planting techniques on problematic sites is very limited and moreover specific to specific areas. Therefore, there is an urgent need to undertake such work on scientific lines to develop techniques in tune with the existing problems.

The present study was undertaken to address the problems of problematic sites through scientific interventions for getting the better survival and growth of the plantations. The study was conducted by dividing it into following objectives:

- To standardize the out planting techniques with intervals in problematic sites existing in temperate region.
- To determine the best physiological attributes of out planting stock for better survival and growth.
- To elucidate the effect of nitrogen fertilizer on establishment and growth of plantations.
- To suggest suitable moisture conservation measures for problematic sites.
- To work out the relative economics of plantations.

Chapter-2

REVIEW OF LITERATURE

Review of literature has been divided into the following sections based on the objectives of the investigations:

2.1 Out planting techniques for problematic sites

2.2 Physiological attributes of out planting stock

2.3 Effect of nitrogen fertilizer on establishment and growth of plantations

2.4 Moisture conservation measures for problematic sites

2.5 Economics of plantations

2.1 Out planting techniques for problematic sites

Singh and Tiwari (1996) found that there are different categories of problematic lands namely degraded and wastelands which need immediate attention for rehabilitation to increase the vegetative cover in the country. The only answer to this problem is afforestation of the area with suitable tree species. The techniques for treating such lands vary with the type and area of the land to be treated.

Balagopalan *et al.* (1998) studied the effect of various silvicultural treatments and nutrient combinations on growth and volume of *Eucalyptus grandis* and observed that pit size of 40 cm^3 out of 3 tested pit sizes and fertilizer dosage of 30 g N/plant was found to be most effective among all the four treatments.

Viero *et al.* (2000) conducted an experiment to study the effect of different pits and hydrogel applications on the growth and establishment of *Eucalyptus camaldulensis* and *Eucalyptus grandis*. Five levels of hydrogel (0, 3, 6, 9 and 12 g) were applied to all the planting pits to determine the best treatment level. Tree height, collar diameter and leaf area index were assessed at regular intervals for determining the effect of tested treatments. It was reported that 9-12 g of hydrogel per litre per pit is best for the establishment and growth of both the Eucalyptus species.

Pal and Sharma (2001) showed that the productive capacity of problematic lands can be improved by planting trees. Twelve species of trees were planted in the Aravalli hills (Haryana) and only *Acacia nilotica*, *Leucaena leucocephala* and *Terminalia arjuna* grew well. The soil pH, electrical conductivity, organic carbon and available phosphorous recorded significant improvement at three depths (upto 45 cm) in the study area.

Mishra *et al.* (2003) conducted an experiment to analyze the effect of different plantation techniques on degraded sodic soils at Sultanpur, U.P, India. Effect of pit shape, spacing and size of pits was studied under 3, 6 and 9 years old plantations with regard to changes in soil characteristics of sodic wastelands. The results showed an improvement in the physical as well as chemical properties of sodic soil after plantation. It was further reported that pH, electrical conductivity (EC) and exchangeable sodium percentage (ESP) values were declined whereas, the values of organic carbon, total N, available P and exchangeable Ca^{2+}, Mg^{2+} and K^{+} levels of the soils get increased . There was a decrease in bulk density and an increase in soil porosity and water holding capacity of the soil. The ameliorative effect of the trees became more distinct with the increasing age of plantation. It was also reported that the productivity and fertility of the degraded sodic soils can be restored by tree plantation.

Kumar *et al.* (2004) reported the effect of different land management methods on the growth behavior and establishment of four tree species (*Acacia nilotica, A. auriculiformis, Casuarina junghuhniana* and *Leucaena leucocephala*) under problematic soil conditions. The experiment consisted of different land management methods: (M_1) broadbed and furrow method, (M_2) raised mound method, (M_3) saucer method and (M_4) pit method. The plant height, collar girth and root length of the tree species were significantly influenced by the land management practices. M_3 method of planting registered the highest plant height, collar girth and root length among the different land management methods.

Goel and Behl (2004) investigated the performance of three leguminous species (*Acacia farnesiana*, *Acacia nilotica* and *Acacia siamea*) at three planting distances and under three pit types (auger planting, ring pit planting and saucer planting) on a highly alkaline soil. The results revealed that *Acacia nilotica* showed better growth performance under saucer pit planting compared to other species in problematic soil.

Melo *et al.* (2004) reported the effect of *Eucalyptus camaldulensis* plantations on soil carbon and nutrient contents at different pit depths and fertilizer applications on degraded soils of Cerrado, Brazil. At the time of outplanting, fertilizers were applied at the rate of 40 g of ammonium phosphate, 60 g of triple superphosphate, 20 g of potassium chloride, 2 g zinc sulphate, 3 g of borax and 500 g dolomitic lime for plant per planting pit. It was found that the increasing pit depth resulted in increase of organic carbon and potassium contents in the upper layers of soil. Whereas, the elements namely phosphorus, calcium, magnesium and organic carbon showed an inverse trend with the increasing depth of pits.

Shams-ur-Rehman (2004) recommended that pit of 60 cm^3 is found to be best for plantation on saline soils. He further screened that *Casuarina obesa* and *A. ampliceps* may be helpful in improving the fertility level of saline soils while conducting the experiment in Punjab, Pakistan.

Vlasin and Holonac (2006) conducted a study to establish the best working technology for reforestation of *Quercus robus*. The effect of tillage, chemical fertilizer (5 and 10 g Ammonium Nitrate/pit), and mulching (polythene, carton, straw) was worked out on plant establishment and growth. The observations recorded after one growing season revealed that the best management practices are in order of tillage + 10 g N fertilizer > control > 20 g N fertilizer+ tillage.

Nasim *et al.* (2007) worked out the effect of different plantation techniques adopted for establishment and growth of *Eucalyptus camaldulensis* under degraded salt affected sites and found that the pit size 60 cm^3 gave higher values of all the growth parameters of outplanted *Eucalyptus* species. They further reported that soil pH, EC and SAR were significantly lower in the pits where plants had good growth.

Qian *et al.* (2007) reported the effect of different pit types on plantation establishment and growth in sandy desert areas. It was observed that saucer pit, ordinary pit, ridge ditches and ring pit were found to be out performed for outplanting of trees among all the tested pits in sandy soils. Planting period was equally responsible to effect the different soil parameters. The content of soil organic carbon, available nitrogen, phosphorus and potassium were all increased in their status with the increase of planting period in new opened up bad lands.

Subudhi and Behera (2008) conducted a study to determine the suitable moisture conservation techniques for forestry plantations under dryland hill slopes in Kandhmal, Orissa, India and found that the rate of growth of teak and mango under T_5 (Ring pit) was significantly higher as compared with all the other treatments. Ring pit is recommended to get higher plant growth particularly in the north eastern ghats of Orissa.

Gardini *et al.* (2008) conducted an experiment to study the effect of open and gravel pits on the growth of *Prunus avium* plantations in the Soria provenance of Spain. The plantation was established at a spacing of 650 stems/ha, after the application of organic amendments during site preparation and also during plantation establishment via fertigation. Preliminary indication of just 3 years old plantation showed good growth of the outplanted stock. The organic carbon content of the soil was increased significantly with the advancing age of plantations whereas, the soil pH was decreased.

Pazhanivelan *et al.* (2009) conducted a field experiment in alkali soil at Agricultural College and Research Institute, Trichy, Tamil Nadu, India, with three tree species and three planting techniques and found that *Leuceana leucocephala* survived more than 90% than the rest of tree species. The highest growth and collar girth was observed in *Leuceana leucocephala* followed by *Hardwikia binata* and *Annona squamosa*. Among the planting techniques, auger hole method recorded higher plant height as compared to pit method of planting. In pit method, there was reduction in soil pH and ESP at 0-15 cm. However, higher pH and ESP were observed in 60-90 cm depth.

Pensa *et al.* (2010) reported the effect of different plantation techniques on growth and establishment of *Populus balsamifera* on semi coke dumping degraded sites. Three plantation techniques namely pit planting, ridge ditch planting and ordinary planting were adopted. It was found that pit planting along with application of organic manure found to improve the growth of plantation under degraded conditions. It was also observed that plantation promotes the under growth of herbaceous vegetation.

2.2 Physiological attributes of out planting stock

Wilson and Jacobs (1996) reported that the assessment of seedling quality is an important component of reforestation and afforestation programmes. Use of low quality seedlings may result in poor growth rates and plantation establishment. They also reported that the evaluation of root electrolyte leakage is promising means for this purpose. Three species of hardwoods like red oak, black walnut and black cherry were evaluated for electrolyte leakage and found that higher the leakage more is the cell damage and difficult in establishment of plantation.

Rose *et al.* (1997) reported that seedling root volume had positive correlation with field survival performance. Seedlings with larger initial root volumes (> 7 cm^3) had significantly higher field survival than those with smaller root volumes (< 4.5 cm^3). Seedlings in the higher root volume category also had greater height growth. It was also reported that seedlings with larger root volumes were better able to mitigate the effects of transplant shock except in the case of extensive moisture stress.

Mackay (1998) reported that root electrolyte leakage is of immense significance in seedling quality test. After outplanting, the main cause of seedling mortality is transplant shock induced by water stress. A newly planted seedling must be able to extract water from the surrounding soil using its existing roots and root electrolyte leakage measures the viability of the root system. A low electrolyte leakage indicates high root viability, thus responsible to allow water uptake to mitigate transplant shock.

Singh (1998) reported the effect of fibrous root biomass on rehabilitation of problematic sodic soils at Lucknow, India. The contribution of root fibrosity was apparently greater in the reclamation of soil structure, pH and water permeability. The net change in soil nutrient pool on afforestation increased the soil C pool to 13 times and total N twice through the regular inputs from fine roots and litter fluxes. It was also reported that higher root fibrosity results in better plant survival on problematic soils.

McNabb and Takahashi (2000) reported that electrolyte leakage is directly related to seedling performance. Electrolytes are contained within the membranes of plant tissues. These membranes are sensitive to environmental stresses such as chilling and freezing conditions. An estimation of cell damage and hardiness can be made by comparing the leaked contents from injured and uninjured tissues. It was also found that electrolyte leakage from both roots and shoots directly influence seedling establishment and growth.

Noland *et al.* (2001) reported that number of first order lateral roots

(roots > 1 mm) is a measure of seedling quality. It was also reported that there is a positive correlation between number of first order lateral roots and performance of oak (*Quercus alba*) tree seedlings on problematic sites.

Bolu and Polle (2004) reported the effect of saline soils on growth and physiology of poplar species. After exposure to saline conditions, the relative growth rate and establishment of seedlings were initially stimulated but declined the growth in control after several days. It was further showed that leaves display severe injury indicated by chlorophyll loss and significant electrolyte leakage as compared to control after three weeks of exposure to saline conditions. Stability of membranes was also damaged as seedlings were continuously exposed to saline conditions.

Jacobs *et al.* (2004) found that *Quercus rubra* seedlings with larger root volumes at the time of transplanting had similar water potential values during summer as those with lower root volumes. They also reported that seedlings with larger root volumes could initially be at a disadvantage following transplant because of corresponding greater leaf area which acts to increase water loss due to higher transpirational demand.

Davis and Jacobs (2005) reported that seedling quality assessment is critical to ensure plantation success. Root system morphology and physiological status may provide accurate indication of seedling potential. Large root volume, high root fibrosity and an increased number of first order lateral roots have shown some correlation to improve field performance of outplanted seedlings. The high morphological and physiological standards of seedlings enable them to rapidly establish and thrive upon outplanting sites.

Molla *et al.* (2006) studied the physiological and transplanting performance of *Quercus ilex* seedlings with different winter conditions. It was found that seedlings grown in cold winter sites have higher stress resistance, vigour and transplanting performance than the seedlings grown in mild winter conditions. Root growth activity and electrolyte leakage had the same seasonal variation pattern at both locations and did not correlate with frost hardiness.

Amanullah *et al.* (2007) reported the response of specific leaf area and leaf area index to plant density and timing of nitrogen application. It was found that specific leaf area and leaf area index increased with increase in plant density. Balanced amount of nitrogen application at proper time found to decrease nitrogen losses and increase the growth and establishment of plantations. It was further recorded that more leaf area of a plant results in higher photosynthetic activity and finally higher growth as outcome.

Immanuel and Ganapathy (2007) reported the effect of degraded soils (saline soils) on growth and physiology of *Ceiba pentandra.* The effect of salinity on germination, electrolyte leakage, vigor index, chlorophyll stability index and ionic uptake of seedlings were examined. The seed germination, morphological and physiological parameters were slightly affected by 3-9 dsm^{-1} salinity concentration but were markedly reduced on the 12-15 dsm^{-1}. Raising of salinity in soil solution increased ionic concentration in the leaf tissue leading to reduction in leaf size and leaf area.

Jozefek (2007) reported that electrolyte leakage has been used extensively for testing the cold hardiness, dormancy status cell membrane integrity and physiological activity. It effects not only physiological characteristics such as cold hardiness, water potential, etc. but can indirectly affect indicators of morphology such as plant height and root structure.

Zhao and Liu (2009) reported the effect of physiological parameters on growth and establishment of *Picea asperata* seedlings under elevated temperature and nitrogen fertilization. Nitrogen fertilization significantly improved seedling growth in unwarmed plots by stimulating electrolyte leakage and maximizing net photosynthetic rate. The beneficial effects of physiological parameters on *Picea asperata* seedlings could not be magnified by artificial warming.

Coll *et al.* (2011) reported the effect of nitrogen availability on photosynthetic capacity, root shoot ratio, leaf area and electrolyte leakage of hybrid poplar plantations. The changes in photosynthetic capacity which accounted for most of the differences in growth between trees with different levels of nitrogen and other parameters were less influential. The study recommends that physiological rather than morphological traits predominate in determining growth of fast growing early successional broadleaved species like poplar.

Sajid *et al.* (2012) reported the effect of different planting dates on survival and physiological parameters of *Platanus orientalis*. It was reported that survival percentage, sprouting percentage, root volume per plant, number of roots per plant, leaf area per plant, root & shoot leakage and root membrane stability were significantly influenced by planting dates. Hardwood plants showed maximum sprouting percentage (57.56%), survival percentage (44.78%), root length (47.27 cm), root volume (12.52 cm^3), leaf area (832 cm^2) and root leakage (0.0000872 dsm^{-1}) than semi hardwood and softwood plants for early planting (January).

2.3 Effect of nitrogen fertilizer on establishment and growth of plantations

Bowersox *et al.* (1991) reported the effects of different concentrations of nitrogenous fertilizers on survival, height and diameter of *Populus hybrid* in central Pennsylvania. Treatments namely control, fertilization and fertilization/irrigation were given on two sites continuously for two years. Overall treatment survival was not effected by site but values were lower for 1980 planted trees (83%) than 1981 planted trees (90%). Treatments with fertilizers had lower survival (78%) than the treatments without fertilizers (86%). The two years old trees gave 5.3 and 6.8 m average height and 3.4 and 4.2 cm diameter for the 1980 and 1981 establishment years, respectively. Fertilization, with or without irrigation consistently increased annual height and diameter over the control.

Davidson *et al.* (1998) reported the effect of nitrogenous fertilizers on growth and establishment of fifteen native tree species planted on volcanic degraded lands. Fertilizer was applied in different concentrations (50, 80 and 120 kg/ha). It was reported that survival and growth was higher in early successional species with moderate concentration of nitrogen. i,e. 80 kg/ha.

Schielle *et al.* (1999) reported the effect of different fertilizers on Balsam poplar, aspen and *Salix species*. It was reported that *Salix* and aspen responded significantly to nitrogen fertilization (50 and 100 kg N/ha/year) and no effect of Ca, Mg and P was observed. The Balsam poplar proved to be most interesting species as it does not responded to any kind of fertilization for at least 10-15 years.

Evans (2000) reported that nitrogen, phosphorous and potassium played an important role in limiting plant growth and yield. Nitrogen is primarily required for increasing plant growth more than any other nutrient. High amount of nitrogen often results in excessive shoot and foliage growth, reduced root growth and increased susceptibility to environmental stresses.

Gilman *et al.* (2000) reported the influence of different nitrogen doses (20, 40 and 80 g/m^2) on the growth parameters of Magnolia and Oak. The results showed that 40 g/m^2/year resulted in greater height than 20 and 80 g/m^2/year in first year after planting. Nitrogen rates greater than 40 g/m^2 did not result in more growth. Seedlings received nitrogen soon after transplanting responded by growing faster than those that received no nitrogen.

Paul *et al.* (2000) reported that the application of N and P fertilizers gave 8 times higher values of growth parameters than the unfertilized treatments (control). It was further added that the higher rates of N application with P dosages produced the plants with uniform quality in leaves and twigs.

Xu *et al.* (2002) reported the influence of nitrogen fertilizer on establishment and growth of *Araucaria cunninghamii* plantations. It was observed that nitrogen fertilizer is required to improve the nutritional status and found to enhance the plantation growth after the initial nitrogen supply.

Marigoudra and Madiwalar (2004) conducted an experiment to study the effect of planting techniques and fertilizer levels on the initial growth increment in teak plantations. The treatment consisted of two planting methods: pit and crow bar hole methods, FYM and NPK fertilizers. The net growth increment attributes such as plant height, collar diameter, number of main stem nodes and leaf area per plant of teak was not effected which might be due to the planting methods. The net increment in all the growth attributes was significantly higher with application of NPK @ 30 g/plant over the control.

Mtui *et al.* (2005) carried out an investigation to determine the effect of fertilization on second rotation of *Pinus patula* stands as an option for increasing growth and yield in hill forest plantations. Five fertilization treatments consisting of nitrogen (0 and 60 kg/ha) and phosphorus (0, 30 and 60 kg/ha) were applied to plantations. Tree height and DBH were measured after 18 and 22 months after fertilization, respectively. It was observed that both tree heights and DBH of trees increased significantly at 60 kg nitrogen per hectare. However, the application of nitrogen decreased tree survival from 96 to 89 percent.

Salvador *et al.* (2005) reported the effect of nitrogen fertilization in the plantations done on frost and water stress conditions in Mediterranean forest species. Plants were cultivated under two contrasting nitrogen fertilization regimes. It was reported that nitrogen fertilization found to effect the morphological than the physiological characters. High fertilized plants in all the species were larger and had greater shoot root ratio than low fertilized and unfertilized plants. High nitrogen showed higher number of new roots than low nitrogen applied plants. Shoot size was greater in high nitrogen than in low nitrogen treated plants.

Oskarsson *et al.* (2006) reported the effect of fertilization in plantation with respect to survival, growth and nutrition of tree seedlings on problematic soils. Seedlings provided with slow release fertilizer of easily soluble nitrogen showed significantly improved survival and growth. Higher dosages of nitrogen increased mortality during the first year. Fertilization in afforestation activities with similar climatic and soil conditions could make the difference between plantation success and failure.

Sarvar *et al.* (2007) studied the influence of different nitrogenous fertilizers on the growth and survival of three years old *Camellia sinensis* plants. The nitrogenous fertilizers used were ammonium sulphate, calcium ammonium nitrate, urea and nitrophos (biofertilizer) along with control. All the nitrogenous fertilizers were applied at the rate of 100 kg/acre along with the constant dosages of P and K (25 and 15 kg/acre). It was found that the effect of all the fertilizers on plant height and survival was non-significant. However, ammonium sulphate produced the highest plant height with canopy. The response of other fertilizers was in the order of nitrophos, urea and calcium ammonium nitrate, respectively.

Moscatelli *et al.* (2008) reported that nitrogen fertilization is required to maintain the production of short rotation forest plantations. Two fertilizer dosages were applied, i.e. 212 kg N/ha at the time of out-planting and 290 kg N/ha after one growing season. It was showed that fertilization did not modify soil capacity to accumulate organic matter although, a positive variation was observed at the beginning of the study. At the end of first growing season fertilization did not change soil nitrogen content although, significant changes were seen after second growing season.

Cicek *et al.* (2010) reported the effect of fertilization in first growing season on early survival and growth of narrow leaved ash (*Fraxinus angustifolia*). Fertilization treatments per tree were control, 67 g of NPK and 54 g of urea per tree. After the first growing season, 98 per cent trees were found survived. Fertilizer had positive effect on diameter and height growth as compared to the control treatment. The results showed that nitrogen fertilization had the potential to improve the early field growth of narrow leaved ash.

Stofko (2010) reported the effect of nitrogen fertilizers on height and diameter growth of a young plantation of Norway spruce and European larch after one year of fertilizer application. The fertilizer was applied at the rate of 50 g/plant. It was observed that the use of nitrogen fertilizer resulted in significant effect on height growth of larch trees.

Mohapatra and Panda (2011) reported the influence of nitrogen fertilizers on the growth of *Jatropa curcas* plantations. Five years old standing crop was treated with two levels of nitrogen (50 and 60 g/plant). It was observed that the application of nitrogen fertilizer proved to be beneficial for *Jatropa curcas* plantations on growth and yield attributes. The nitrogen level (50 g/plant) showed significant increase in height and collar diameter than (60 g/plant) nitrogen level.

Jaisankar *et al.* (2013) reported the location specific nutrient requirement based on soil test value during the first year growth and development of *Dalbergia sisoo* plantations. The results indicated that soil test value based on integrated application of organics along with inorganic nitrogen fertilizers increased the growth as well as dry matter production of *Dalbergia sissoo* during the initial growth stages.

Khamis *et al.* (2013) analyzed the effect of nitrogen fertilizer on growth efficiency of *Melia azedarach* and *Populus euphratica* on problematic sites of Wadi el Natrun, Egypt. The results clearly showed that growth response of both the species in terms of height, stem diameter, leaf area and fresh leaf weight was better in nitrogen treated plots. Nitrogen application enhanced the growth efficiency of *Melia azedarach* and *Populus euphratica* through increasing vegetative growth and biomass.

Kunes *et al.* (2013) evaluated the potential of nitrogen fertilizer to stimulate the survival, growth and nutrition of Norway spruce planted in an acidified air polluted mountain site. The nitrogen application resulted in a significant growth stimulation of spruce as compared to control.

Verma *et al.* (2013) reported that nitrogen is an essential element for plant growth. Three dosages of N (0 kg N ha^{-1} yr^{-1}, 60 kg N ha^{-1} yr^{-1} and 120 kg N ha^{-1} yr^{-1}) were tested on herbaceous vegetation in a seasonally dry tropical environment of India. Results showed that moderate levels of rainfall and N application @ 60 kg N ha^{-1} yr^{-1} facilitated the establishment and growth of herbaceous species.

Alle *et al.* (2014) estimated the effect of mineral fertilization on physico-chemical properties of soil and vegetative growth behavior of *Hevea brasilences*. The rate of fines (silt and clay) decreased from unfertilized soils to fertilized soils with high dosages. Vegetative parameters like plant height, collar diameter and number of branches showed significant increase as a result of nitrogen fertilization.

2.4 Moisture conservation measures (mulching) for problematic sites

Profit and Scott (1984) observed that poplar showed higher growth when the pits were mulched with black polythene sheets than rice straw.

Davis (1988) recommended the use of black polythene mulching for *Fraxinus excelsior* plantations on degraded sites of New Zealand. Black polythene was found superior than transparent polythene and ordinary mulch because of less weed growth.

Byard *et al.* (1996) conducted an experiment to determine the effect of mulching on mixed and mono specific tree plantations of *Jacranda capaia* in Costa Rica. It was observed that all mulching treatments found to improve seedling performance while compared with control. Mulching gave the most beneficial effects on initial seedling height growth and nitrogen uptake.

Arthur and Wang (1999) reported that organic mulches (ordinary grasses) were more efficient in conserving water than inorganic mulches (plastic materials). Organic mulches can significantly reduce amount of irrigation needed for all landscapes in some cases and even can eliminate it altogether. In addition to protecting soil reserves, the coarse organic mulches found to hold water much like a sponge and thereby capturing rainfall and irrigation water for later release and overall preventing runoff. It was also reported that mulches can protect soils and plantations from wind, water and traffic induced erosion and compaction. Otherwise all these factors contributed directly to root stress and poor plant health.

Green *et al.* (2003) studied the impact of black polythene mulch under different site conditions and cultivation treatments in poplar plantations under short rotation. It was reported that during establishment poly mulch enhanced the reduction of vegetative competition and improved the edaphic environment. After one growing season, the benefit of mulching was largely restricted to reduction of vegetative competition. In general, poly mulch may be beneficial to improve early growth of short rotation poplar plantations under a wide range of site conditions.

Jiang *et al.* (2002) studied the effect of three commonly used mulching materials, namely rice straw (RS), mixture of rice straw and rice grain hulls (RH) and leaves of bamboo trees (BL) on bamboo plantations. A control plot without covering was also established. The results showed that changes of soil organic matter, total nitrogen and available phosphorus were similar from summer to winter. Over this time, soil organic matter and nitrogen decreased and available phosphorus had a little increase. It was also found that establishment and growth of bamboo was better under RH as compared to other tested mulches.

Faber *et al.* (2003) studied the influence of mulching on wild *Persea americana* over a period of two years. Soil moisture, weed suppression, tree canopy, root growth and soil nutrient status was measured. The pronounced effect of mulches on soil moisture (reduced evaporative loss) and weed growth (substantially reduced with mulch) was obtained. It was also reported that an important effect of mulches on root architecture was an increase in root length.

Paris *et al.* (2003) investigated the influence of polythene mulching on the establishment and growth of *Juglans regia.* Establishment, annual growth rates and leaf water potentials of walnut were measured. Tree growth in mulched treatment was slightly high but significantly reduced in height as compared to unmulched trees. The mulched treatment because of its three advantages viz. highest cumulative stem growth, annual fodder production and soil erosion protection appeared to be promising for walnut cultivation in drought experiencing areas.

Gilman and Grabosky (2004) reported the impact of mulching and mulch depth on tree establishment. The mulch placed over root ball intercepted water causing a drier root ball and resulted in greater tree stress and reduced survival than trees with no mulch over the root ball. Negative effects of deep mulch occurred for ordinary leaf mulch. This result did not occur following heavy application of water. It was finally assumed that mulching material and mulch depth did not found to effect during first year stress, establishment and growth of oak seedlings.

Arnold (2005) reported the effect of mulching on soil properties and tree establishment. Mulching applied to the surface of a planted root ball and to the surrounding soil of relatively young trees found to be associated with reduced tree survival, slightly enhanced growth rate or no impact. Mulching also influenced anchorage by impacting root growth.

Shogren and Rousseau (2005) studied the effect of bio-degradable polymerized vegetable oil paper as mulches for stopping weeds and promoting growth of cotton wood trees. At the end of first growing season, the average height of cotton wood trees grown with paper mulches were not significantly different from trees growing with black polythene mulch. The results suggested that black polythene mulch can function as effective mulches during the first year of tree growth.

Scott (2007) recommended that mulches provide aesthetic, economic and environmental benefits to degraded landscapes. Mulching is especially useful in the establishment of trees on degraded sites which receive minimal care. In general, mulches improve soil health, creating healthy population of plants and micro- organisms.

Fang *et al.* (2008) studied the effect of grass mulch on growth and establishment of poplar plantations on degraded upland areas of China. Circular areas were mulched around each tree at four rates 0, 2.5, 5.0 and 7.5 kg/m^2 fresh grass. It was found that the grass mulch increased the nutrient availability of degraded soil and results in better establishment and growth of poplar seedlings. Grass mulch significantly effected the tree height and collar diameter of poplar plantations. The results also revealed that mulching may therefore be an important tool for better establishment and growth of poplar plantations on degraded soils.

Cerrillo *et al.* (2009) reported that weed control is essential for a successful establishment and growth of tree seedlings on abandoned agriculture lands. Weed control methods are effective but can be costly in terms of time, damage to non-target vegetation and increased soil erosion. Living and plastic mulches can be used to protect vegetation and soil. The soil under mulch can have better soil pH, EC, organic matter and nitrogen content in comparison to cultivated soil. Photosynthesis and foliar nutrient concentrations can be improved by the mulching treatments.

Cregg *et al.* (2009) reported the effect of mulching on height, diameter and survival of newly planted Fraser fir and Blue spruce. Mulching materials included black polythene, white polythene, vispore mulch mats and woodchips. It was found that black polythene mulch increased more growth as compared to other mulching treatments. The ranking of magnitude of growth response effects were black polythene > white polythene > vispore mulch mats > woodchips.

Linhares *et al.* (2009) reported the effect of *Gliricidia sepium* mulching on heavily weeded plantation sites of Vicosa, Brazil. Soil mulching with Gliricidia (*Gliricidia sepium*) branches did not show an allelopathic effect but found to responsible in decreasing the weed populations.

Percival *et al.* (2009) reported the effect of pure mulches on the growth and establishment of two species (European beech and Howthorn). The results showed that survival rate increased from 10-70 percent in case of beech. Whereas, in case of hawthorn, no difference in survival rates between mulched and non-mulched (control) were recorded. Pure mulches (polythene mulches) required no capital investment and offered positive benefits for tree establishment on abandoned lands.

Klimek *et al.* (2011) studied the influence of organic mulching on European larch seedlings and found that mulching helped in the establishment and growth of seedlings besides, the improvement in soil properties. The influence of mulching on seedling growth parameters was significant in both the cases of one and two years old seedlings. Seedling growth in mulched plots were characterized by better height and diameter as compared to control plots.

Tabasi *et al.* (2012) reported that shrub planting under oil mulches has frequently been used for stabilizing mobile sands over last three decades in South Africa. The study was designed to investigate the effect of mulching on soil and vegetation properties. The results of the study revealed that oil mulch and Haloxylon plantation caused a significant reduction in the percentage of total canopy and density. The living aerial foliage volume was also found to increase.

Jimenez *et al.* (2014) studied the effect of three mulch treatments (control, stone and straw) on the growth and establishment of *Quercus ilex*. The parameters like survival, diameter at breast height and leaf nutrient concentrations were analyzed in one year old Oak seedlings. Saplings with high initial DBH showed the highest establishment and growth at the end of first growing season.

Leaf nutrient concentrations changed significantly. A combination of saplings with more than 10 mm of DBH and straw mulch is recommended for restoring silvipastures systems.

2.5 Economics of plantations

Strauss *et al.* (1988) conducted a research to determine the least cost method for supplying biomass to an ethanol conversion facility. The plantations were *Populus hydrid* NE-388 plantations with spacing of 0.6 m × 0.8 m, and managed under four years rotation. Four management strategies (control, fertilization, irrigation and fertilization-irrigation) were evaluated. It was observed that the control strategy had the lowest production costs averaging 532 Mg^{-1} (OD). It was also found that 50 percent cost related to equipments and material inputs. Whereas, labour and land cost was 30 and 20 percent, respectively.

Pohjonen and Pukkala (1988) reported the profitability of establishing *Eucalyptus globulus* plantations in Ethiopia. The plantation establishment cost involved all the inputs (labor, planting material, planting tools, etc.) needed to establish a fully stocked stand. The plantation establishment cost was estimated to be 2000 Euros per hectare.

Hazara and Singh (1994) planted the degraded lands (problematic lands) of Gaharawa village with *Acacia indica, Albizia lebbeck*, *Acacia procera* & *Prosopis juliflora* and found that runoff reduced from 70 to 30 per cent. They further observed that cost benefit ratio of the plantation was 1:2.89.

Kort (2000) conducted a study to estimate the total cost of short rotation planting. Such plantations usually require intensive management similar to agricultural practices. It was estimated that the cost of soil preparation, plantation and vegetation control ranged from 1500-2200 Canadian dollar per hectare.

Cunningham *et al.* (2002) estimated the the total cost and benefit involved in establishing and maintaining *Prunus africana* plantations in USA. The total revenue required to establish one hectare of plantation was 6,57,000 FCF. It involved the labor cost (30000 FCF), transport cost (350000 FCF), dying cost (15000 FCF), material cost (75000 FCF) and miscellaneous cost (165000 FCF). The net profit from the invested capital was estimated to be 270000 FCF ha^{-1} $year^{-1}$.

Tee and Labo (2010) carried out an economic analysis to determine the socio-economic variables involved in establishing tree plantations. Descriptive statistics were utilized in analyzing the socio-economic variables whereas, gross income, net income and rate of return on investment were adapted for economic analysis. The rate of return from these plantations varied from 16.9 to 76.2 percent, the net income varied from Rs 36,250- 90,000 and the highest rate of return on investment was 76.9 percent.

Pande *et al.* (2010) suggested that net investment for planting bamboos in one hectare of degraded lands require Rs. 30,500 to 48,000/.

Salek and Sloup (2012) conducted a study to calculate the total cost of planting pure and mixed stands. It was reported that cost of planting of pure stands was comparatively low as compared to mixed stands. The internal rate of return was also highest in case of pure plantations in comparison with mixed stand. The average profit per hectare per year was almost five times higher than the mixed stands.

Schweier and Becker (2013) conducted a study to calculate the value of inputs (labour, implements, fertilizers, transport, etc.) used for the establishment of short rotation poplar plantations. The results showed that the cost of plantation was 70 Euros ha^{-1}. It was also reported that the implementation of drip irrigation to increase the biomass yield turned to be uneconomic.

Furuya *et al.* (2014) estimated the cost of inputs required for establishing teak plantations based on survey conducted in North East Thailand. Most of the farmers (59%) were satisfied with their tree plantations. The expenditure on tree plantation per hectare was estimated to Rs 35,900. It can be predicted that after 15 years the net profit from plantation would be Rs 3,25,000 ha^{-1} $year^{-1}$. It included the profit from thinning as well as main felling.

Rancane *et al.* (2014) conducted a study in Canada and found that total input required to establish a tree stand vary from place to place. It was reported that plantation establishment under degraded conditions required more inputs as compared to agricultural lands. In addition to labors, fertilizers and seedlings degraded lands require soil stabilizers which required more money. The amount required only to stabilize soil was $100 ha^{-1}.

Rasool *et al.* (2014) carried out a research to determine the net cash input required for establishing one hectare of *Dalbergia sissoo* plantations. It was found that cost of labor, seedlings and fertilizer cost accounted for Rs. 30,000 ha^{-1}. The benefit cost ratio was 0.77. It was also reported that the benefit cost ratio increased with increase in rotation age of plantations.

Chapter-3

MATERIAL AND METHODS

The investigation titled "Plantation Techniques of *Populus deltoides* Bartr for Problematic Sites in Temperate Region of North Western Himalayas" were conducted in the Faculty of Forestry, Sher-e-Kashmir University of Agricultural Sciences and Technology of Kashmir during 2013-14. A detailed account of the methodology adopted and materials used during the conduct of the research work is presented below:

3.1 Experimental area description

3.1.1 Location

The plantations of *Populus deltoides* where different plantation and moisture conservation techniques were uded in problematic (degraded) site of the Faculty of Forestry, SKUAST-Kashmir, Benhama, Ganderbal, Jammu and Kashmir located at an altitude of 5,850 feet amsl (Fig. 1). The plantation site lies in southern aspect at 34^{o}-$16^{/}$N and 74^{o}-$46^{/}$E longitude. The existing land of the experimental site was pertaining to three types of land problems namely: degraded underutilized (scrub dominated), degraded pastures/grazing lands and barren rocky/stony waste (Plate 1).

3.1.2 Climate and weather conditions

The experimental site falls in a mid to high altitude characterized by mild summers and severe winters. The average precipitation is 690 mm and most of which is received from December to April in the form of snow and rains. The mean metrological data for the experimentation period (2013-14) obtained from the meteorological observatory Ganderbal. The total rainfall received during the experimentation period was 281.2 (November-December) and 418.80 mm (January-October) during 2013 and 2014, respectively. The minimum temperature ranged from -1 to -6^{o}C and 3.4 to 14.1^{o}C and maximum

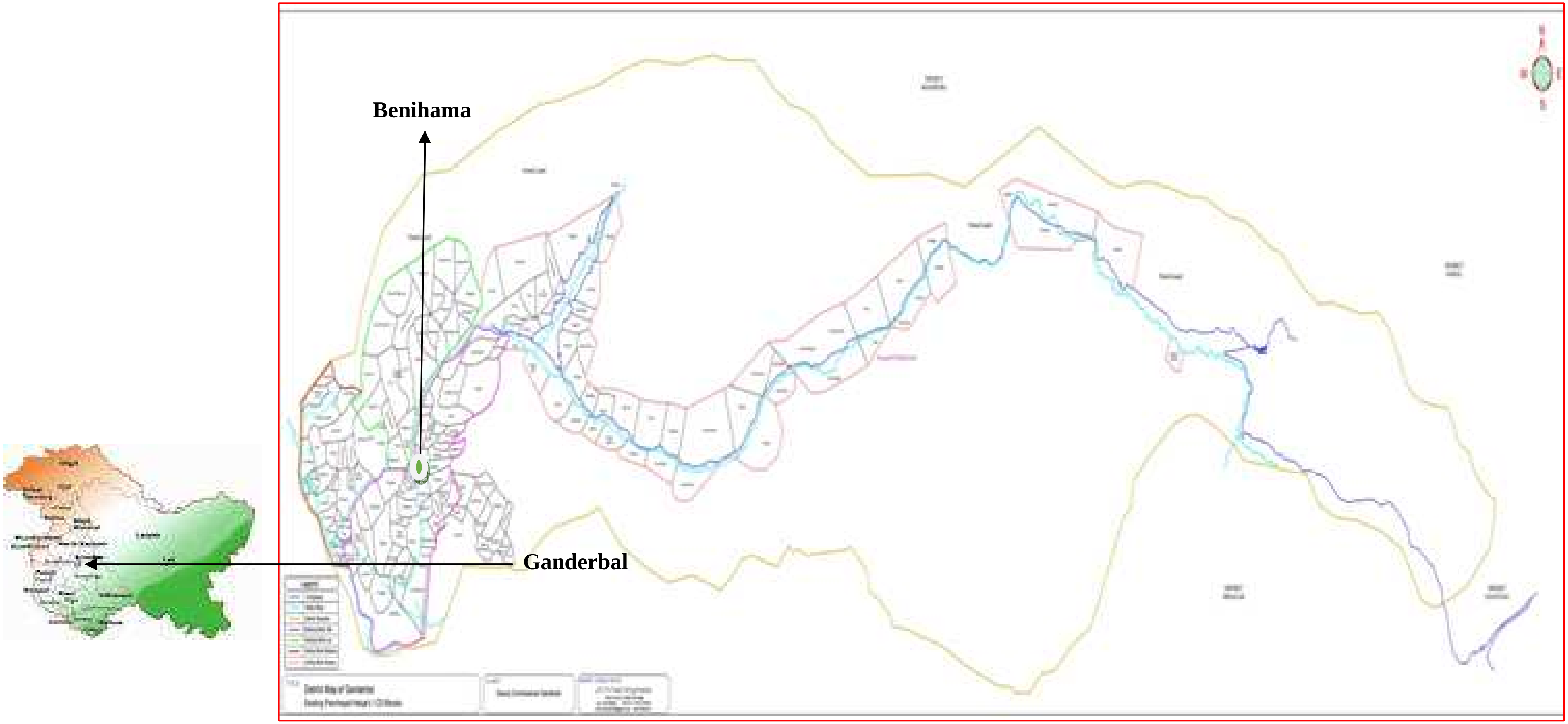


Fig. 1 : Map showing the plantation site


Plate-1 : A view of plantation site before start of experiments

temperature varied from 17.7 to 24.4°C and 21.7 to 32.5°C and the average maximum relative humidity was 74.5 to 95.1 percent and 70.4 to 90.8 percent. The mean minimum relative humidity ranged from 43.1 to 78.7 percent and 37.1 to 80.1 percent during the plantation seasons (Fig. 2).

3.1.3 Physico-chemical properties of soil

The soil samples were taken from plantation site from randomly selected spots before laying out of the experiment from at least four locations in each plot in autumn and spring seasons, separately. These samples were air dried on paper and after that the samples were grinded separately and sieved through 2 mm mesh. The samples in each season were composited and subjected to physical and chemical analysis. The results of composite soil samples drawn at the beginning of the experiment revealed that the soil was sandy loam in texture; high in organic carbon with slightly neutral in pH and normal in electrical conductivity (Table-1).

Table 1: Initial status of physico-chemical properties of soil of plantation site

S. No.	Parameters	Season	
		S_1	S_2
1.	Texture	Sandy loam	Sandy loam
2.	Bulk density (g/cc)	1.40	1.35
3.	Water holding capacity (%)	53.70	45.20
4.	pH (1:2.5 soil water suspension)	7.36	7.32
5.	Electrical conductivity dSm^{-1} at 25°C	0.27	0.24
6.	Organic carbon (%)	1.55	1.48
7.	Available nitrogen (kg ha^{-1})	285	276
8.	Available phosphorus (kg ha^{-1})	6.04	5.90
9.	Available potassium (kg ha^{-1})	336	325

*S_1 = Autumn season *S_2 = Spring season

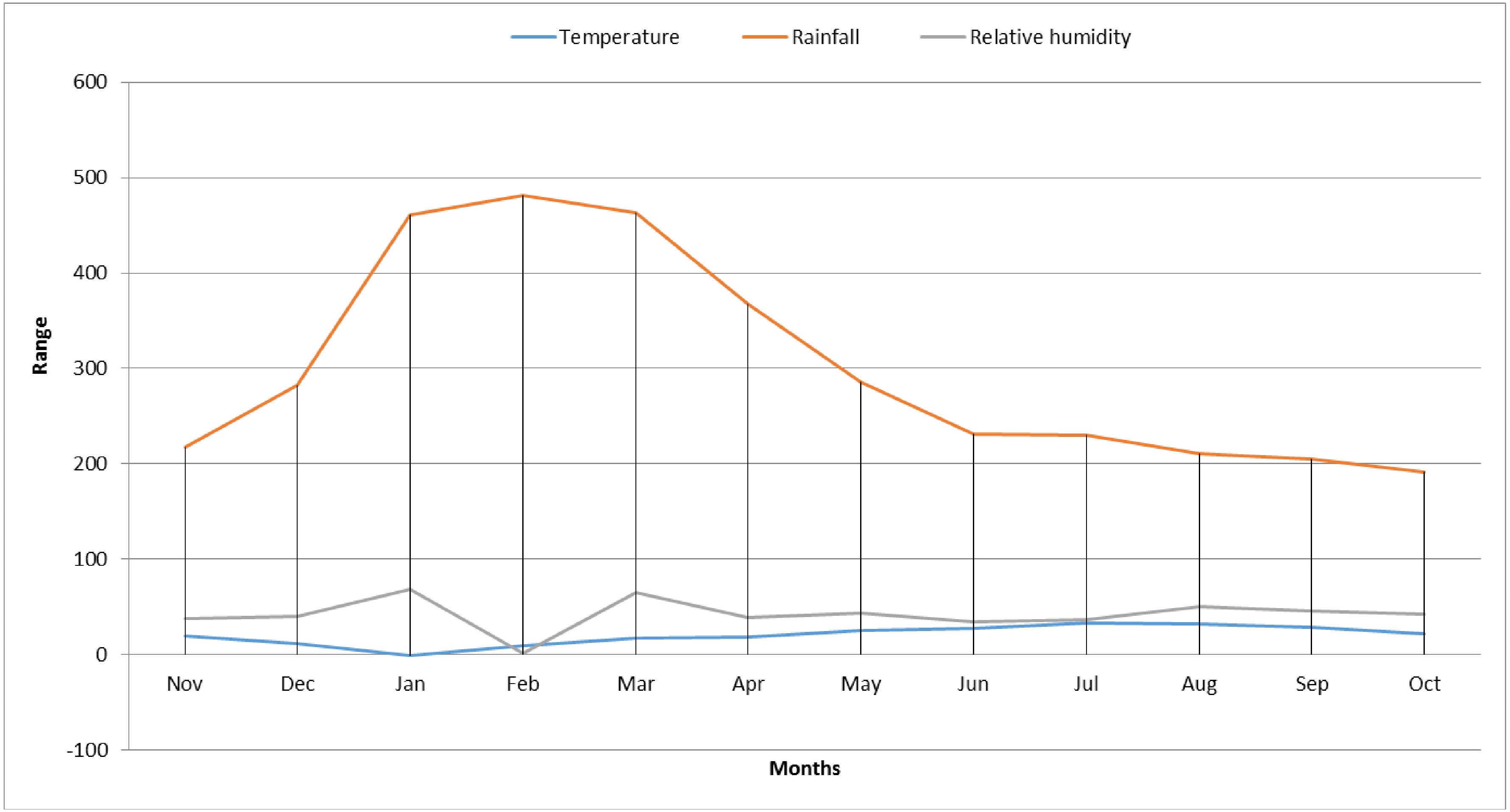


Fig. 2: Average weather conditions of the plantation site for the year 2013-2014

3.2 Technical Programme

3.2.1 Plantation details

The plantation of *Populus deltoides* Bartr was done under three experiments which have been described in detail as below. Each experiment was laid out in a Randomized Complete Block Design (Factorial).

3.2.2 Experiment 1: Effect of planting seasons with intervals and nitrogen fertilizer on establishment & growth of *Populus deltoides* plantations on problematic sites

Populus deltoides was taken for experimentation because of its multifarious uses and abundant availability in the temperate region especially in Kashmir province.

Plant species	:	*Populus deltoides* Bartr.
Spacing	:	2×2 m
Planting design	:	line planting

Treatments

(A) Planting seasons: 02 (two)

Two planting seasons were taken for out planting the stock in the field.

1. Autumn planting (Nov. to Dec., 2013)
2. Spring planting (Feb. to March, 2014)

The separate & independent experiments were laid out in each season for finding out the best planting season with the intervals in the region.

(B) Planting intervals

Three planting intervals comprising of 15 days (fortnight) in both the seasons were tested.

Autumn planting (Season I)		Spring planting (Season II)	
PI_1	15^{th} Nov. to 30^{th} Nov., 2013	**PI_1**	15^{th} Feb. to 28^{th} Feb., 2014
PI_2	1^{st} Dec. to 15^{th} Dec., 2013	**PI_2**	1^{st} March. to 15^{th} March, 2014
PI_3	16^{th} Dec. to 31^{th} Dec., 2013	**PI_3**	16^{th} March to 31^{st} March, 2014

(C) Fertilizer application (urea): 04 levels

Four levels of nitrogenous fertilizers (urea) were selected to find out the optimum dose of nitrogen fertilizer for poplar plantation. However, Phosphorous and Potassium were applied as the basic dose at the time of out planting. The details of applied fertilizer is given here as under.

N_0: Control

N_1: 100 kg/ha

N_2: 150 kg/ha

N_3: 200 kg/ha

Number of treatments = 3 (Planting season, planting intervals and fertilizer application)

Number of treatment combinations = $2 \times 3 \times 4 = 24$

Number of replications = 2

Plants per replication= 3

Total planting stock raised: 144

Experimental design: Randomized Block Design (factorial)

3.2.2 Experiment 2: Effect of planting seasons, pit shapes, sizes and moisture conservation measures on establishment and growth of *Populus deltoides* plantations on problematic sites

(A) Planting seasons: 02 (two)

Two planting seasons were tested for finding out the best season with respect to planting of poplar saplings on problematic sites in temperate region.

1. Autumn planting (November to December, 2013)
2. Spring planting (February to March, 2014)

(B) Types of pit: 03

Three types of pits with varying sizes were made to study the effect of pit on poplar plantation in problematic sites pertaining to establishment and growth of the plantations (Plate-2).

1. PT_1 : Ordinary pit (Auger planting 60 cm deep)
2. PT_2 : Saucer pit
3. PT_3. : Ring pit

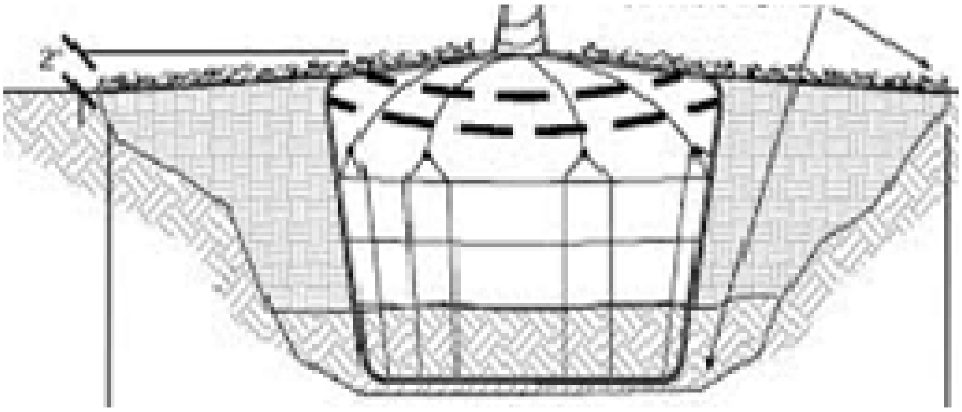
(C) Size of pits (cm^3): 03

1. PS_1 : 30×45
2. PS_2 : 45×60
3. PS_3 : 60×60

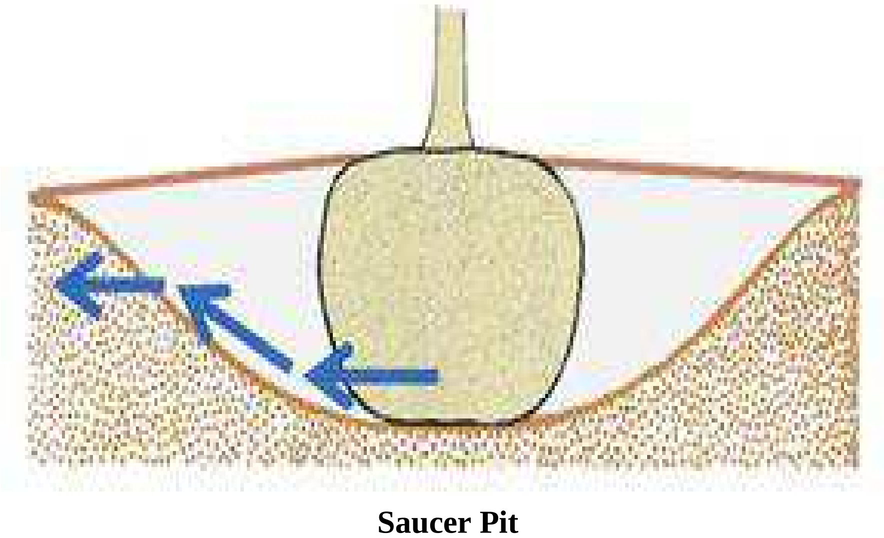
(D) Mulching: 03 (Plate-3)

1. M_0 : Control (No mulching)
2. M_1 : Ordinary mulch (paddy straw)
3. M_2 : Black polythene sheet

Ordinary Pit



Ring Pit



Saucer Pit

Plate-2 : Types of pits used for plantation of *Populusdeltoides*on problematic site

Control (No Mulch)

Ordinary Mulch (paddy straw)

Black Polythene Mulch

Plate-3 : Conservation of moisture by using different types of mulches for raising *Populus deltoides* plantations on problematic site

Number of treatments = 4 (planting season, pit types, pit sizes and moisture conservation measures)

Number of treatment combinations = 2×3×3×3 = 54

Number of replications = 2

Plants per replication= 3

Total planting stock raised: 324

Experimental design: Randomized Block Design (factorial)

3.2.4 Experiment 3: Effect of planting seasons, age of planting stock and hydrogel application on establishment & growth of *Populus deltoides* plantations on problematic sites

(A) Planting seasons: 02 (two)

Two planting seasons were tested to find out the best planting season corresponding to the age of planting stock including hydrogel application in the field.

1. Autumn planting (November to December, 2013)
2. Spring planting (February to March, 2014)

(B) Type of planting stock: 02

Two types of planting stocks based on age groups were taken for out planting in the field (Plate-4).

1. Planting stock (PS_1) : 1 year old
2. Planting stock (PS_2) : 2 years old

(C) Hydrogel application: 05

Five levels of hydrogel including control were tested for finding out the alternatives to conserve the soil moisture in moisture deficit sites. Both types of

One year old seedling

Two years old seedling

Plate-4 : **A view of poplar seedlings based on age of planted stock planted in the field**

hydrogel i.e. solid and liquid application were tried in the outplanted seedlings of *Populus deltoides*.

1. H_0 Control
2. H_1 Solid application (3.0 g/plant)
3. H_2 1.5 g/plant (liquid application)
4. H_3 3.0 g/plant (liquid application)
5. H_4 4.5 g/plant (liquid application)

Number of treatments = 5

Number of treatment combinations = 2 × 2 × 5 = 20

Number of replications = 2

Plants per replication= 3

Total planting stock raised: 120

Experimental design: Randomized Block Design (factorial)

3.3 Plot size (m^2)

Experiment 1 = 12 × 12 m^2

Experiment 2 = 14 × 24 m^2

Experiment 3 = 10 × 12 m^2

3.4 Field preparation

The area marked for each experiment was prepared before going for plantation with the help of colored sticks and measuring tape. After demarcation, it was cleared and the pits were dug out. The field was laid out as per the statistical model used in the experiment.

3.5 Transplanting of seedling

One and two years (for experiment 3 only) old seedlings of *Populus* *deltoides* were taken. The seedlings were outplanted in line planting design with 2×2 m spacing.

3.6 Nutrient management

A uniform dose of phosphorous and potassium at the rate of 60 kg P_2O_5/ha^{-1} and 40 kg K_2O ha^{-1}, respectively was applied at the time of plantation. Nitrogen was applied as per treatments to find out the optimum dose of nitrogen fertilizer for poplar plantation grown on problematic site.

3.7 Plant protection measures

No plant protection measure with regard to disease/insect pest control was taken due to non- observance of such problems.

3.8 Details of observations recorded

The following observations were recorded during the course of investigations.

3.8.1 Physiological and quality parameters of seedlings at the time of out planting

The seedlings taken for out planting were tested for the following physiological parameters to establish the correlation between the survival & growth attributes of plantations with the status of physiological traits of the planting stock.

3.8.1.1 Relative water content (%)

Relative water content was obtained from fresh leaves of poplar seedlings by using the formulae as given below :

$$\text{RWC (\%)} = \frac{\text{Fresh weight} - \text{Dry weight}}{\text{Saturated weight} - \text{Dry weight}} \times 100$$

3.8.1.2 Root electrolyte leakage (REL)

Root electrolyte leakage was determined by using the technique developed by Mackay (1992). The roots were meshed and placed in distilled water for a period till constant reading comes in conductivity meter. The beaker containing roots was then heated in an autoclave for half an hour and again reading was taken. The REL is determined by:

$$REL = \frac{\text{EC (before heating)}}{\text{EC (after heating)}}$$

3.8.1.3 Shoot electrolyte leakage (SEL)

Shoot electrolyte leakage was determined by using the same technique developed by Mackay (1992).

$$SEL = \frac{\text{EC (before heating)}}{\text{EC (after heating)}}$$

3.8.1.4 Root fibrosity

Root fibrosity is measured by counting the total number of lateral roots having length greater than 2 cm (Thompson, 1985).

3.8.1.5 Root volume (cm^3)

Root volume of seedlings was measured by using the water displacement method given by Burdett, 1979. It gives an accurate measurement of quality of seedlings under field conditions. Seedlings with larger root volumes are able to bear transplant shocks better than seedlings with smaller root volumes.

3.8.1.6 Root length (cm)

Root length was measured by using the measuring tape after removal of soil by proper washing with running tap water.

3.8.1.7 Shoot height (cm)

Shoot height was measured with the help of measuring tape from base of the seedlings to the leading point.

3.8.1.8 Root/shoot ratio

Root/shoot is the ratio of tap root length to the total shoot length. This ratio is a measure of balance between the water absorbing area and the transpirational area of a seedling proposed by Racey *et al.* (1983). Seedlings with higher root/shoot ratio have better chances of survival.

3.8.1.9 Sturdiness quotient

The Sturdiness quotient is the height in centimeters divided by collar diameter in millimeters. It is good indicator of the ability of seedlings to withstand physical damage (Roller, 1977).

3.8.1.10 Membrane stability index (MSI)

Membrane Stability Index is a measure of seedling hardiness and was determined by the formulae as given below:

$$MSI = 1 - \frac{\text{EC (before heating)}}{\text{EC (after heating)}} \times 100$$

3.8.2 Physiological and quality parameters of seedlings after the completion of one growing season

3.8.2.1 Survival percentage

Survival percentage was calculated for each treatment of plantation by using the formulae:

$$SP = \frac{\text{Total No. of seedlings survived after one growing season}}{\text{Total No. of seedlings planted}} \times 100$$

3.8.2.1 Plant height (cm)

Plant height was recorded with the help of measuring tape at the time of plantation and after the completion of one growing season (ending October). Height was measured from the soil surface to the leading tip of the plant.

3.8.2.3 Collar diameter (mm)

Collar diameter was measured by digital caliper at the time of plantation and after completion of one growing season (ending October).

3.8.2.4 Number of branches

All lateral branches of seedlings were counted manually to access growth and development.

3.8.2.5 Leaf area (cm^2)

Leaf area gives the total transpirational area of seedlings and is a measure of seedling quality. Leaf area was measured by using leaf area meter.

3.8.3 Physico-chemical parameters of soil (at the time of out planting and at the end of one growing season *i.e.* ending October)

The following physico-chemical parameters were measured by taking the soil samples from sub-surface at the start of the experiment and at the end of first growing season.

Observations	**Methodology to be used**
Soil texture	International Pipette Method (Piper, 1966)
Bulk density (Mg/cu.m)	It was estimated by drying the sample in an oven for 18 hours as described by Wild *et al.* (1972)
Water holding capacity (%)	It was determined by using brass boxes with holes at bottom as described by Piper (1966)
pH	1:2.5 soil water suspension with the help of pH meter (Jackson, 1973)
Electrical conductivity (dS/m)	1:2.5 soil water suspension with the help of conductivity meter
Organic carbon (%)	Wet digestion method of Walkley and Black (1934)
Nitrogen (kg/ha)	Alkaline potassium permanganate method of Subbiah and Asija (1956)
Phosphorous (kg/ha)	Olsen *et al.* (1954)
Potassium (kg/ha)	Merwin and Peech (1951)

3.8.3.1 Soil texture

Soil texture is one of the important measures of soil. It was determined by International Pipette Method (Piper, 1966).

3.8.3.2 Bulk density (Mg/cm^3)

Bulk density is an indicator of soil compaction and health. It effects infiltration, rooting depth, available water capacity, soil porosity, plant nutrient availability and soil microorganism activity which influence the key processes and productivity of soil. Bulk density was determined by cylindrical method.

3.8.3.3 Water holding capacity (%)

Water holding capacity is the amount of water that a given soil can hold for crop use. It was determined by oven dry method.

3.8.3.4 pH

pH was determined by making a suspension of soil water in the ratio of 1:2.5 and was read on Blackman's glass electrode pH meter (Jackson, 1973).

3.8.3.5 Organic carbon (%)

The organic carbon was determined by Walkely and Black Rapid Titration method, Jackson (1973) and calculated in per cent.

3.8.3.6 Electrical conductivity (dS/m)

Electrical conductivity of soil samples were determined by using Sloubridge conductivity meter (Piper, 1966).

3.8.3.7 Nitrogen (kg/ha)

The available soil nitrogen was determined by using alkaline potassium permanganate method (Subbiah and Asija, 1956) and was calculated in kg ha^{-1}.

3.8.3.8 Phosphorous (kg/ha)

The available phosphorus in soil was determined by using the 0.5 N $NaHCO_3$ at pH 8.5 (Olsen *et al.*, 1954) and recorded in kg ha^{-1}.

3.8.3.9 Potassium (kg/ha)

The potassium was determined with the help of extraction with 1N ammonium acetate at pH 7.0 (Jackson, 1973) and was recorded in kg ha^{-1}.

3.9 Observations recorded

The soil moisture was recorded at fortnightly intervals from each treatment of experiment after the completion of one month from the day of outplanting till the end of first growing season (ending of October) with the help of moisture meter from the sub-surface of soil. Moisture percentage of soil on plantation site was measured with the help of moisture meters under different moisture conservation measures viz. mulching materials, pit shapes and sizes. In autumn planting, a total of 20 intervals were taken, whereas, in spring planting it was only 14 intervals.

3.10 Economic valuation

The relative economics of all the inputs were worked out by taking all the attributes under considerations.

3.11 Statistical analysis

The data collected from all the experiments were analyzed as per the standard procedures outlined by Cochran and Cox (1968).

Chapter-4

EXPERIMENTAL FINDINGS

The results obtained during the present investigation on **"Plantation Techniques of *Populus deltoides* Bartr. for Problematic Sites in Temperate Region of North Western Himalayas"** are described under following heads as per the objectives:

4.1 Effect of planting seasons with intervals and nitrogen fertilizer on establishment & growth of *Populus deltoides* plantations on problematic sites

4.1.1 Effect of planting seasons with intervals and nitrogen fertilizer on survival percentage of *Populus deltoides* plantations on problematic sites

4.1.2 Effect of planting seasons with intervals and nitrogen fertilizer on plant height increment (cm) in *Populus deltoides* plantations on problematic sites

4.1.3 Effect of planting seasons with intervals and nitrogen fertilizer in collar diameter increment (mm) of *Populus deltoides* plantations on problematic sites

4.1.4 Effect of planting seasons with intervals and nitrogen fertilizer on number of branches per plant of *Populus deltoides* plantations on problematic sites

4.1.5 Effect of planting seasons with intervals and nitrogen fertilizer on leaf area per plant (cm^2) of *Populus deltoides* plantations on problematic sites

4.1.6 Correlation between survival percentage and growth attributes of *Populus deltoides* plantations with physiological and quality parameters of seedlings on problematic sites

4.1.7 Effect of *Populus deltoides* plantations on physico-chemical properties of soil with respect to planting seasons, planting intervals and nitrogen fertilizers on individual factor means

4.2 Effect of planting seasons, pit shapes, pit sizes and moisture conservation measures on establishment & growth of *Populus deltoides* plantations on problematic sites

4.2.1 Effect of planting seasons, pit shapes, pit sizes and moisture conservation measures on survival percentage of *Populus deltoides* plantations on problematic sites

4.2.2 Effect of planting seasons, pit shapes, pit sizes and moisture conservation measures in plant height increment (cm) of *Populus deltoides* plantations on problematic sites

4.2.3 Effect of planting seasons, pit shapes, pit sizes and moisture conservation measures in collar diameter increment (mm) of *Populus deltoides* plantations on problematic sites

4.2.4 Effect of planting seasons, pit shapes, pit sizes and moisture conservation measures on number of branches per plant of *Populus deltoides* plantations on problematic sites

4.2.5 Effect of planting seasons, pit shapes, pit sizes and moisture conservation measures on leaf area per plant (cm^2) of *Populus deltoides* plantations on problematic sites

4.2.6 Correlation between survival percentage and growth attributes of *Populus deltoides* plantations with physiological and quality parameters of seedlings on problematic sites

4.2.7 Effect of *Populus deltoides* plantations on physico - chemical properties of soil with respect to planting seasons, pit shapes, pit sizes and moistures conservation measures (mulching) on individual factor means

4.2.8 Effect of different moisture conservation measures on moisture regimes of soils in *Populus deltoides* plantations done on problematic sites

4.3 Effect of planting seasons, age of planting stock and hydrogel application on establishment & growth of *Populus deltoides* plantations on problematic sites

4.3.1 Effect of planting seasons, age of planting stock and application of hydrogel on survival percentage of *Populus deltoides* plantations on problematic sites

4.3.2 Effect of planting seasons, age of planting stock and application of hydrogel on plant height increment (cm) in *Populus deltoides* plantations on problematic sites

4.3.3 Effect of planting seasons, age of planting stock and application of hydrogel on collar diameter increment (mm) in *Populus deltoides* plantations on problematic sites

4.3.4 Effect of planting seasons, age of planting stock and application of hydrogel on number of branches per plant of *Populus deltoides* plantations on problematic sites

4.3.5 Effect of planting seasons, age of planting stock and application of hydrogel on leaf area per plant (cm^2) of *Populus deltoides* plantations on problematic sites

4.3.6 Correlation between survival percentage and growth attributes of *Populus deltoides* plantations with physiological and quality parameters of seedlings on problematic sites

4.3.7 Effect of *Populus deltoides* plantations on physico-chemical properties of soil with respect to planting seasons, age of planting stock and hydrogel application on individual factor means

4.4 Relative economics of plantations

4.1 Effect of planting seasons with intervals and nitrogen fertilizer on establishment & growth of *Populus deltoides* plantations on problematic sites

The seedlings of *Populus deltoides* were obtained from the nursery of Faculty of Forestry, SKUAST-K and were outplanted on problematic site in temperate region of North Western Himalayas (2013-2014) to evaluate the effect of planting seasons with intervals and nitrogen fertilizer levels on growth and establishment of the plantations. Two planting seasons viz. Autumn Planting (S_1) and Spring Planting (S_2), three planting intervals viz. Planting Interval I (PI_1), Planting Interval II (PI_2) and Planting Interval III (PI_3) of 15 days interval and four nitrogen levels viz. N_0 (control), N_1 (100 kg/ha), N_2 (150 kg/ha) and N_3 (200 kg/ha) were evaluated with respect to the *Populus deltoides* plantations done on problematic sites.

4.1.1 Effect of planting seasons with intervals and nitrogen fertilizer on survival percentage of *Populus deltoides* plantations on problematic sites

The results obtained for survival percentage of *Populus deltoides* are presented in Table 2. A perusal of the data reveals that both the planting seasons with intervals and nitrogen fertilizer levels effected the survival percentage significantly. Planting interval I was recorded with greater survival percentage (83.33%) followed by planting interval II (74.99%) and planting interval III (70.82%) in autumn planting. The same trend was observed in spring planting with planting interval I gave highest value (70.82%) then the planting interval II

Table-2: Effect of planting seasons with intervals and nitrogen fertilizer on survival percentage of *Populus deltoides* plantations on problematic sites

Season→	Autumn planting					Spring planting					Factor means					
Nitrogen levels / Planting intervals	N_0	N_1	N_2	N_3	Mean	N_0	N_1	N_2	N_3	Mean	Nitrogen levels		Planting intervals		Planting seasons	
I_1	66.66	83.33	100	83.33	83.33	66.66	66.66	83.33	66.66	70.82	N_0	63.88	I_1	77.07	S_1	76.38
I_2	66.66	83.33	83.33	66.66	74.99	66.66	66.66	83.33	50.00	66.66	N_1	72.21	I_2	70.82	S_2	66.66
I_3	66.66	66.66	83.33	66.66	70.82	50.00	66.66	83.33	50.00	62.64	N_2	86.35	I_3	66.73		
Mean	66.66	77.77	88.88	72.21	76.38	61.10	66.66	83.83	55.55	66.66	N_3	63.68				

C.D. ($p \leq 0.05$):			
N=0.48	N_0 = 0 kg/ha	PI_1 = Planting Interval I	S_1= Autumn Planting Season
S=2.38	N_1 = 100 kg/ha	PI_2 = Planting Interval II	S_2= Spring Planting Season
I=1.48	N_2 = 150 kg/ha	PI_3 = Planting Interval III	
N×S =1.57	N_3 = 200 kg/ha		
N×I=2.67			
S×I=NS			
N×S×I=NS			

(66.66%) and planting interval III (62.64%). Survival percentage of *Populus deltoides* increased with increase in nitrogen dosages from N_0 (0 kg/ha) to N_2 (150 kg/ha) and then decreased under N_3 (200 kg/ha) level in both the planting seasons. Nitrogen level N_2 recorded highest survival percentage (88.88%) followed by N_1 (77.77%), N_3 (72.21%) and N_0 (66.66%) in autumn planting. In spring planting, highest survival percentage was recorded with N_2 (83.83%) followed by N_1 (66.66%), N_0 (61.10%) and N_3 (55.55%), respectively.

Individual factors were also evaluated to determine the best possible factor for *Populus deltoides* plantations pertaining to problematic sites. Maximum survival percentage was registered in autumn planting (76.38%) than spring planting where it was minimum (66.66). It was recorded from the Table 2 that among three planting intervals, planting interval I gave high survival percentage (77.07%) and was followed by planting interval II (70.82%) and planting interval III (66.73%). It was observed from the table 2 that among four nitrogen levels applied to the plantations, N_2 gave highest survival percentage (86.35%) and lowest in N_1 (72.21%) level. The N_0 (63.88%) and N_3 (63.68%) levels were statistically at par with each other.

The data also reveal that interaction between planting seasons, planting intervals and nitrogen levels were found to effect significantly to each other. Overall, the effect of interaction among planting seasons, intervals and nitrogen levels were found to be non-significant (Table 2.0). It was also observed that cent percent survival percentage of *Populus deltoides* plantations on problematic site was found with treatment combination $S_1I_1N_{2,}$ (Autumn planting × Planting interval I × 150 kg N/ha) in autumn planting and minimum value was observed in $S_2I_3N_0$ (Spring planting × Planting interval III × 0 kg N/ha) in spring planting.

4.1.2 Effect of planting seasons with intervals and nitrogen fertilizer on plant height increment (cm) in *Populus deltoides* plantations on problematic sites

The data presented in Table 3 reveal that both the planting seasons with intervals and nitrogen fertilizer levels significantly effected the plant height increment of poplar plantations done on the problematic sites. It was observed that all the planting intervals significantly effected the plant height increment of *Populus deltoides* in both the seasons. The plant height increment was found to decrease with the advancing of planting intervals from I_1 to I_3. The maximum height increment (31.69 cm) was recorded in I_1 interval and minimum (31.49 cm) was found in I_3 in autumn planting. The same trend has been observed in spring planting with I_1 recorded highest value (31.29 cm) and lowest by I_3 (31.02 cm). It is further observed that all the nitrogen levels significantly effected the plant height increment in both the seasons. Height increment of *Populus deltoides* plantations increased with increase in nitrogen dosages from N_0 (control) to N_2 (150 kg/ha) and then showed a marked decline. Maximum plant height increment was recorded with nitrogen level N_2 (31.79 cm) and minimum with N_0 (31.17 cm) in autumn planting. In spring planting, maximum height increment was recorded with N_2 (31.30 cm) and followed by N_1 (31.20 cm), N_3 (31.04 cm) and N_0 (31.00 cm), respectively.

Individual factors were also evaluated to determine the best possible factor responsible for fate of plantation programme. Higher plant height increment (31.48 cm) was reported in autumn planting than in (31.13 cm) spring planting. It was found that planting interval I recorded maximum plant height increment (31.49 cm) followed by planting interval II (31.28 cm) and planting interval III (31.15 cm). Among the four nitrogen levels N_2 gave maximum height increment (31.54 cm) and minimum was found with N_0 (31.08 cm). However, it was observed that two nitrogen levels viz. N_0 and N_2 were statistically significant and rest of the two N_1 and N_3 were statistically at par with each other.

It was also observed that the effect of interaction between planting

Table-3: Effect of planting seasons with intervals and nitrogen fertilizer on plant height increment (cm) in *Populus deltoides* plantation on problematic site

Season→	Autumn planting					Spring planting					Factor means					
Nitrogen levels / Planting intervals	N_0	N_1	N_2	N_3	Mean	N_0	N_1	N_2	N_3	Mean	Nitrogen levels		Planting intervals		Planting seasons	
I_1	31.33	31.56	32.10	31.77	31.69	31.10	31.33	31.56	31.17	31.29	N_0	31.08	I_1	31.49	S_1	31.48
I_2	31.20	31.42	31.71	31.53	31.46	31.01	31.19	31.21	31.00	31.10	N_1	31.30	I_2	31.28	S_2	31.13
I_3	31.00	31.27	31.56	31.33	31.29	30.91	31.09	31.15	30.95	31.02	N_2	31.54	I_3	31.15		
Mean	31.17	31.41	31.79	31.54	31.48	31.00	31.20	31.30	31.04	31.13	N_3	31.29				

C.D. ($p \leq 0.05$):

C.D.	Nitrogen levels	Planting intervals	Planting seasons
N= 0.03	N_0 = 0 kg/ ha	PI_1 = Planting Interval I	S_1= Autumn Planting Season
S= 0.06	N_1 = 100 kg/ha	PI_2 = Planting Interval II	S_2= Spring Planting Season
I= 0.05	N_2 = 150 kg/ha	PI_3 = Planting Interval III	
N×S = 0.07	N_3 = 200 kg/ha		
N×I= 0.06			
S×I= 0.07			
N×S×I= 0.11			

seasons with intervals and nitrogen levels were significant with each other. It was recorded that best possible treatment combination for plant height increment was $S_1I_1N_2$ (autumn season × planting interval I × 150 kg N/ha). The treatment combination with least value of plant height increment was $S_1I_3N_0$ (autumn season × planting interval III × 0 kg N/ha). Similar trends have been observed in spring planting as far as interaction effects are concerned on plant height increment.

4.1.3 Effect of planting seasons with intervals and nitrogen fertilizer in collar diameter increment (mm) of *Populus deltoides* plantations on problematic sites

A perusal of the data presented in Table 4 reveals that both the planting seasons, planting intervals and nitrogen levels significantly effected the collar diameter increment of *Populus deltoides* plantations on problematic site. Highest collar diameter increment was recorded in first interval (5.63 mm) and lowest in third interval (5.41 mm). However, all the planting intervals were found statistically significant with each other. Similar trend has been reported in spring planting where maximum diameter increment was observed in first interval (5.33 mm) and minimum in third interval (5.05 mm). All the nitrogen levels were found to effect collar diameter increment in both the seasons. It was progressively increased with increase in nitrogen dosages from N_0 (control) to N_2 (150 kg/ha) and then declined. Maximum collar diameter increment was recorded for nitrogen level N_2 (5.79 mm) followed by N_1 (5.56 mm), N_0 (5.41 mm) and minimum increment was recorded for N_3 (5.30 mm) in autumn planting. In spring planting, maximum collar diameter increment was recorded for N_2 (5.35 mm) followed by N_1 (5.22 mm), N_0 (5.13 mm) and N_3 (5.07 mm). In both the planting seasons, the level N_3 (200 kg/ha) gave the lowest collar diameter increment.

The data on individual factor means presented in Table 4 reveal that autumn planting with interval first (I_1) and (150 kg N/ha) level of nitrogen fertilizer gave the more collar diameter increment over the rest of the tested individual treatments.

Table-4: **Effect of planting seasons with intervals and nitrogen fertilizer in collar diameter increment (mm) of *Populus deltoides* plantations on problematic site**

Season→	Autumn planting					Spring planting					Factor means					
Nitrogen levels / Planting intervals	N_0	N_1	N_2	N_3	Mean	N_0	N_1	N_2	N_3	Mean	Nitrogen levels		Planting intervals		Planting seasons	
I_1	5.53	5.62	5.98	5.42	5.63	5.29	5.36	5.49	5.20	5.33	N_0	5.27	I_1	5.48	S_1	5.51
I_2	5.40	5.56	5.77	5.28	5.50	5.11	5.27	5.36	5.05	5.19	N_1	5.39	I_2	5.34	S_2	5.19
I_3	5.31	5.50	5.62	5.21	5.41	5.00	5.05	5.21	4.96	5.05	N_2	5.57	I_3	5.23		
Mean	5.41	5.56	5.79	5.30	5.51	5.13	5.22	5.35	5.07	5.19	N_3	5.18				

C.D. ($p \leq 0.05$):

C.D.	Nitrogen levels	Planting intervals	Planting seasons
N= 0.07	N_0 = 0 kg/ha	PI_1 = Planting Interval I	S_1= Autumn Planting Season
S= 0.08	N_1 = 100 kg/ha	PI_2 = Planting Interval II	S_2= Spring Planting Season
I= 0.05	N_2 = 150 kg/ha	PI_3 = Planting Interval III	
N×S = 0.10	N_3 = 200 kg/ha		
N×I= 0.09			
S×I= 0.10			
N×S×I= 0.10			

It was also recorded that interaction between planting seasons with intervals and nitrogen levels were statistically significant with each other. It was also observed from Table 4 that best treatment combination for collar diameter increment was $S_1I_1N_2$ (5.98 mm) in autumn planting. Similar combinations were found to outperform in spring planting. The least value of collar diameter increment was observed in treatment combination of $S_1I_3N_3$ (5.21 mm).

4.1.4 Effect of planting seasons with intervals and nitrogen fertilizer on number of branches per plant of *Populus deltoides* plantations on problematic sites

The results pertaining to the effect of planting seasons with intervals and nitrogen levels on number of branches per plant are presented in Table 5. Maximum number of branches per plant were recorded in planting interval I (3.73) followed by planting interval II (3.65) and planting interval III (3.55) in autumn planting. Similar trend was observed in spring planting. Nitrogen levels behaved statistically significant irrespective of the planting seasons. In autumn planting, maximum number of branches per plant were reported with N_2 (3.83) followed by N_1 (3.69), N_0 (3.54) and N_3 (3.51). It was also observed that the maximum number of branches per plant were recorded in N_2 (3.53) followed by N_1 (3.37), N_3 (3.27) and N_0 (3.26) in spring planting. In both the planting seasons, it has been observed that the number of branches per plant increased up to level N_2 (150 kg/ha) and then decreased in N_3 (200 kg/ha) level and this number was even less than N_0 level where no nitrogen was applied. However, the value of number of branches per plant at N_0 and N_3 levels in both the planting seasons were statistically at par with each other.

Autumn planting season gave higher (3.64) number of branches per plant than in spring planting (3.36) with respect to the effect of individual factor means. It was observed that planting interval I recorded maximum number of branches (3.59) while compared with planting interval II (3.52) and planting interval III (3.39). N_2 gave maximum number of branches per plant (3.68) followed by N_1

Table-5: **Effect of planting seasons with intervals and nitrogen fertilizer on number of branches per plant of *Populus deltoides* plantations on problematic sites**

Season→	Autumn planting					Spring planting					Factor means					
Nitrogen levels / Planting intervals	N_0	N_1	N_2	N_3	Mean	N_0	N_1	N_2	N_3	Mean	Nitrogen levels		Planting intervals		Planting seasons	
I_1	3.64	3.75	3.89	3.62	3.73	3.36	3.45	3.62	3.40	3.46	N_0	3.40	I_1	3.59	S_1	3.64
I_2	3.56	3.70	3.83	3.51	3.65	3.30	3.39	3.54	3.31	3.39	N_1	3.53	I_2	3.52	S_2	3.36
I_3	3.41	3.62	3.77	3.40	3.55	3.11	3.28	3.43	3.10	3.23	N_2	3.68	I_3	3.39		
Mean	3.54	3.69	3.83	3.51	3.64	3.26	3.37	3.53	3.27	3.36	N_3	3.39				

C.D. ($p \leq 0.05$):

N= 0.03
S= 0.06
I= 0.04
N×S = 0.07
N×I= 0.05
S×I= 0.08
N×S×I= 0.10

N_0 = 0 kg/ha
N_1 = 100 kg/ha
N_2 = 150 kg/ha
N_3 = 200 kg/ha

PI_1 = Planting Interval I
PI_2 = Planting Interval II
PI_3 = Planting Interval III

S_1= Autumn Planting Season
S_2= Spring Planting Season

(3.53), N_0 (3.40) and N_3 (3.39) among the four nitrogen levels applied to the poplar plantations.

Planting seasons with intervals and nitrogen levels were found to be significant with the number of branches per plant. The best combinations namely $S_1I_1N_2$ (3.89) and $S_1I_3N_3$ (3.40) gave highest and lowest values of number of branches per plant in autumn season, respectively. Similar trends have been observed in spring planting season.

4.1.5 Effect of planting seasons with intervals and nitrogen fertilizer on leaf area per plant (cm^2) of *Populus deltoides* plantations on problematic sites

A perusal of the data given in Table 6 reveals that all the treatment combinations behaved statistically significant with each other. Highest value of leaf area per plant was recorded in planting interval I (344.09 cm^2) which was followed by planting interval II (343.06 cm^2) and planting interval III (342.09 cm^2) in autumn season. In spring season, similar observations were recorded as in order of planting interval I > planting interval II > planting interval III. Nitrogen levels applied to the *Populus deltoides* plantations effected the leaf area per plant significantly. In autumn planting, highest leaf area per plant was recorded in N_2 (346.22 cm^2) and minimum with N_0 (341.52 cm^2). Whereas, the maximum leaf area per plant was found in N_2 (341.23 cm^2) and followed by N_1 (340.50 cm^2), N_0 (339.40 cm^2), N_3 (339.24 cm^2), respectively in spring planting, respectively.

Individual factors were also evaluated to determine the best possible factor for leaf area per plant of *Populus deltoides* on problematic site. Highest leaf area (343.08 cm^2) was recorded for autumn planting and minimum (340.10 cm^2) for spring planting. However, both the planting seasons were found to be statistically significant with each other. Among planting intervals, it was observed that planting interval I recorded highest leaf area per plant (342.45 cm^2) and followed by planting interval II (341.61 cm^2) and planting interval III (340.70 cm^2). All the planting intervals were found to be behaved statistically significant

Table-6: **Effect of planting seasons with intervals and nitrogen fertilizer on leaf area per plant (cm^2) of *Populus deltoides* plantations on problematic sites**

Season→	Autumn planting					Spring planting					Factor Means					
Planting intervals \ Nitrogen levels	N_0	N_1	N_2	N_3	Mean	N_0	N_1	N_2	N_3	Mean	Nitrogen levels		Planting intervals		Planting seasons	
I_1	342.61	343.11	347.12	343.50	344.09	340.53	341.11	342.50	339.12	340.82	N_0	340.46	I_1	342.45	S_1	343.08
I_2	341.52	342.33	346.27	342.13	343.06	339.54	340.42	341.09	339.58	340.16	N_1	341.41	I_2	341.61	S_2	340.10
I_3	340.42	341.50	345.28	341.17	342.09	338.13	339.98	340.11	339.03	339.31	N_2	343.73	I_3	340.70		
Mean	341.52	342.31	346.22	342.27	343.08	339.40	340.50	341.23	339.24	340.10	N_3	340.76				

C.D. ($p \leq 0.05$):	N= 0.12	N_0 = 0 kg/ha	PI_1 = Planting Interval I	S_1= Autumn Planting Season
	S= 0.13	N_1 = 100 kg/ha	PI_2 = Planting Interval II	S_2= Spring Planting Season
	I= 0.11	N_2 = 150 kg/ha	PI_3 = Planting Interval III	
	N×S = 0.14	N_3 = 200 kg/ha		
	N×I= 0.15			
	S×I= 0.13			
	N×S×I= 0.17			

with each other. Among the four nitrogen levels applied to the plantations, N_2 recorded highest leaf area per plant (343.73 cm^2) followed by N_1 (341.41 cm^2), N_3 (340.76 cm^2) and N_0 (340.46 cm^2). It is also observed that all the nitrogen levels were found to be statistically significant with each other.

It is evident from the Table 6 that interaction between nitrogen levels with planting seasons, nitrogen levels with planting intervals, planting seasons with intervals and over all interactions between planting seasons with intervals and nitrogen levels were significant for leaf area per plant of *Populus deltoides* plantations on problematic site. It was also further observed that best treatment combination with respect to leaf area per plant was $S_1I_1N_2$ which gave the value 347.12 cm^2. The minimum value of leaf area per plant was recorded with $S_1I_3N_0$ (340.42 cm^2) in autumn season. Similar observations were recorded in spring season for leaf area per plant.

4.1.6 Correlation of physiological and quality parameters of seedlings with survival percentage and growth attributes of *Populus deltoides* plantations on problematic sites

The survival percentage and growth attributes (plant height increment, collar diameter increment, number of branches per plant and leaf area per plant) were taken as dependent variables whereas, physiological and quality parameters (relative water content, root electrolyte leakage, shoot electrolyte leakage, root fibrosity, root volume, root length, root shoot ratio, sturdiness quotient and membrane stability index) were taken as independent variables for correlation studies.

A perusal of the data presented in Table 7 reveals that out of the nine independent variables, only 7 variables had direct positive effect on survival percentage of *Populus deltoides* plantations. Root electrolyte leakage and shoot electrolyte leakage correlated negatively to the dependent variables. Relative water content (0.813) contributed maximum to survival percentage of *Populus deltoides* plantations followed by root fibrosity (0.810) and root length (0.803). The lowest positive correlation (0.653) was observed between survival percentage

Table 7: Correlation of physiological and quality parameters of seedlings with survival percentage and growth attributes of *Populus deltoides* plantations on problematic sites

	Survival percentage	Plant height increment	Collar diameter increment	Number of branches per plant	Leaf area per plant
Relative water content	0.813**	0.811**	0.798**	0.821**	0.775**
Root electrolyte leakage	-0.831**	-0.765**	-0.786**	-0.876**	-0.643**
Shoot electrolyte leakage	-0.776**	-0.686**	-0,712**	-0.854**	-0.742**
Root fibrosity	0.810**	0.862**	0.784**	0.806**	0.884**
Root volume	0.721**	0.740**	0.764**	0.821**	0.776**
Root length	0.803**	0.756**	0.817**	0.744**	0.765**
Root shoot ratio	0.293	0.299	0.154	0.266	0.231
Sturdiness quotient	0.787**	0.941**	0.846**	0.903**	0.970**
Membrane stability index	0.653**	0.675**	0.714**	0.698**	0.665**

**significant at 1% level

and membrane stability index. Root electrolyte leakage (-0.831) and shoot electrolyte leakage (-0.776) showed direct correlation with survival percentage but with negative sign. A critical analysis of data reveals that correlation of root shoot ratio with survival percentage was statistically non-significant.

The Table 7 also indicates that leaf area per plant and sturdiness quotient have maximum direct positive correlation (0.970) followed by plant height increment and sturdiness quotient (0.941) and number of branches per plant and sturdiness quotient (0.903), respectively. It is also observed from the data that number of branches per plant gave highest negative correlation with root electrolyte leakage (-0.876) and shoot electrolyte leakage (-0.854), respectively.

4.1.7 Effect of *Populus deltoides* plantations on physico-chemical properties of soil with respect to planting seasons, planting intervals and nitrogen fertilizers on individual factor means

The values of the soil physico-chemical properties were given on average basis and not analyzed statistically. It was observed during the course of investigation that the change of soil physico-chemical parameters was minor or slight over the initial status. In context of this, if the statistical analysis was done then the effect of all the treatments would be non-significant. The purpose of discussing the results on average values to show the initial trend and it may give variations in the obtained results over the time.

So, the results presented in Tables 8, 15 and 22 show only the indication but not the final effect of the tested treatments.

The results pertaining to the effect on physico-chemical properties of soil with respect to planting seasons, planting intervals and nitrogen fertilizers on individual factor means of *Populus deltoides* plantations done on problematic sites are presented in Table 8. It was observed that there was no change in the texture at the time of completion of the experiment (one year) from the initial status. It was sandy loam at the time of outplanting and remained the same when the observation was made. The initial value of bulk density was 1.40 and 1.35 g/cc in autumn and spring season, respectively (Table 8). The values of bulk density slightly changed in both the seasons and were found to be 1.37 and 1.36 g/cc after completion of first growing season. It was observed from the Table 8 that highest bulk density was observed in PI_1 (1.38 g/cc) and lowest in PI_3 (1.36 g/cc) in autumn season. In spring season, it was again planting interval I (PI_1) which showed highest value (1.37 g/cc) as compared to PI_2 (1.36 g/cc) and PI_3 (1.35 g/cc). Bulk density followed the same trend with respect to nitrogen fertilizer levels in both the planting seasons. The highest value of bulk density was observed under N_3 and lowest under N_0 nitrogen level in autumn and spring planting seasons after the completion of first growing season. The water holding capacity was found to increase over the initial status in both the planting seasons. It was 53.70 percent in autumn season and 45.20 percent in spring season at the time of outplanting (Table 8). It was further observed that water holding capacity increased to 57.86 percent in autumn season 49.71 percent in spring season. It infers from the data presented in Table 8 that maximum water holding capacity was found in PI_1 (60.02%) and minimum in PI_3 (54.17%) in autumn season. Similar observations were observed in spring season where PI_1 gave maximum (54.17%) value of water holding capacity. It was also observed that water holding capacity was maximum under N_2 fertilizer level (58.17%) and (50.86%) and minimum under N_1 level (57.78%) and (48.25%) in autumn and spring season, respectively. Soils under plantations gave difference in pH values between the plantation seasons. The pH gave little bit higher (+.25) autumn planting than the spring planting. The highest pH was recorded in PI_1 and lowest in PI_3 in both the planting seasons, respectively. The pH value was observed higher under N_0 and N_1 nitrogen levels (7.29) in autumn planting seasons. It is observed that the pH value was found to decrease as the fertilizer dosages increased from N_0 to N_3 level in spring planting. The pH value was observed higher under N_0 nitrogen level and was same for both the planting seasons (7.29). Electrical conductivity was found to be 0.23 dsm^{-1} in both the planting seasons and in all the three planting intervals. It was also found that the electrical conductivity showed a decrease from initial values with the application of nitrogen fertilizer. Electrical conductivity was found same from N_0 to N_2 (0.24 dsm^{-1}) and then decreased under N_3 (0.22 dsm^{-1}) nitrogen level in autumn season. In spring season, the electrical conductivity did not change in N_0 and N_1 (0.24 dsm^{-1}) level and thereafter found to decrease from N_2 (0.23 dsm^{-1}) to N_3 (0.22 dsm^{-1}). The organic carbon was found to increase in both the planting seasons from their initial status. It was observed that the organic carbon content was more in autumn season (1.81%) than the spring season (1.78%). The PI_1 gave highest organic carbon (1.86%) while compared with the rest of the intervals. Similar trend was observed in spring planting season. It was found that N_2 nitrogen level outperformed over the rest of the tested levels in both the planting seasons. The level N_0 (control) came out to be at the bottom in both the planting seasons. The availability of nitrogen, phosphorous and potassium showed a decreasing trend in both the seasons from initial status. The availability of nitrogen, phosphorous and potassium was observed to be 261 kg N/ha, 5.05 kg P_2O_5/ha and 309 kg K_2O/ha in autumn season and 249 kg N/ha, 5.12 kg P_2O_5/ha and 320 kg K_2O/ha in spring season, respectively. The highest nitrogen availability was found in PI_1 (264 kg N/ha) and lowest in PI_3 (257 kg N/ha) in autumn season. In spring season, the nitrogen availability was highest in PI_3 (252 kg N/ha) and lowest in PI_1 (247 kg N/ha). The available nitrogen was observed to be highest under N_2 nitrogen level in both the planting seasons. It was also recorded from the Table 8 that available phosphorous was highest in PI_3 (5.06 kg P_2O_5/ha) whereas, PI_1 and PI_2 gave same value (5.04 kg P_2O_5/ha) in autumn season. In spring season, the value was highest for PI_2 (5.15 kg P_2O_5/ha) and lowest in PI_1 (5.10 kg P_2O_5/ha). The phosphorous availability was found higher under N_2 nitrogen level in both the planting seasons as compared to other levels. The available potassium was recorded highest in PI_2 (311 kg K_2O/ha) and lowest in PI_3 (307 kg K_2O/ha) in autumn season. In spring season, the observed values of available potassium with respect to planting intervals were PI_1 (320 kg K_2O/ha), PI_3 (319 kg K_2O/ha) and PI_2 (317 kg K_2O/ha). It was also observed that potassium

Table 8 **Effect of *Populus deltoides* plantations on physico-chemical properties of soil with respect to planting seasons, planting intervals and nitrogen fertilizers on individual factor means**

Parameters	Initial status		Autumn planting								Spring planting								Factor means							
	S_1	S_2	S_1	PI_1	PI_2	PI_3	N_0	N_1	N_2	N_3	S_2	PI_1	PI_2	PI_3	N_0	N_1	N_2	N_3	S	PI_1	PI_2	PI_3	N_0	N_1	N_2	N_3
Soil texture	Sandy loam	Sandy loam	Sandy loam	Sandy loam	Sandy loam	Sandy loam	Sandy loam	Sandy loam	Sandy loam	Sandy loam	Sandy loam	Sandy loam	Sandy loam	Sandy loam	Sandy loam	Sandy loam	Sandy loam	Sandy loam	Sandy loam	Sandy loam	Sandy loam	Sandy loam	Sandy loam	Sandy loam	Sandy loam	Sandy loam
Bulk density (g/cc)	1.40	1.35	1.37	1.38	1.37	1.36	1.35	1.35	1.37	1.40	1.36	1.37	1.36	1.35	1.35	1.35	1.36	1.38	1.36	1.37	1.36	1.36	1.35	1.35	1.36	1.39
Water holding capacity (%)	53.70	45.20	57.86	60.02	59.40	54.17	57.79	57.78	58.17	57.72	49.71	54.17	48.85	46.10	48.25	49.03	50.86	50.70	53.78	57.09	54.12	50.13	53.02	53.40	54.51	54.21
pH	7.36	7.32	7.25	7.31	7.25	7.19	7.29	7.29	7.23	7.21	7.21	7.23	7.21	7.20	7.26	7.22	7.20	7.18	7.23	7.27	7.23	7.19	7.27	7.25	7.21	7.19
Electrical conductivity (dsm^{-1})	0.27	0.24	0.23	0.23	0.23	0.23	0.24	0.24	0.24	0.22	0.23	0.23	0.23	0.23	0.24	0.24	0.23	0.22	0.23	0.23	0.23	0.23	0.24	0.24	0.23	0.22
Organic carbon (%)	1.55	1.48	1.81	1.86	1.80	1.77	1.77	1.80	1.86	1.82	1.78	1.81	1.78	1.75	1.75	1.78	1.81	1.77	1.79	1.83	1.79	1.76	1.76	1.79	1.84	1.75
Available nitrogen (kg N ha^{-1})	285	276	261	264	262	257	254	260	270	262	249	247	248	252	248	248	250	249	255	256	255	254	251	254	260	255
Available phosphorus (kg P_2O_5 ha^{-1})	6.04	5.90	5.05	5.04	5.04	5.06	5.02	5.05	5.07	5.05	5.12	5.10	5.15	5.12	5.11	5.13	5.15	5.10	5.08	5.07	5.10	5.09	5.06	5.09	5.11	5.08
Available potassium (kg K_2O ha^{-1})	336	325	309	309	311	307	305	308	313	309	316	320	317	319	314	318	321	322	314	314	314	313	309	313	317	315

Planting season (S) S_1= autumn and S_2= spring

Planting interval (PI) PI_1 = Planting interval I, PI_2 = Planting interval II & PI_3 = Planting interval III

Nitrogen fertilizer (N) N_0 = 0 kg/ha, N_1 = 100 kg/ha, N_2 = 150 kg/ha & N_3 = 200 kg/ha availability was highest in N_2 nitrogen level and lowest in N_0 nitrogen level in both the planting seasons.

Overall factor means were also evaluated to determine the best possible individual factor which effect the physico-chemical properties of soil under poplar plantations. It was observed that the value of bulk density was decreased from initial status and was found to be 1.36 g/cc. The highest bulk density was observed in PI_1 (1.37 g/cc) followed by PI_2 and PI_3 which gave the same value (1.36 g/cc). The highest bulk density was recorded under N_3 nitrogen level (1.39 g/cc) and lowest under N_0 (1.35 g/cc). The Table 8 also infers that the maximum water holding capacity was found in PI_1 (57.09%) and lowest in PI_3 (50.13%). The maximum value for water holding capacity was observed under N_2 (54.51%) followed by N_3 (54.21%), N_1 (53.40%) and N_0 (53.02%). The pH value was observed to be highest in PI_1 (7.27) while lowest in PI_3 (7.19). The pH showed a declining trend with the increase in nitrogen fertilizer from N_0 to N_3 irrespective of planting seasons. The highest pH was recorded under nitrogen level N_0 (7.27) and lowest under N_3 (7.19). The electrical conductivity was found same in all the planting intervals whereas, it showed a slight change under the influence of different nitrogen levels. It was also recorded that organic carbon was maximum in PI_1 (1.83%) followed by PI_2 (1.79%) and PI_3 (1.76%). The maximum organic carbon was recorded under N_2 (1.84%) and minimum under N_3 (1.75%). The available nitrogen was observed to be highest under PI_1 (256 kg N/ha) and lowest in PI_3 (254 kg N/ha). It was also recorded from the data that highest available nitrogen was under N_2 (260 kg N/ha) while it was lowest under N_0 (251 kg N/ha). The available phosphorous was recorded to be highest in PI_2 (5.10 kg P_2O_5/ha) and lowest in PI_1 (5.07 kg P_2O_5/ha). The phosphorous availability was highest under N_2 (5.11 kg P_2O_5/ha) while it was lowest under N_0 (5.06 kg P_2O_5/ha). It was also recorded from the Table 8 that the potassium availability was same for PI_1 and PI_2 (314 kg K_2O/ha) whereas, it showed a slight decrease in PI_3 (313 kg

K_2O/ha). The available potassium was found to be maximum under nitrogen level N_2 (317 kg K_2O/ha) and minimum under N_0 (309 kg K_2O/ha).

4.2 Effect of planting seasons, pit shapes, pit sizes and moisture conservation measures on establishment & growth of *Populus deltoides* plantations on problematic sites

The seedlings of *Populus deltoides* were planted on problematic site in temperate region of North Western Himalayas to standardize the planting season, pit shape, pit size and moisture conservation measures to make the successful plantations. For this purpose, two planting seasons, three pit shapes and sizes including mulching measures were taken to find out the best treatment as per the site specification and species requirement.

4.2.1 Effect of planting seasons, pit shapes, pit sizes and moisture conservation measures on survival percentage of *Populus deltoides* plantations on problematic sites

The results for the survival percentage of *Populus deltoides* plantations done on problematic site are presented in Table 9. It was found that both the planting seasons, pit shapes, pit sizes and moisture conservation measures significantly effected the survival percentage. It indicates from the data presented in Table 9 that all the pit types found to effect survival percentage significantly in both the seasons. Highest survival percentage was recorded for PT_2 (81.47%) followed by PT_1 (75.91%) and PT_3 (72.21%) in autumn planting. Similar trend has been observed with pit type in spring planting. It has been observed that ordinary and ring pit gave same value of survival percentage (64.80%). It was found that PS_3 recorded highest survival percentage (90.73%) which was followed by PS_2 (74.06%) and PS_1 (64.80%), respectively. In spring planting, PS_3 again gave highest survival percentage (79.79%) over the rest of the two pit sizes. The black polythene (M_2) found to give higher values of survival percentage in all the three types of pits and their sizes in both the planting seasons. Saucer pit gave better survival in all three pits sizes in both the seasons. All the three mulching treatments found to effect survival percentage significantly. Highest survival

Table-9: Effect of planting seasons, pit shapes, pit sizes and moisture conservation measures on survival percentage of *Populus deltoides* plantations on problematic sites

Season	Autumn planting												Spring planting												Factor Means			
Pit type	PT_1			Mean	PT_2			Mean	PT_3			Mean	PT_1			Mean	PT_2			Mean	PT_3			Mean				
Pit size / Mulching	PS_1	PS_2	PS_3		PS_1	PS_2	PS_3		PS_1	PS_2	PS_3		PS_1	PS_2	PS_3		PS_1	PS_2	PS_3		PS_1	PS_2	PS_3		Mulching	Pit Type	Pit size	Season
M_0	50.00	66.66	83.33	66.66	66.66	66.66	83.33	72.21	50.00	66.66	83.33	66.66	50.00	50.00	66.66	55.55	50.00	66.66	66.66	61.10	50.00	50.00	66.66	55.55	62.95	70.36	61.10	76.53
M_1	66.66	66.66	83.33	72.21	66.66	83.33	100	83.33	50.00	66.66	83.33	66.66	50.00	66.66	83.33	66.66	66.66	83.33	83.33	77.77	50.00	66.66	83.33	66.66	72.21	77.85	70.36	67.88
M_3	83.33	83.33	100	88.88	83.33	83.33	100	88.88	66.66	83.33	100	83.33	66.66	66.66	83.33	72.21	66.66	83.33	100	83.33	66.66	66.66	83.33	72.21	81.47	68.50	85.26	
Mean	66.66	72.21	88.88	75.91	72.21	77.77	94.44	81.47	55.55	72.21	88.88	72.21	55.55	61.10	77.77	64.80	61.10	77.77	83.83	74.06	55.55	61.10	77.77	64.80				

C.D. ($p \le 0.05$):

M= 1.38
S=3.77
P_T=1.10
P_s=2.48
M×S=3.11
M× P_T=1.57
M× P_s=3.48
P_T × P_s =2.57
S× P_T=2.38
P_s ×S=4.38
M × P_T × P_s × S = NS

PS_1 = 30×45 (cm^3)
PS_2 = 45×60 (cm^3)
PS_3 = 60×60 (cm^3)

PT_1 = Ordinary pit
PT_2 = Saucer pit
PT_3 = Ring pit

M_0 = Control
M_1 = Ordinary Mulch
M_2 = Black Polythene

S_1= Autumn Planting Season
S_2= Spring Planting Season

percentage was recorded in M_2 (87.03%) and minimum in M_0 (68.51%) mulching treatment in autumn planting. Similarly in spring planting, M_2 recorded highest survival percentage (75.91%) and followed by M_1 (74.23%) and M_0 (57.40%).

The data on factor means (Table 9) reveal that the maximum survival percentage (76.53%) was recorded in autumn planting whereas lowest value (67.88%) was observed in spring planting. Saucer pit (PT_2) gave maximum survival percentage (77.85%) which was followed by PT_1 (70.36%) and PT_3 (68.50%). It was also observed from the Table 9 that all the three pit sizes were found to effect the survival percentage in *Populus deltoides* plantations. Highest survival percentage was found for PS_3 (85.26%) and lowest in PS_1 (61.10%). Maximum survival percentage was found with M_2 (81.47%) and lowest with M_0 (62.95%) irrespective of planting seasons. However, all the mulching treatments were found to be significantly different from each other.

It infers from Table 9 that interaction between mulching and pit types, mulching and pit sizes, mulching and planting seasons, pit types and pit sizes, planting seasons and pit types and planting seasons and pit sizes were found to be statistically significant with each other. Whereas, overall interaction between planting seasons, pit types, pit sizes and mulching were non-significant for survival percentage parameter of *Populus deltoides* plantations. However, the treatment combinations namely $S_1M_2PT_2PS_3$, $S_1M_1PT_2PS_3$, $S_1M_2PT_3PS_3$ and $S_2M_2PT_2PS_3$ gave 100 percent survival of poplar plantations. The least value of survival percentage was observed in treatment combinations $S_1M_0PT_1PS_1$, $S_1M_0PT_3PS_1$ and $S_2M_0PT_1PS_1$.

4.2.2 Effect of planting seasons, pit shapes, pit sizes and moisture conservation measures in plant height increment (cm) of *Populus deltoides* plantations on problematic sites

A critical analysis of the data presented in Table 10 reveals that both the planting seasons, pit types, pit sizes and moisture conservation measures were found to effect the plant height increment significantly. Maximum plant height increment was recorded in PT_2 (31.11 cm) and lowest in PT_3 (27.24 cm) in autumn planting. Similar trend has been observed with PT_2 in spring planting. It was found that PS_3 gave maximum plant height increment (29.42 cm) which was followed by PS_2 (29.19 cm) and PS_1 (28.99 cm) in autumn planting. In spring planting, PS_3 again gave highest plant height increment (27.98 cm) over the rest of the two pits. Maximum plant height increment was recorded in M_2 (29.87 cm) and minimum in M_0 (28.51 cm) in autumn planting. Similarly in spring planting, M_2 recorded maximum height increment (28.17 cm) which was followed by M_1 (27.72 cm) and M_0 (27.52 cm), respectively.

Individual factors were also evaluated to determine the best individual factor for *Populus deltoides* plantations pertaining to problematic sites. Maximum plant height increment (29.20 cm) was observed in autumn planting and lowest (27.81 cm) in spring planting. PT_2 gave maximum plant height increment (29.91 cm) which was followed by PT_1 (28.34 cm) and PT_3 (27.26 cm). It was also observed from the Table 10 that all the three pit sizes were found to effect plant height increment in *Populus deltoides* plantations significantly. Maximum plant height increment was reported in PS_3 (28.71 cm) and lowest in PS_1 (28.33 cm). Maximum height increment was observed in M_2 (29.02 cm) which was followed by M_1 (28.47 cm) and M_0 (28.02 cm).

It is evident from the Table 10 that interaction between mulching and pit types, mulching and pit sizes, mulching and planting seasons, pit types and pit sizes, planting seasons and pit types, planting seasons and pit sizes and overall interaction between planting seasons, pit types, pit sizes and mulching were found to be statistically significant with each other. The treatment combinations namely $S_1M_2PT_2PS_3$ (32.01 cm), $S_1M_2PT_2PS_2$ (31.66 cm) and $S_1M_2PT_2PS_1$ (31.50 cm) were recorded with maximum plant height increment for *Populus deltoides* on problematic sites. The minimum values were observed in $S_1M_0PT_1PS_1$ (28.53 cm), $S_1M_0PT_2PS_1$ (26.21 cm) and $S_1M_0PT_2PS_1$ (30.23 cm) in autumn planting. Similar trend has been observed in spring planting with respect to the said treatment combinations.

Table-10: Effect of planting seasons, pit shapes, pit sizes and moisture conservation measures in plant height increment (cm) of *Populus deltoides* plantations on problematic sites

Season	Autumn planting												Spring planting												Factor Means			
Pit type	PT_1			Mean	PT_2			Mean	PT_3			Mean	PT_1			Mean	PT_2			Mean	PT_3			Mean				
Pit size / Mulching	PS_1	PS_2	PS_3		PS_1	PS_2	PS_3		PS_1	PS_2	PS_3		PS_1	PS_2	PS_3		PS_1	PS_2	PS_3		PS_1	PS_2	PS_3		Mulching	Pit Type	Pit size	Season
M_0	28.53	28.66	28.83	28.67	30.23	30.42	30.78	30.48	26.21	26.39	26.60	26.40	27.10	27.16	27.25	27.16	28.23	28.35	28.44	28.34	27.00	27.08	27.13	27.07	28.02	28.34	28.33	**29.20**
M_1	29.10	29.33	29.46	29.30	30.91	31.13	31.36	31.13	27.07	27.23	27.41	27.24	27.28	27.35	27.40	27.34	28.45	28.59	28.66	28.57	27.20	27.26	27.31	27.26	28.47	29.91	28.48	27.81
M_3	29.61	29.78	30.09	29.83	31.50	31.66	32.01	31.72	27.77	28.10	28.32	28.06	27.55	27.78	27.94	27.76	28.79	28.85	30.06	29.23	27.43	27.49	27.66	27.53	29.02	27.26	28.71	
Mean	29.08	29.26	29.46	29.27	30.88	31.07	31.38	31.11	27.02	27.24	27.44	27.24	27.31	27.43	27.52	27.42	28.49	28.60	29.05	28.71	27.21	27.28	27.37	27.28				

C.D ($p \leq 0.05$):

$M = 0.21$
$S = 0.16$
$P_T = 0.71$
$P_s = 0.20$
$M \times S = 0.19$
$M \times P_T = 0.21$
$M \times P_s = 0.30$
$P_T \times P_s = 0.21$
$S \times P_T = 0.20$
$P_s \times S = 0.21$
$M \times P_T \times P_s \times S = 0.21$

$PS_1 = 30 \times 45$ (cm^3)
$PS_2 = 45 \times 60$ (cm^3)
$PS_3 = 60 \times 60$ (cm^3)

PT_1 = Ordinary pit
PT_2 = Saucer pit
PT_3 = Ring pit

M_0 = Control
M_1 = Ordinary Mulch
M_2 = Black Polythene

S_1 = Autumn Planting Season
S_2 = Spring Planting Season

4.2.3 Effect of planting seasons, pit shapes, pit sizes and moisture conservation measures in collar diameter increment (mm) of *Populus deltoides* plantations on problematic sites

A perusal of the data presented in Table 11 reveals that planting seasons, pit types, pit sizes and moisture conservation measures found to effect the collar diameter increment of *Populus deltoides* significantly on problematic sites. Highest diameter increment was observed with PT_2 (5.64 mm) which was followed by PT_1 (4.91 mm) and PT_3 (4.50 mm) in the plantations done in autumn season. Similar trend has been observed in spring planting. It was found that the treatment PS_3 gave the highest diameter increment (5.11 mm) and lowest under PS_1 (4.92 mm) in autumn season. In spring planting, PS_3 gave the highest diameter increment as compared to the other two pit sizes. It was observed that black polythene (M_2) used as mulching material found to outperform over the rest of the tested mulch i.e. ordinary mulch (paddy straw) and no mulch (control). Highest diameter increment was recorded in M_2 (5.30 mm) and lowest in M_0 (4.73 mm) in autumn planting. Similarly in spring planting, M_2 recorded highest diameter increment (4.77 mm) which was followed by M_1 (4.52 mm) and M_0 (4.25 mm), respectively.

Factor means were evaluated to determine the best possible factor for collar diameter increment of *Populus deltoides* plantations on problematic sites. Autumn planting gave higher diameter increment values as compared to spring planting. It is further observed from the Table 10 that the highest diameter increment (5.01 mm) was found in autumn planting while it was lowest in spring planting (4.51 mm). It was found that saucer pit (PT_2) gave highest collar diameter increment (5.20 mm) while the lowest value of collar diameter was observed in PT_3 (4.42 mm). It was also seen that the bigger sized pit (PS_3: 60 cm^3) gave more increment of collar diameter as compared to the smaller sized pit i.e. PS_1 and PS_2. Highest diameter increment was recorded in PS_3 (4.86 mm) and lowest in PS_1 (4.67 mm). The highest diameter increment was recorded under M_2 (5.04 mm) which was followed by M_1 (4.76 mm) and M_0 (4.49 mm), respectively.

Table-11: Effect of planting seasons, pit shapes, pit sizes and moisture conservation measures in collar diameter increment (mm) of *Populus deltoides* plantations on problematic sites

Season	Autumn planting												Spring planting												Factor Means			
Pit type	PT_1			Mean	PT_2			Mean	PT_3			Mean	PT_1			Mean	PT_2			Mean	PT_3			Mean				
Pit size / Mulching	PS_1	PS_2	PS_3		PS_1	PS_2	PS_3		PS_1	PS_2	PS_3		PS_1	PS_2	PS_3		PS_1	PS_2	PS_3		PS_1	PS_2	PS_3		Mulching	Pit Type	Pit size	Season
M_0	4.47	4.53	4.66	4.55	5.23	5.36	5.48	5.36	4.23	4.28	4.36	4.29	4.10	4.17	4.25	4.17	4.36	4.48	4.57	4.47	4.00	4.12	4.20	4.11	4.49	4.67	4.67	**5.01**
M_1	4.78	4.84	4.98	4.87	5.57	5.66	5.79	5.67	4.42	4.45	4.53	4.47	4.33	4.48	4.57	4.46	4.69	4.75	4.84	4.76	4.27	4.35	4.43	4.35	4.76	5.20	4.76	4.51
M_3	5.13	5.33	5.45	5.30	5.83	5.87	5.94	5.88	4.68	4.72	4.80	4.73	4.63	4.68	4.75	4.69	4.88	5.09	5.20	5.06	4.48	4.56	4.66	4.57	5.04	4.42	4.86	
Mean	4.79	4.90	5.03	4.91	5.54	5.63	5.74	5.64	4.44	4.48	4.56	4.50	4.35	4.44	4.52	4.44	4.64	4.77	4.87	4.76	4.25	4.34	4.43	4.34				

C.D ($p \leq 0.05$):

M = 0.10
S= 0.12
P_T = 0.11
P_s= 0.14
M×S= 0.13
M× P_T = 0.17
M× P_s = 0.15
P_T × P_s = 0.16
S× P_T =0.32
P_s ×S= N.S
M × P_T × P_s × S = NS

PS_1 = 30×45 (cm^3)
PS_2 = 45×60 (cm^3)
PS_3 = 60×60 (cm^3)

PT_1 = Ordinary pit
PT_2 = Saucer pit
PT_3 = Ring pit

M_0 = Control
M_1 = Ordinary Mulch
M_2 = Black Polythene

S_1= Autumn Planting Season
S_2= Spring Planting Season

It is reported from the Table 11 that interaction between mulching and pit types, mulching and pit sizes, mulching and planting seasons, pit types and pit sizes, planting seasons and pit types, planting seasons and pit sizes and interaction among all the treatments were found to be statistically significant. The best treatment combination for collar diameter increment was $S_1M_2PT_2PS_3$ (5.94 mm). The other equally good treatment combinations were $S_1M_2PT_2PS_2$ (5.87 mm) and $S_1M_2PT_2PS_1$ (5.83 mm) in autumn planting. Whereas, the lowest value was observed in $S_1M_0PT_3PS_3$ (4.23 mm). Similar observations were reported from the plantations done in spring season on problematic site.

4.2.4 Effect of planting seasons, pit shapes, pit sizes and moisture conservation measures on number of branches per plant of *Populus deltoides* plantations on problematic sites

The results pertaining to the effect of planting seasons, pit types, pit sizes and moisture conservation measures on number of branches per plant are presented in Table 12. It was recorded that all the pit types were significantly effect the number of branches per plant in both the planting seasons. Maximum number of branches were recorded in PT_2 (8.48) followed by PT_1 (7.91) and PT_3 (7.60) in autumn planting. The trends with respect to pit types were similar in spring planting which gave maximum number of branches in PT_2 (7.88) and minimum under PT_3 (7.31). Pit sizes behaved statistically significant irrespective of the planting seasons. The effect of pit sizes on number of branches per plant was determined by averaging the values in all the three sizes of pits separately. PS_3 (8.08) gave maximum number of branches per plant followed by PS_2 (7.99) and PS_1 (7.91) in autumn planting. Similar trend was observed in spring planting where PS_3 performed better as compared to the other tested pit sizes. The plants covered with black polythene mulch were found to give maximum value. The lowest number of branches was obtained in treatments where no mulching was used in both the planting seasons. Maximum number of branches per plant were recorded in M_2 (8.28) and lowest in M_0 (7.73) in autumn planting. Similarly in

Table-12: Effect of planting seasons, pit shapes, pit sizes and moisture conservation measures on number of branches per plant of *Populus deltoides* plantations on problematic sites

Season	Autumn planting												Spring planting												Factor Means			
Pit type	PT_1			Mean	PT_2			Mean	PT_3			Mean	PT_1			Mean	PT_2			Mean	PT_3			Mean				
Pit size / Mulching	PS_1	PS_2	PS_3		PS_1	PS_2	PS_3		PS_1	PS_2	PS_3		PS_1	PS_2	PS_3		PS_1	PS_2	PS_3		PS_1	PS_2	PS_3		Mulching	Pit Type	Pit size	Season
M_0	7.50	7.61	7.69	7.60	8.12	8.23	8.30	8.22	7.31	7.39	7.46	7.39	7.19	7.26	7.31	7.25	7.50	7.58	7.66	7.58	7.03	7.10	7.16	7.10	7.52	7.68	7.69	8.00
M_1	7.77	7.84	7.98	7.86	8.39	8.46	8.55	8.47	7.50	7.58	7.69	7.59	7.38	7.44	7.52	7.45	7.79	7.85	7.99	7.88	7.21	7.28	7.38	7.29	7.76	8.18	7.77	7.55
M_3	8.15	8.28	8.36	8.26	8.67	8.73	8.88	8.76	7.77	7.83	7.86	7.82	7.56	7.66	7.71	7.64	8.10	8.19	8.26	8.18	7.47	7.55	7.62	7.55	8.04	7.46	7.85	
Mean	7.81	7.91	8.01	7.91	8.39	8.47	8.58	8.48	7.53	7.60	7.67	7.60	7.38	7.45	7.51	7.45	7.80	7.87	7.97	7.88	7.24	7.31	7.39	7.31				

C.D .($p \leq 0.05$):

M = 0.11
S= 0.81
P_T = 0.17
P_s= 0.15
M×S= 0.13
M× P_T = 0.14
M× P_s = 0.16
P_T × P_s = 0.15
S× P_T =0.12
P_s ×S= 16
M × P_T × P_s ×S=0.12

PS_1 = 30×45 (cm^3)
PS_2 = 45×60 (cm^3)
PS_3 = 60×60 (cm^3)

PT_1 = Ordinary pit
PT_2 = Saucer pit
PT_3 = Ring pit

M_0 = Control
M_1 = Ordinary Mulch
M_2 = Black Polythene

S_1= Autumn Planting Season
S_2= Spring Planting Season

spring planting, M_2 gave maximum number of branches (7.79) followed by M_1 (7.54) and M_0 (7.31), respectively.

The data on individual factor means presented in Table 12 reveal that number of branches per plant were little bit more in autumn planting (8.00) than the spring planting (7.55). The value of number of branches per plant in both the planting seasons was found to be statistically significant with each other. Saucer pit (PT_2) gave maximum number of branches (8.18) which was followed by PT_1 (7.68) and PT_3 (7.46), respectively. Maximum number of branches per plant were recorded in PS_3 (7.85) and lowest in PS_1 (7.69). Number of branches per plant were recorded maximum in M_2 (8.04) and minimum in M_0 (7.52).

It is evident from the Table 12 that interaction between mulching and pit types, mulching and pit sizes, mulching and planting seasons, pit types and pit sizes, planting seasons and pit types, planting seasons and pit sizes and interaction among planting seasons, pit types, pit sizes and mulching individually or jointly were found to be statistically significant. It was also observed that the number of branches per plant of *Populus deltoides* plantations on problematic sites was found highest with treatment combinations $S_1M_2PT_2PS_3$ (8.88). The other treatments like $S_1M_2PT_2PS_2$ (8.73) and $S_1M_2PT_2PS_1$ (8.67) gave equally good values while compared with the best treatment combinations. Whereas, lowest value was reported in $S_1M_0PT_3PS_1$ (7.31) in autumn season. Similar observations were observed for number of branches per plant in spring season.

4.2.5 Effect of planting seasons, pit shapes, pit sizes and moisture conservation measures on leaf area per plant (cm^2) of *Populus deltoides* plantations on problematic sites

A perusal of the data given in Table 13 reveals that the planting seasons, pit types, pit sizes and moisture conservation measures significantly effected leaf area per plant of *Populus deltoides* plantations on problematic sites. Highest leaf area was recorded in PT_2 (928.83 cm^2) and lowest in PT_3 (905.22 cm^2) in autumn planting. In spring planting, similar observations were recorded which were in

Table-13: Effect of planting seasons, pit shapes, pit sizes and moisture conservation measures on leaf area per plant (cm^2) of *Populus deltoides* plantations on problematic sites

Season	Autumn planting												Spring planting												Factor Means			
Pit type	PT_1			Mean	PT_2			Mean	PT_3			Mean	PT_1			Mean	PT_2			Mean	PT_3			Mean				
Pit size / Mulching	PS_1	PS_2	PS_3		PS_1	PS_2	PS_3		PS_1	PS_2	PS_3		PS_1	PS_2	PS_3		PS_1	PS_2	PS_3		PS_1	PS_2	PS_3		Mulching	Pit Type	Pit size	Season
M_0	906.53	906.88	907.12	906.84	923.30	925.11	927.15	925.19	903.10	903.19	904.42	903.57	900.01	900.54	900.98	900.51	910.13	912.43	916.31	912.96	899.12	900.09	900.53	899.91	908.16	908.33	910.52	915.81
M_1	910.42	911.09	917.58	913.03	927.81	929.52	930.01	929.11	904.98	905.13	905.77	905.29	902.32	903.10	903.77	903.06	917.33	917.98	918.13	917.81	901.12	902.58	902.98	902.23	911.76	922.78	911.50	907.40
M_3	918.40	920.13	922.22	920.25	931.13	932.43	932.98	932.18	906.51	906.82	907.03	906.79	905.23	906.12	907.53	906.29	918.81	919.30	920.10	919.40	903.16	904.48	905.53	904.39	914.88	903.70	912.79	
Mean	911.78	912.70	915.64	913.37	927.41	929.02	930.05	928.83	904.86	905.05	905.74	905.22	902.52	903.25	904.09	903.29	915.42	916.57	918.18	916.72	901.13	902.38	903.01	902.18				

C.D ($p \leq 0.05$):

$M = 2.11$
$S = 5.10$
$P_T = 4.23$
$P_s = 0.48$
$M \times S = 1.48$
$M \times P_T = 2.50$
$M \times P_s = 2.19$
$P_T \times P_s = 2.76$
$S \times P_T = 1.77$
$P_s \times S = 2.34$
$M \times P_T \times P_s \times S = 1.79$

$PS_1 = 30 \times 45$ (cm^3)
$PS_2 = 45 \times 60$ (cm^3)
$PS_3 = 60 \times 60$ (cm^3)

PT_1 = Ordinary pit
PT_2 = Saucer pit
PT_3 = Ring pit

M_0 = Control
M_1 = Ordinary Mulch
M_2 = Black Polythene

S_1 = Autumn Planting Season
S_2 = Spring Planting Season

order of PT_2 (916.72 cm^2), PT_1 (903.29 cm^2) and PT_3 (902.18 cm^2). It was found that PS_3 (917.14 cm^2) gave highest leaf area which was followed by PS_2 (915.59 cm^2) and PS_1 (914.68 cm^2) in autumn season. Similar type of trend was observed in spring planting where PS_3 outperformed over the other two pit sizes. Highest leaf area was recorded in M_2 (919.74 cm^2) and minimum in M_0 (911.86 cm^2) in autumn planting. Similarly in spring planting, M_2 gave highest leaf area (910.02 cm^2) which was followed by M_1 (907.70 cm^2) and M_0 (904.46 cm^2), respectively.

Factor means were evaluated to determine the best individual factor for leaf area per plant of *Populus deltoides* plantations. Autumn season plantations gave higher value of leaf area (915.81 cm^2) as compared to spring planting which gave only 907.40 cm^2 leaf area per plant. Leaf area per plant was recorded highest in PT_2 (922.78 cm^2) and lowest in PT_3 (903.70 cm^2). It is observed from the Table 13 that highest leaf area per plant was recorded in PS_3 (912.79 cm^2) and lowest in PS_1 (910.52 cm^2). Highest leaf area was recorded in M_2 (914.88 cm^2) which was followed by M_1 (911.76 cm^2) and M_0 (908.16 cm^2), respectively.

A cursory glance of Table 13 reveals that effect of interaction between mulching and pit types, mulching and pit sizes, mulching and planting seasons, pit types and pit sizes, planting seasons and pit types, planting seasons and pit sizes and interaction among all the treatments were found to be statistically significant. The treatment combinations namely $S_1M_2PT_2PS_3$ (932.98 cm^3) followed by $S_1M_2PT_2PS_2$ (932.43 cm^3) and $S_1M_2PT_2PS_1$ (931.13 cm^3) gave better leaf area per plant while compared with other treatment combinations in *Populus deltoides* plantations. The lowest values were observed in $S_1M_0PT_3PS_1$ (903.10 cm^3) and $S_1M_0PT_2PS_2$ (903.19 cm^3). The similar trend was reported in spring season with respect to leaf area per plant.

4.2.6 Correlation of physiological and quality parameters of seedlings with survival percentage and growth attributes of *Populus deltoides* plantations on problematic sites

The survival percentage and growth attributes (plant height increment,

Table 14: Correlation of physiological and quality parameters of seedlings with survival percentage and growth attributes of *Populus deltoides* plantations on problematic sites

	Survival percentage	Plant height increment	Collar diameter increment	Number of branches per plant	Leaf area per plant
Relative water content	0.825**	0.786**	0.754**	0.812**	0.785**
Root electrolyte leakage	-0.822**	-0.775**	-0.743**	-0.851**	-0.757**
Shoot electrolyte leakage	-0.764**	-0.657**	-0.723**	-0.832**	-0.734**
Root fibrosity	0.822**	0.801**	0.802**	0.814**	0.712**
Root volume	0.712**	0.753**	0.734**	0.804**	0.737**
Root length	0.811**	0.744**	0.835**	0.858**	0.831**
Root shoot ratio	0.682**	0.310*	0.751**	0.760**	0.612**
Sturdiness quotient	0.657**	0.360*	0.905**	0.963**	0.819**
Membrane stability index	0.632**	0.654**	0.721**	0.687**	0.665**

*significant at 5% level **significant at 1% level collar diameter increment, number of branches per plant and leaf area per plant) were taken as dependent variables whereas, physiological (relative water content, root electrolyte leakage and shoot electrolyte leakage) and quality parameters (root fibrosity, root volume, root length, root shoot ratio, sturdiness quotient and membrane stability index) were taken as independent variables for correlation studies.

A perusal of the data from Table 14 reveals that out of the nine independent variables, only 7 variables gave direct positive effect on survival percentage of *Populus deltoides* plantations done on problematic sites. Root electrolyte leakage and shoot electrolyte leakage correlated negatively to the dependent variables. Relative water content (0.825) found to contribute maximum towards survival percentage of *Populus deltoides* plantations and followed by root fibrosity (0.822) and root length (0.811). The lowest positive correlation was observed between survival percentage and membrane stability index (0.632). Root electrolyte leakage (-0.822) and shoot electrolyte leakage (-0.764) found to negatively correlated with survival percentage.

It was further observed that the number of branches per plant and sturdiness quotient gave direct positive correlation with the value (0.963) and followed by collar diameter increment and sturdiness quotient (0.905) and number of branches per plant and root length (0.858), respectively. The number of branches per plant correlated negatively with root electrolyte leakage (-0.851) and shoot electrolyte leakage (-0.832).

4.2.7 Effect of *Populus deltoides* plantations on physico-chemical properties of soil with respect to planting seasons, pit shapes, pit sizes and moistures conservation measures (mulching) on individual factor means

The results pertaining to the effect of *Populus deltoides* plantations on physico-chemical properties of soil with respect to planting seasons, pit shapes, pit sizes and moisture conservation measures (mulching) on individual factor means are presented in Table 15. The data from the Table 15 illustrate that there was no change in the status of soil texture from its initial status. It was sandy loam at the time of outplanting and remained sandy loam when the observations were made after the completion of one growing season. The initial value of bulk density was 1.40 and 1.35 g/cc in autumn and spring seasons, respectively. The values of bulk density showed a slight change in both the seasons and were found to be 1.35 and 1.36 g/cc after first growing season. It was observed from the Table 15 that highest bulk density (1.37 g/cc) was recorded in PT_1 and lowest (1.34 g/cc) in PT_3 in autumn season. In spring season, PT_1 and PT_2 gave same value (1.36 g/cc) while the PT_3 showed a slight decrease and gave the minimum value (1.35 g/cc). Bulk density was observed to follow the same trend with respect to pit sizes in both the planting seasons. The value of bulk density was found to decrease with the increase in pit size. The highest value of bulk density was observed in PS_1 (1.37 and 1.38 g/cc) and lowest in PS_3 (1.33 and 1.34 g/cc) in both the seasons, respectively. It was also observed that the value of bulk density was reported to be higher in spring season as compared to autumn season. The highest bulk density was found in M_0 (1.37 g/cc) where no mulching was applied and lowest under M_2 (1.33 g/cc) mulching with black polythene in autumn season. Similar observations were found in spring season with the bulk density parameter. The initial value of water holding capacity was 53.70 and 45.20 percent where autumn and spring planting was done, respectively. There was increase in the value of water holding capacity over the initial status in both the planting seasons. Water holding capacity was 57.17 percent under autumn planting and 56.42 percent under spring planting after the completion of one growing season. The Table 15 infers that maximum water holding capacity was found in PT_3 (60.61%) and minimum in PT_2 (53.16%) in autumn season. Similarly, PT_3 (ring pit) outperformed as compared to PT_2 (saucer pit) and PT_1 (ordinary pit) in spring season. It was also observed that the water holding capacity was maximum in PS_3 (60.61%) and minimum in PS_1 (53.66%) under the plantations done in autumn season. In spring season, maximum value of water holding capacity was recorded in PS_3 (59.62%) and minimum value in PS_1 (53.98%). Black polythene mulch outperformed over the other mulching treatments with respect to water holding capacity. The highest value of water holding capacity was observed under M_2 (60.29%) and lowest under M_0 (54.09%) mulching treatments in autumn season. Similar observations were made with mulching treatment under spring planting. The pH value was recorded slightly more in autumn season (7.23) as compared to spring season (7.22). Ordinary pit (PT_1) showed higher value of pH while compared with saucer (PT_2) and ring (PT_3) pit in both the planting seasons. It was also recorded that highest pH value was observed in PS_1 (7.26) and lowest in PS_3 (720) in autumn season. In spring season, again it was PS_1 which gave higher pH value as compared to other tested pit sizes. The effect of mulching on pH was same in both the planting seasons where M_2 performed better as compared to other tested mulching materials. The electrical conductivity showed a slight decrease from initial value and was found to be same for both the planting seasons (0.21 dsm^{-1}). Electrical conductivity was found highest in PT_1 (0.22 dsm^{-1}) and lowest in PT_2 (0.19 dsm^{-1}) in autumn planting season. Similar results were recorded in spring planting season. The Table 15 also reveals that with increase in pit sizes the electrical conductivity found to decrease in both the planting seasons. The highest value of electrical conductivity was observed in PS_1 (0.22 dsm^{-1}) and lowest in PS_3 (0.19 dsm^{-1}) in autumn season. In spring season, the value of electrical conductivity was again found higher in PS_1 (0.22 dsm^{-1}) as compared to PS_2 (0.21 dsm^{-1}) and PS_3 (0.20 dsm^{-1}). The mulching was found to decrease the value of electrical conductivity. In autumn season, electrical conductivity was highest under M_0 (0.22 dsm^{-1}) and lowest under M_2 (0.19 dsm^{-1}). Similarly in spring season, electrical conductivity was higher under M_0 (0.22 dsm^{-1}) as compared to other tested mulches including control. It was further observed that the organic carbon was found to increase in both the planting seasons from their initial status. The percentage of organic carbon was high in autumn season (1.81%) and low in spring season (1.78%). The PT_3 recorded higher value of organic carbon (1.96%) whereas, PT_1 (1.72%) gave the lowest value. Same trend was observed under spring planting where PT_3 gave high value (1.93%) and low in PT_1 (1.69%). It was found that the PS_3 gave better results pertaining to organic carbon in both the planting seasons. The organic carbon was found maximum in PS_3 (1.83%) and minimum in PS_1 (1.73%) in autumn planting. Similar observations were made in spring planting. It was also observed that the highest percentage of organic carbon was found with black polythene mulch (M_2) and lowest where no mulch was used (M_0) in both the planting seasons. The availability of nitrogen, phosphorous and potassium showed a decreasing trend in both the planting seasons from their initial status. The availability of nitrogen, phosphorous and potassium was observed to be 226 kg N/ha, 4.61 kg P_2O_5/ha and 295 kg K_2O/ha in autumn season and 215 kg N/ha, 4.51 kg P_2O_5/ha and 294 kg K_2O/ha in spring season, respectively. The highest nitrogen availability was found in PT_2 (236 kg N/ha) and lowest in PT_1 (213 kg N/ha) in autumn season. In spring season, the nitrogen availability was highest in PT_1 (232 kg N/ha) and lowest in PT_3 (196 kg N/ha). The available nitrogen was observed to be highest in PS_1 followed by PS_2 and PS_3 in both the planting seasons. Mulching did not show any on effect the availablility of available nitrogen in the plantations. The highest available nitrogen was found under M_0 (229 kg N/ha) and lowest under M_2 (223 kg N/ha) in autumn season. Similarly, in spring season, the value was higher in M_0 (218 kg N/ha) as compared to other applied mulching materials. It was also recorded from the Table 15 that available phosphorous was highest in PT_1 (4.69 kg P_2O_5/ha) which was followed by PT_2 (4.64 kg P_2O_5/ha) and PT_3 (4.52 kg P_2O_5/ha) in autumn season. In spring season, the value was highest in PT_1 (4.67 kg P_2O_5/ha) and lowest in PT_3 (4.33 kg P_2O_5/ha). The phosphorous availability was found higher in PS_2 in both the planting seasons as compared to other tested levels. The highest value of availability of phosphorous was observed under M_0 (4.64 kg P_2O_5/ha) and lowest under M_2 (4.59 kg P_2O_5/ha) in autumn season. In spring season, again the value was highest under M_0 (4.55 kg P_2O_5/ha) and lowest under M_2 (4.48 kg P_2O_5/ha). The available potassium was recorded highest in PT_1 (303 kg K_2O/ha) and lowest in PT_3 (284 kg K_2O/ha) in autumn season. In spring season, the recorded values were PT_1 (303 kg K_2O/ha) followed by PT_2 (297 kg K_2O/ha) and PT_3 (282 kg

Table 15: Effect of *Populus deltoides* plantations on physico-chemical properties of soil with respect to planting seasons, pit type, pit size and moisture conservation measures (mulching) on individual factor means

Parameters	Initial values		Autumn planting									
	S_1	S_2	S_1	PT_1	PT_2	PT_3	PS_1	PS_2	PS_3	M_0	M_1	M_2
Soil texture	Sandy loam	Sandy loam	Sandy loom	Sandy loom	Sandy loom	Sandy loom	Sandy loom	Sandy loom	Sandy loom	Sandy loom	Sandy loom	Sandy loom
Bulk density (g/cc)	1.40	1.35	1.35	1.37	1.35	1.34	1.37	1.35	1.33	1.37	1.35	1.33
Water holding capacity (%)	53.70	45.20	57.17	56.74	53.16	60.61	53.66	57.23	60.61	54.09	56.81	60.29
pH	7.36	7.32	7.23	7.27	7.18	7.24	7.26	7.23	7.20	7.25	7.23	7.20
Electrical conductivity (dsm^{-1})	0.27	0.24	0.21	0.22	0.19	0.21	0.22	0.21	0.19	0.22	0.21	0.19
Organic carbon (%)	1.55	1.48	1.81	1.72	1.74	1.96	1.73	1.78	1.83	1.74	1.81	1.87
Available nitrogen (kg N ha^{-1})	285	276	226	213	236	229	229	226	223	229	226	223
Available phosphorus (kg P_2O_5 ha^{-1})	6.04	5.90	4.61	4.69	4.64	4.52	4.64	4.61	4.59	4.64	4.61	4.59
Available potassium (kg K_2O ha^{-1})	336	325	295	303	299	284	299	295	292	299	295	292

Parameters	Spring planting									
	S_2	PT_1	PT_2	PT_3	PS_1	PS_2	PS_3	M_0	M_1	M_2
Soil texture	Sandy loom	Sandy loom	Sandy loom	Sandy loom	Sandy loom	Sandy loom	Sandy loom	Sandy loom	Sandy loom	Sandy loom
Bulk density (g/cc)	1.36	1.36	1.36	1.35	1.38	1.36	1.34	1.38	1.36	1.34
Water holding capacity (%)	56.42	55.97	52.67	60.61	53.98	56.56	59.62	53.34	56.24	59.66
pH	7.22	7.25	7.17	7.22	7.24	7.22	7.19	7.24	7.22	7.19
Electrical conductivity (dsm^{-1})	0.21	0.22	0.19	0.21	0.22	0.21	0.20	0.22	0.20	0.20
Organic carbon (%)	1.78	1.69	1.73	1.93	1.71	1.77	1.82	1.73	1.78	1.84
Available nitrogen (kg N ha^{-1})	215	232	218	196	218	215	212	218	215	212
Available phosphorus (kg P_2O_5 ha^{-1})	4.51	4.67	4.53	4.33	4.55	4.52	4.48	4.55	4.52	4.48
Available potassium (kg K_2O ha^{-1})	294	303	297	282	297	294	290	297	294	290

Parameters	Factor means									
	S	PT_1	PT_2	PT_3	PS_1	PS_2	PS_3	M_0	M_1	M_2
Soil texture	Sandy loom	Sandy loom	Sandy loom	Sandy loom	Sandy loom	Sandy loom	Sandy loom	Sandy loom	Sandy loom	Sandy loom
Bulk density (g/cc)	1.36	1.36	1.36	1.34	1.37	1.36	1.34	1.37	1.36	1.34
Water holding capacity (%)	56.79	56.35	52.92	61.11	53.82	56.90	60.12	53.71	56.53	59.98
pH	7.22	7.26	7.17	7.23	7.25	7.23	7.20	7.25	7.22	7.20
Electrical conductivity (dsm^{-1})	0.21	0.22	0.19	0.21	0.22	0.21	0.19	0.22	0.21	0.19
Organic carbon (%)	1.79	1.71	1.73	1.94	1.72	1.78	1.83	1.80	1.84	1.85
Available nitrogen (kg N ha^{-1})	220	234	224	214	224	221	217	224	221	217
Available phosphorus (kg P_2O_5 ha^{-1})	4.56	4.68	4.59	4.43	4.59	4.56	4.53	4.59	4.56	4.53
Available potassium (kg K_2O ha^{-1})	295	303	298	283	298	295	291	298	295	291

Planting season (S) S_1=Autumn & S_2=spring

Pit type (PT) PT_1 = Ordinary pit, PT_2= Saucer pit & PT_3 = Ring pit

Pit size (PS) PS_1 = 30×45 cm, PS_2 = 45×60 cm^3& PS_3 = 60×60 cm3

Mulching (M) M_0 = Control, M_1 = Ordinary (paddy straw) & M_2 = Black Polythene

K_2O/ha). It was also observed that potassium availability was highest in PS_1 and lowest in PS_3 in both the planting seasons. The highest available potassium was recorded under M_0 (299 kg K_2O/ha) and lowest under M_2 (292 kg K_2O/ha) in autumn season. Similarly in spring season, the highest value was recorded under M_0 (297 kg K_2O/ha) and lowest in M_2 (290 kg K_2O/ha).

Overall factor means were evaluated to determine the best possible factors which effect the physico-chemical properties of soils under poplar plantations done on problematic sites. It was observed that bulk density decreased from initial value and was found to be 1.36 g/cc after the completion of one growing season. The highest bulk density was observed in PT_1 (1.36 g/cc) and lowest in PT_3 (1.34 g/cc). The highest bulk density was recorded in PS_1 (1.37 g/cc) and lowest in PS_3 (1.34 g/cc). It was also observed that highest bulk density was observed under M_0 (1.37 g/cc) and lowest under M_2 (1.34 g/cc). The Table 15 also infers that the maximum water holding capacity was found in PT_3 (61.11%) and lowest in PT_1 (56.35%). The maximum value for water holding capacity was observed in PS_3 (60.12%) followed by PS_2 (56.90%) and PS_1 (53.82%). It was also observed from the data that maximum water holding capacity was recorded under M_2 (59.98%) and lowest under M_0 (53.71%). The pH value was observed to be higher in PT_1 (7.26) while lowest in PT_2 (7.17). The highest pH was recorded in PS_1 (7.25) and lowest in PS_3 (7.20). The Table 15 reveals that out of three tested mulches including control, pH was recorded higher under M_0 (7.25) and lowest under M_2 (7.20). The electrical conductivity was found highest in PT_1 (22 dsm^{-1}) and lowest in PT_2 (19 dsm^{-1}). It was also observed that highest electrical conductivity was found in PS_1 (0.22 dsm^{-1}) and lowest in PS_3 (0.19 dsm^{-1}). The highest electrical conductivity was recorded under M_0 (0.22 dsm^{-1}) followed by M_1 (0.21 dsm^{-1}) and M_2 (0.19 dsm^{-1}). It was recorded from the data that organic carbon was maximum in PT_3 (1.94%) followed by PT_2 (1.73%) and PT_1 (1.71%). The maximum organic carbon was recorded in PS_3 (1.83%) and minimum in PS_1 (1.72%). A critical analysis of the Table 15 reveals that the maximum organic carbon was found under M_2 (1.85%) and lowest under M_0 (1.80%). The available nitrogen was observed to be highest in PT_1 (234 kg N/ha) and lowest in PT_3 (214 kg N/ha). It was also recorded that highest nitrogen was available in PS_1 (224 kg N/ha) while, it was lowest in PS_3 (217 kg N/ha). The highest available nitrogen was observed under M_0 (224 kg N/ha) and lowest under M_2 (217 kg N/ha). The available phosphorous was recorded to be highest in PT_1 (4.68 kg P_2O_5/ha) and lowest in PT_3 (4.43 kg P_2O_5/ha). The phosphorous availability was higher in PS_1 (4.59 kg P_2O_5/ha) which was decreased from PS_2 (4.56 kg P_2O_5/ha) to PS_3 (4.53 kg P_2O_5/ha). The highest availability of phosphorous was observed in M_0 (4.59 kg P_2O_5/ha) and lowest in M_2 (4.53 kg P_2O_5/ha). It was further observed that the potassium availability was highest in PT_1 (303 kg K_2O/ha) and lowest in PT_3 (283 kg K_2O/ha). The highest available potassium was reported under PS_1 (298 kg K_2O/ha) and lowest in PS_3 (291 kg K_2O/ha).The available potassium was more under M_0 (298 kg K_2O/ha) and lowest with M_2 (291 kg K_2O/ha).

4.2.8 Effect of different moisture conservation measures on moisture regimes of soils in poplar plantations done on problematic sites

The mulching materials (control, ordinary mulch and black polythene) were found responsible for varying the moisture percentage under the poplar plantations done during autumn planting at problematic site. Moisture percentage under black polythene was found highest as compared to ordinary mulch (paddy straw) and control in both the planting seasons. the observation on moisture percentage were made on fortnight interval basis after the completion of one month from the day of out-planting in both the planting seasons. Therefore, 20 intervals in autumn planting (Ist January-31st October) and 14 intervals (Ist April-31st October) in spring planting were made to assess the effect of moisture conservation measures on moisture percentage parameter under *Populus deltoides* plantation done on moisture deficit site. The graphical representation show that moisture percentage remained static in interval P1 (1st-15th January) and P2 (16th-31st January) then increased sharply the peak in P4 (16-28th February) and than follow the declining trend upto P15 (1st-15th August) and again increased invariably in P16 and finally remained static in P18 - P20 interval (Fig. 3). The highest percentage of moisture was found in P4 (16-28th February) and lowest in P15 (1st-15th August) in autumn planting. In spring planting, the highest percentage of moisture was reported in P2 (16-30th April) and lowest in P9 (Fig. 4). Black polythene mulch (M_2) gave higher moisture percentage while compared with other tested mulching materials throughout the experimentation period in both the planting seasons.

The pits of different types were found to responsible in varying the availability of moisture percentage under the plantations in both the planting seasons. The graphical representation show that among the three pit types saucer pit gave highest percentage of moisture which was further followed by ring and ordinary pit (Fig. 5). The moisture percentage was found to increase from P1 (Ist - 15th January) to P2 (16-31st January) and thereafter, showed a declining trend. The highest percentage of moisture was observed in P2 (16-31st January) and lowest in P20 (16-31st October) in all the tested pit types during both the planting seaons. However, in spring planting the moisture percentage found to follow the decreasing trend (Fig. 6). The highest moisture percentage was found in interval P1 (1st-15th April) and lowest in P14 (16-31th October). Saucer pit found to maintain the superiority over the ordinary and ring pits with respect to the moisture percentage in both the planting seasons.

It was found that among three pit sizes the highest moisture was conserved under 60×60 cm^3 followed by 45×60 cm^3 and 30×45 cm^3 in both the planting seasons. The percentage of moisture was estimated after every 15 days interval and was found that highest percentage was observed during P1 (1st-15th January) and lowest in P20 (15-31st October) (Fig. 7). In general moisture percentage showed a declining trend from P1-P15 in autumn planting (Fig. 7). It was observed from Fig. 8 that in spring planting, highest moisture percentage was recorded in P1 (1st-15th January) under 60×60 cm^3 pit size and in P3 (1st-15th February) under 45×60 cm^3 and 30×45 cm^3 pit sizes and lowest in P14 (15-31th

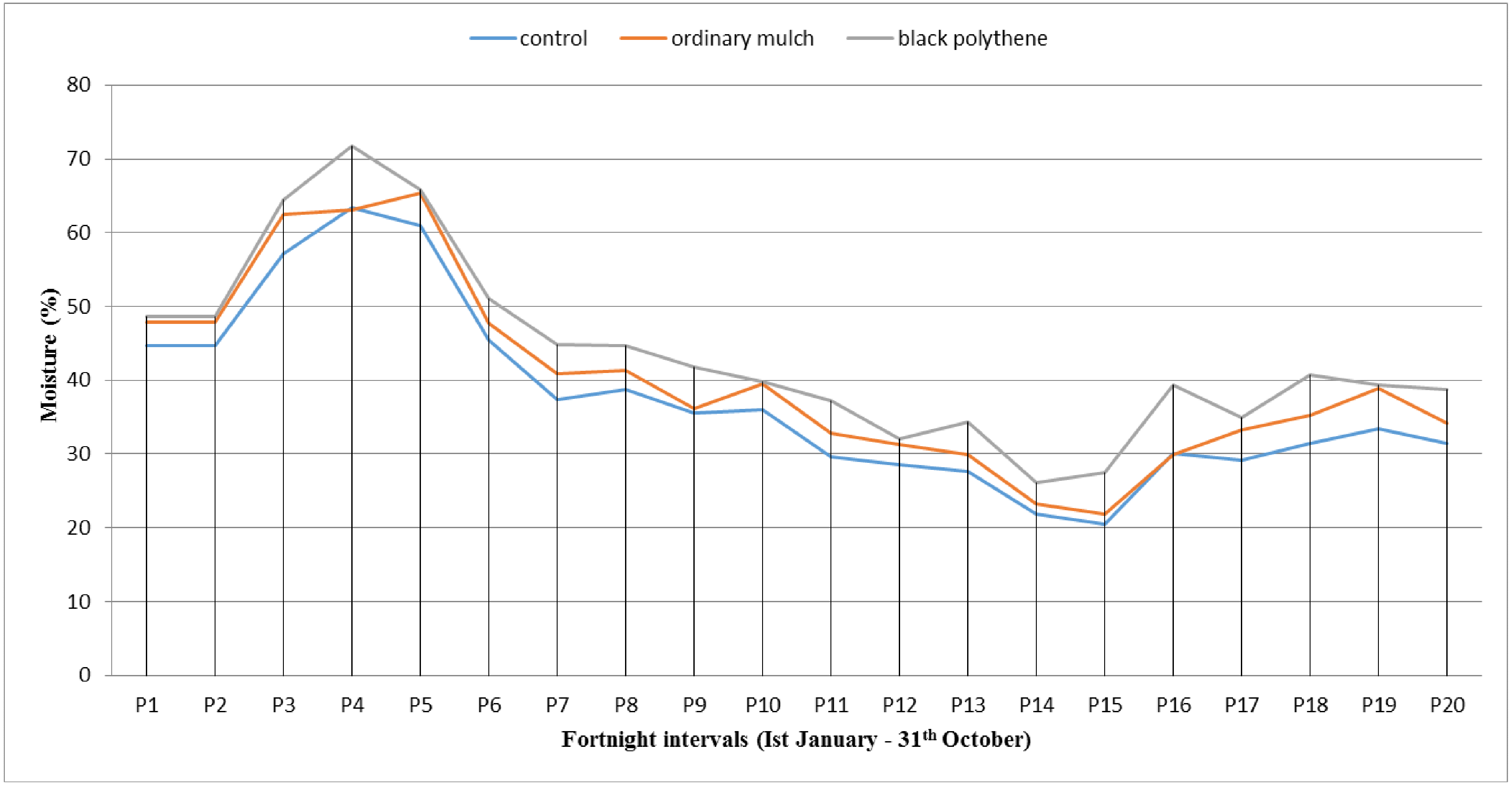


Fig. 3: Effect of different mulching materials on moisture regimes of soils in poplar plantations done on problematic sites in autumn season

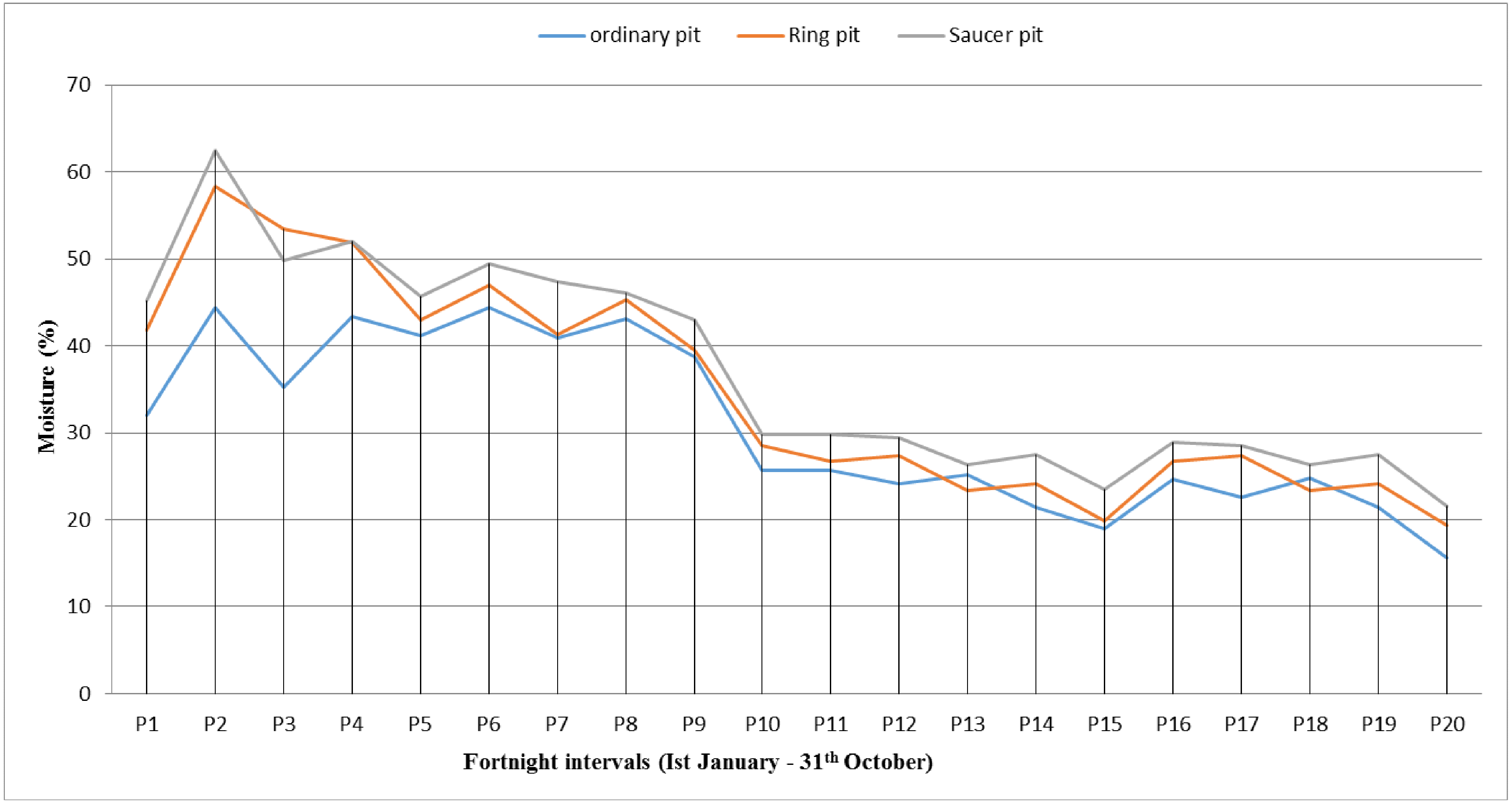


Fig. 4: **Effect of different pit shapes on moisture regimes of soils in poplar plantations done on problematic sites in autumn season**

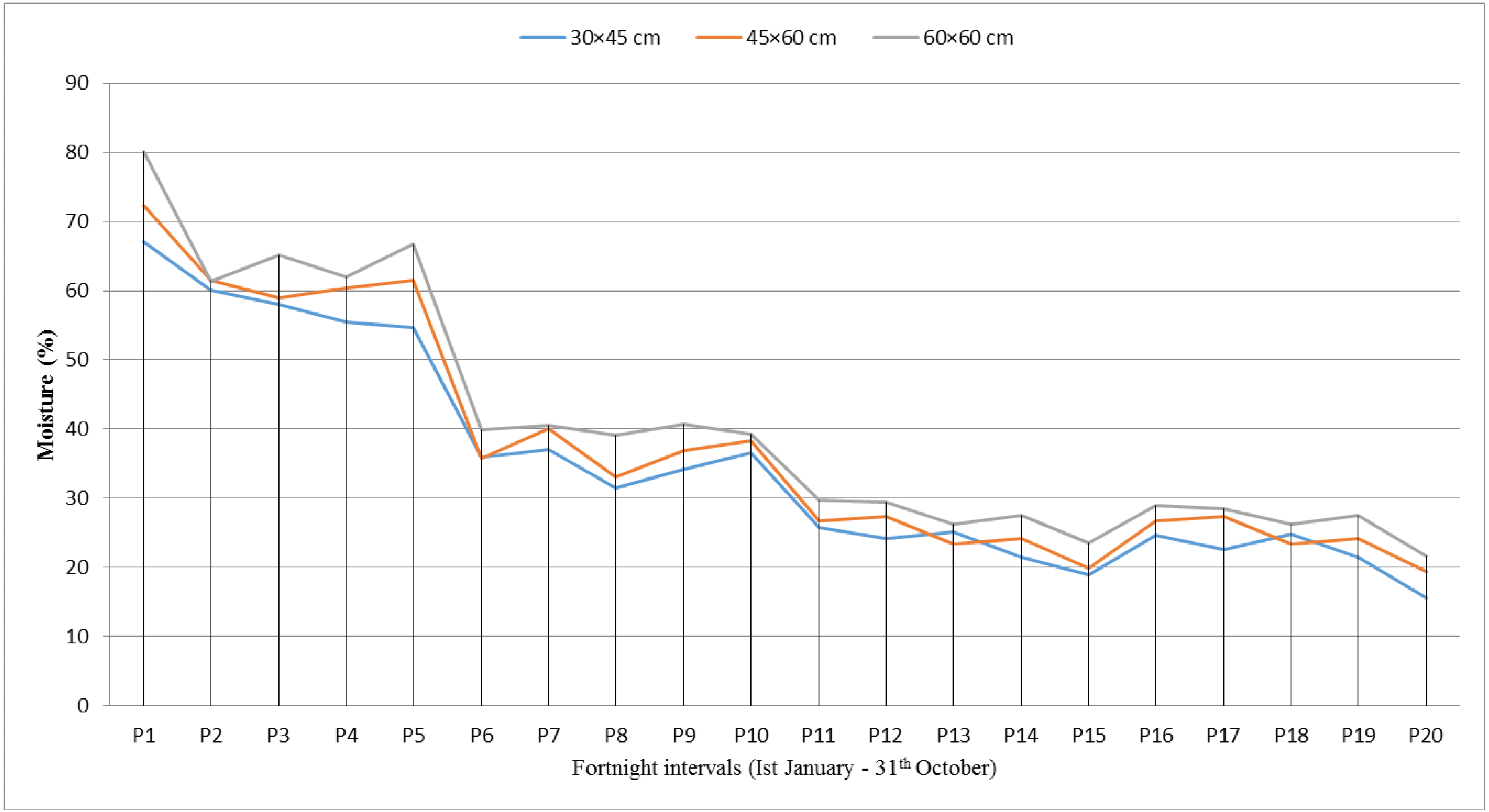


Fig. 5: **Effect of different pit sizes on moisture regimes of soils in poplar plantations done on problematic sites in autumn season**

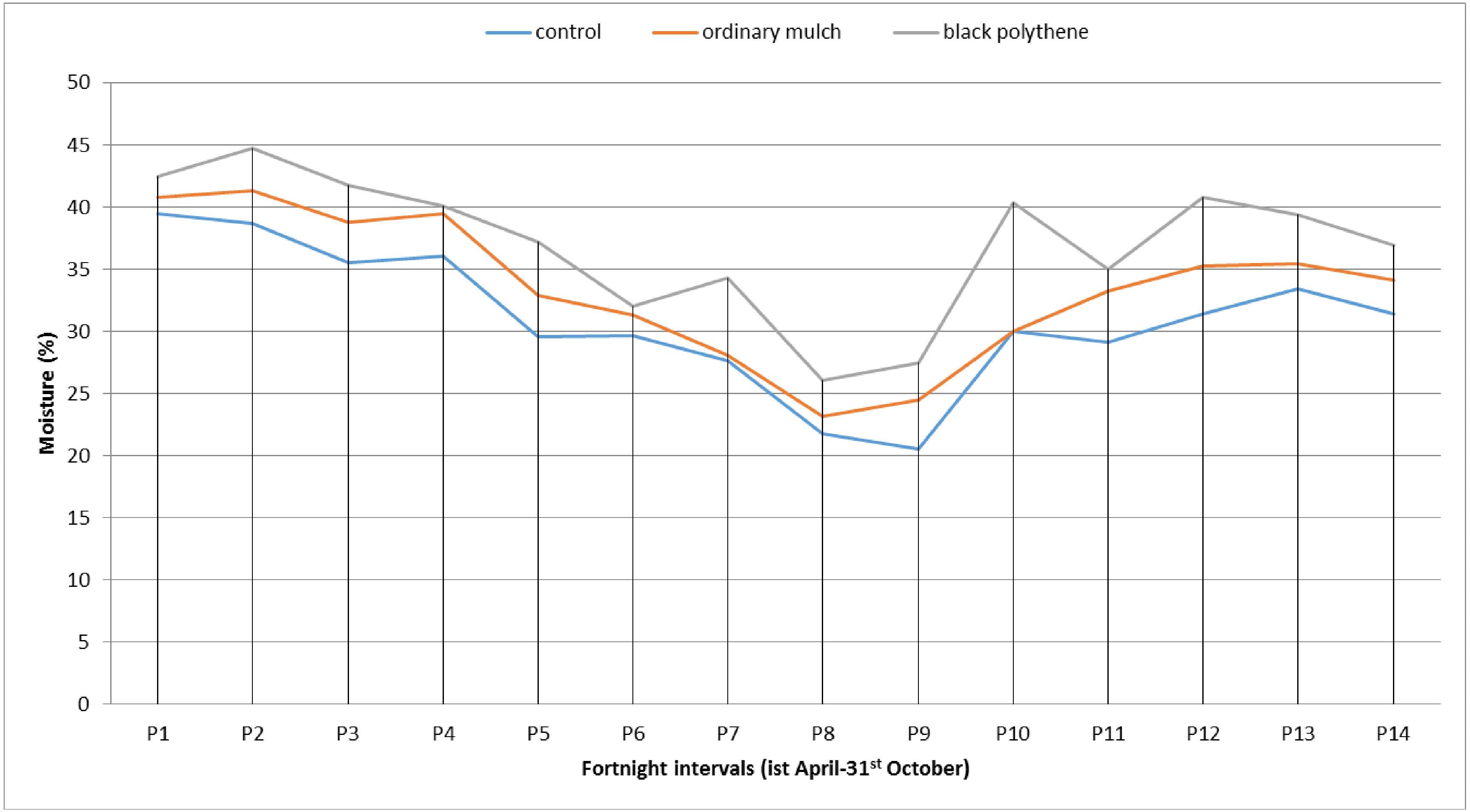


Fig. 6: **Effect of different mulching materials on moisture regimes of soils in poplar plantations done on problematic sites in spring season**

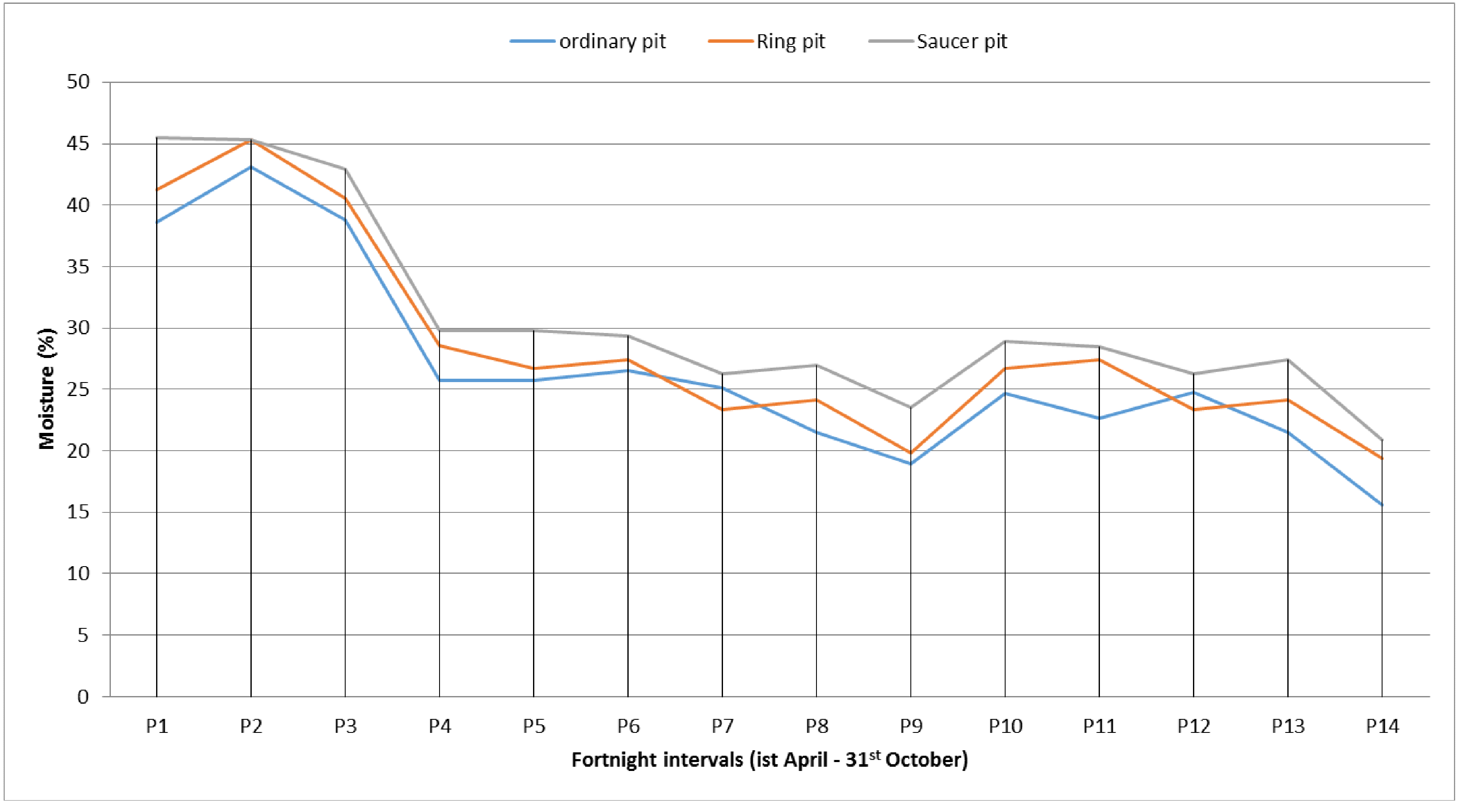


Fig. 7: **Effect of different pit shapes on moisture regimes of soils in poplar plantations done on problematic sites in spring season**

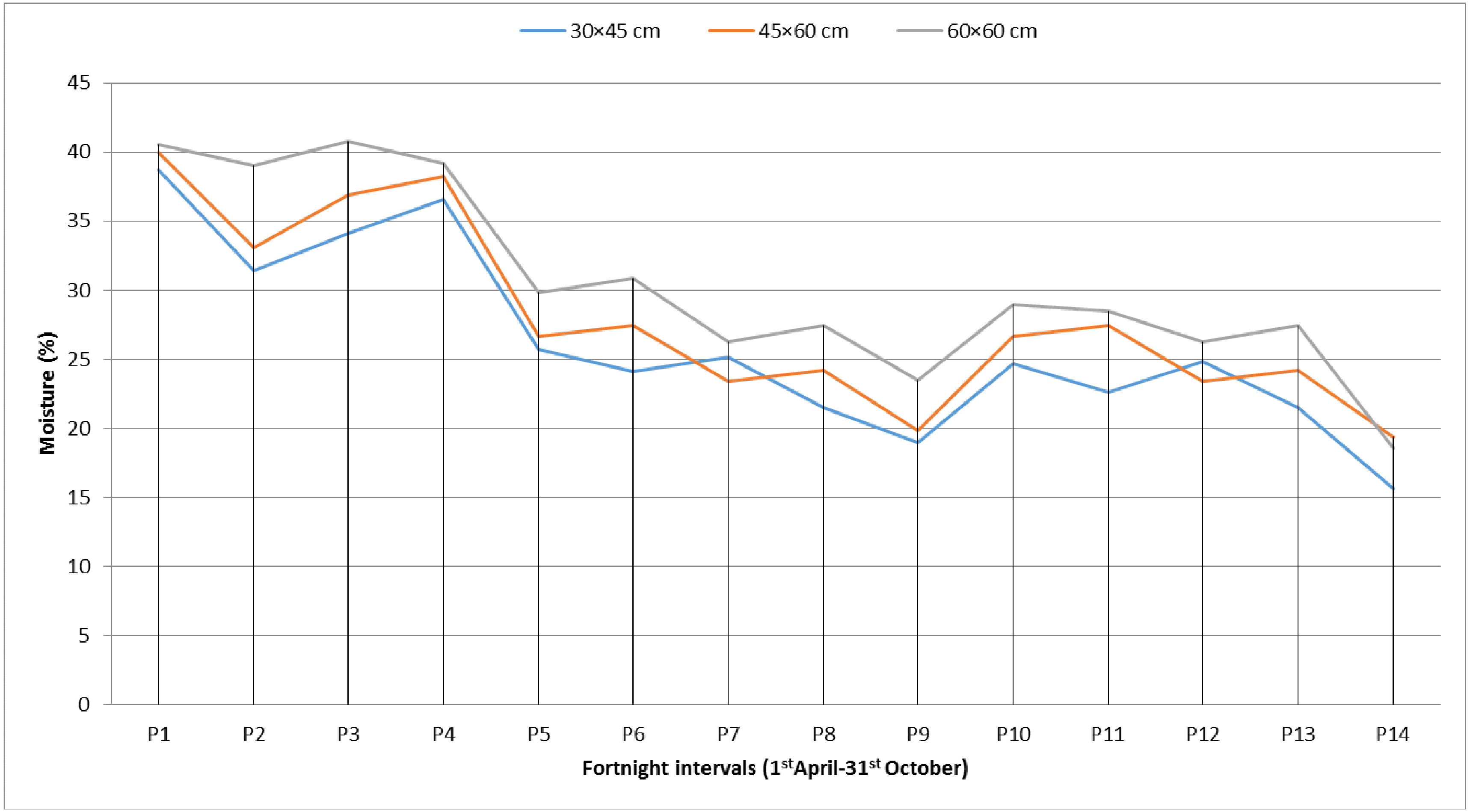


Fig. 8: **Effect of different pit sizes on moisture regimes of soils in poplar plantations done on problematic sites in spring season**

July). The large sized pits (60×60 cm^3) performed better with respect to the moisture percentage over the rest of the two tested pit sizes viz. 45×60 cm^3 and 30×45 cm^3 in both the planting seasons.

4.3 Effect of planting seasons, age of planting stock and hydrogel application on establishment & growth of *Populus deltoides* plantations on problematic sites

Two planting seasons viz. autumn planting and spring planting, seedlings of two ages viz. one year old (A_1) and two years old (A_2) and five levels of hydrogel viz. H_0 (control), H_1 (solid application 3 g/plant), H_2 (liquid application 1.5 g/plant), H_3 (liquid application 3 g/plant) H_4 (4.5 g/plant) were evaluated with respect to establishment and growth of plantations of *Populus deltoides* raised on problematic soils in temperate region.

4.3.1 Effect of planting seasons, age of planting stock and application of hydrogel on survival percentage of *Populus deltoides* plantations on problematic sites

The data on survival percentage of *Populus deltoides* plantations with respect to the planting seasons, age of planting stock and hydrogel application done on problematic site are presented in Table 16. A perusal of the data reveals that both the planting seasons, age of outplanting stock and hydrogel application found to effect survival percentage significantly. Two years old planting stock gave the better survival (83.33%) percentage than the one year old planting stock (76.66%) in autumn planting. Similar trend was reported in spring planting where two years old planting stock gave higher value (76.66%) over the one year old planting stock (63.33%). It is observed from the data presented in Table 16 that the survival percentage of *Populus deltoides* plantations found to increase with the increase in hydrogel concentration upto H_3 (3 g/plant liquid application) and then decreased under H_4 (4.5 g/plant liquid application). Hydrogel level H_3 recorded highest survival percentage (100%) followed by H_2 (83.33%), H_4 (83.33%), H_1 (74.99%) and H_0 (58.33%) in autumn planting. Similarly, the survival of the plantation was maximum in H_3 (91.66%) and minimum in H_0 (50.00%) where no

Table-16: Effect of planting seasons, age of planting stock and application of hydrogel on survival percentage of *Populus deltoides* plantations on problematic sites

Age / Hydrogel levels	Autumn planting A_1	Autumn planting A_2	Mean	Spring planting A_1	Spring planting A_2	Mean	Factor means: Hydrogel levels		Age of planting stock		Planting seasons	
H_0	50.00	66.66	58.33	50.00	50.00	50.00	H_0	54.16	A_1	69.99	S_1	79.99
H_1	66.66	83.33	74.99	50.00	66.66	58.33	H_1	66.66	A_2	79.99	S_2	69.99
H_2	83.33	83.33	83.33	66.66	83.33	74.99	H_2	79.16				
H_3	100	100	100	83.33	100	91.66	H_3	95.83				
H_4	83.33	83.33	83.33	66.66	83.33	74.99	H_4	79.16				
Mean	76.66	83.33	79.99	63.33	76.66	69.99						

C.D. ($p \leq 0.05$):	H=1.48	H_0 = Control	A_1 = 1 year old	S_1= Autumn Planting Season
	S =2.43	H_1 = Solid Application (3.0g/plant)	A_2 = 2 years old	S_2= Spring Planting Season
	A=3.54	H_2 = 1.5 g/plant (liquid application		
	H×S =2.58	H_3 = 3.0 g/plant (liquid application)		
	H×A= 3.68	H_4 = 4.5 g/plant (liquid application)		
	S×A=3.11			
	H×A×S=NS			

hydrogel was applied in spring planting, respectively. It was also observed that the plantations done in autumn season gave better survival as compared to the spring season.

Factor means were evaluated to determine the best possible factor for *Populus deltoides* plantations done on problematic sites. The survival percentage (79.99%) was more in autumn planting than in spring planting (69.99%). The higher survival percentage was observed in two years old planting stock (79.99%) than one year old planting stock (69.99%). It was observed from the table that H_3 gave highest survival percentage (95.83%) while compared with the five levels of hydrogel applied to the plantations.

The data reveal that interaction between hydrogel levels and planting seasons, hydrogel levels and age of planting stock, planting seasons and age of planting stock were found to effect each other significantly. The interaction between hydrogel levels, planting seasons and age of planting stock was found to be non-significant (Table 16). However, the survival percentage was found higher with treatment combination $S_1H_3A_2$ (autumn season × hydrogel level 3 g/plant liquid application × two years old planting stock). The lowest value was reported in treatment combination $S_1H_0A_1$ (autumn season × hydrogel level 0 g/plant × one year old planting stock). Similar trends have been observed in spring planting as far as interactional effects pertaining to survival percentage were concerned.

4.3.2 Effect of planting seasons, age of planting stock and application of hydrogel on plant height increment (cm) in *Populus deltoides* plantations on problematic sites

The results pertaining to plant height increment of *Populus deltoides* with respect to planting seasons, age of planting stock and application of hydrogel are presented in Table 17. It was found that both the planting seasons, age of outplanting stock and hydrogel application effected the plant height increment significantly. Maximum plant height increment (27.05 cm) was recorded in two years old outplanted stock and minimum (26.92 cm) in one year old outplanted

Table-17: Effect of planting seasons, age of planting stock and application of hydrogel on plant height increment (cm) in *Populus deltoides* plantations on problematic sites

Age / Hydrogel levels	Autumn Planting		Mean	Spring Planting		Mean	Factor means					
	A_1	A_2		A_1	A_2		Hydrogel levels		Age of planting stock		Planting seasons	
H_0	26.11	26.20	26.16	26.00	26.05	26.03	H_0	26.09	A_1	26.59	S_1	26.99
H_1	26.33	26.54	26.44	26.16	26.25	26.21	H_1	26.32	A_2	26.71	S_2	26.31
H_2	26.88	27.00	26.94	26.31	26.39	26.35	H_2	26.65				
H_3	28.27	28.39	28.33	26.66	26.92	26.79	H_3	27.56				
H_4	27.01	27.13	27.07	26.12	26.26	26.19	H_4	26.63				
Mean	26.92	27.05	26.99	26.25	26.37	26.31						

C.D. ($p \leq 0.05$):	H=0.08	H_0 = Control	A_1 = 1 year old	S_1= Autumn Planting Season
	S =0.11	H_1 = Solid Application (3.0g/plant)	A_2 = 2 year old	S_2= Spring Planting Season
	A=0.13	H_2 = 1.5 g/plant (liquid application		
	H×S =0.12	H_3 = 3.0 g/plant (liquid application)		
	H×A= 0.11	H_4 = 4.5 g/plant (liquid application)		
	S×A=0.12			
	H×A×S=0.13			

stock irrespective of hydrogel application in autumn season. Similar observations were made in spring planting. It is further observed from the Table 17 that hydrogel application gave significant effect on plant height increment in both the seasons. Maximum plant height increment was observed in H_3 (28.33 cm) which was followed by H_4 (27.07 cm), H_2 (26.94 cm), H_1 (26.44 cm) and H_0 (26.16 cm), respectively. In spring planting, maximum plant height increment was recorded in H_3 (26.79 cm) and minimum in H_0 (26.09 cm). It was also observed that the hydrogel application invariably responded same in both planting seasons.

Individual factor means of the tested treatments were evaluated to determine the best factor for *Populus deltoides* plantations done on problematic sites. Maximum plant height increment (26.99 cm) was found in autumn planting and minimum (26.31 cm) in spring planting. Both the planting seasons were found to be statistically significant with each other. It indicates from the Table 17 that maximum plant height increment was recorded in two years old planting stock (26.71 cm) and minimum in one year old planting stock (26.59 cm). Among the five levels of hydrogel, H_3 gave maximum plant height increment (27.56 cm) which was followed by H_2 (26.65 cm), H_4 (26.63 cm), H_1 (26.32 cm) and H_0 (26.09 cm), respectively. It was further observed that all the applications of hydrogel were found to be statistically significant except H_2 and H_4 which were statistically at par with each other.

It was also recorded that interaction effect of hydrogel levels and planting seasons, hydrogel levels and age of planting stock, planting seasons and age of planting stock and interaction among hydrogel levels, planting seasons and age of planting stock were statistically significant with each other. It was observed that best treatment combination for plant height increment was $S_1H_3A_2$ (28.39 cm) followed by $S_1H_3A_1$ (28.27 cm) and $S_1H_4A_2$ (27.13 cm). The lowest values were recorded with treatment combinations $S_1H_0A_1$ (26.11 cm), $S_1H_0A_2$ (26.20 cm) and $S_1H_1A_1$ (26.33 cm), respectively. Similar trends have been observed in spring planting as far as interactional effects pertaining to plant height increment are concerned.

4.3.3 Effect of planting seasons, age of planting stock and application of hydrogel on collar diameter increment (mm) in *Populus deltoides* plantations on problematic sites

A perusal of the data presented in Table 18 reveals that both the planting seasons, age of planting stock and hydrogel levels were found to effect the collar diameter increment significantly in *Populus deltoides* plantations on problematic sites. Highest collar diameter increment (5.38 mm) was recorded in two years old planting stock and lowest in one year old planting stock (5.31 mm) in autumn planting. Similar trend has been observed in spring planting where highest collar diameter increment was reported in two years old planting stock (5.37 mm) and lowest in one year old planting stock (5.26 mm). Highest collar diameter increment was observed in H_3 (5.52 mm) and minimum in H_0 (5.14 mm) in autumn planting. In spring planting, highest collar diameter increment was recorded in H_3 (5.89 mm) which was followed by H_2 (5.36 mm), H_1 (5.21 mm), H_4 (5.09 mm) and H_0 (5.04 mm), respectively. It was further reported that the hydrogel gave the similar trend in spring planting as was found in autumn planting with respect to collar diameter increment.

Factor means reveal that the highest collar diameter increment was recorded in autumn planting (5.34 mm) and lowest in spring planting (5.32 mm). It was found that highest collar diameter increment was observed in two years old planting stock (5.34 mm) and lowest in one year old planting stock (5.31 mm). Among the five levels of hydrogel, H_3 recorded highest collar diameter increment (5.70 mm) which was followed by H_2 (5.38 mm), H_1 (5.27 mm), H_4 (5.20 mm) and H_0 (5.09 mm), respectively. However, all the applications of hydrogel were found to be statistically significant except H_1 and H_4 which were at par with each other.

It was also recorded that interaction between hydrogel levels and planting seasons, hydrogel levels and age of planting stock, planting seasons and age of

Table-18: Effect of planting seasons, age of planting stock and application of hydrogel on collar diameter increment (mm) in *Populus deltoides* plantations on problematic sites

Age / Hydrogel levels	Autumn Planting		Mean	Spring Planting		Mean	Factor means					
	A_1	A_2		A_1	A_2		Hydrogel levels		Age of planting stock		Planting seasons	
H_0	5.08	5.21	5.14	5.00	5.07	5.04	H_0	5.09	A_1	5.31	S_1	5.34
H_1	5.30	5.38	5.34	5.18	5.24	5.21	H_1	5.27	A_2	5.34	S_2	5.32
H_2	5.40	5.42	5.41	5.32	5.40	5.36	H_2	5.38				
H_3	5.50	5.55	5.52	5.77	6.00	5.89	H_3	5.70				
H_4	5.28	5.37	5.32	5.05	5.13	5.09	H_4	5.20				
Mean	5.31	5.38	5.34	5.26	5.37	5.32						

C.D. ($p \leq 0.05$):	H=0.09	H_0 = Control	A_1 = 1 year old	S_1= Autumn Planting Season
	S =0.10	H_1 = Solid Application (3.0g/plant)	A_2 = 2 year old	S_2= Spring Planting Season
	A=0.12	H_2 = 1.5 g/plant (liquid application		
	H×S =0.11	H_3 = 3.0 g/plant (liquid application)		
	H×A= 0.10	H_4 = 4.5 g/plant (liquid application)		
	S×A=0.12			
	H×A×S=0.13			

planting stock and interactions between hydrogel levels, planting seasons and age of planting stock were found to be statistically significant with each other. It was observed from Table 18 that the best treatment combination for collar diameter increment was $S_1H_3A_2$ (5.55 mm) in autumn planting which was statistically at par with $S_1H_3A_1$ (5.50 mm) and $S_1H_2A_2$ (5.42 mm). In spring planting, the treatment combinations $S_2H_3A_2$ gave highest (6.00 mm) value of collar diameter increment over all the other treatment combinations. It was also observed that the minimum (5.00 mm) value of collar diameter increment was found under the $S_2H_0A_1$ treatment combination.

4.3.4 Effect of planting seasons, age of planting stock and application of hydrogel on number of branches per plant of *Populus deltoides* plantations on problematic sites

The results pertaining to the effect of planting seasons, age of planting stock and hydrogel application on number of branches per plant are presented in Table 19. It was recorded that age of planting stock significantly effected the number of branches per plant of *Populus deltoides* in both the seasons. Maximum (9.51) number of branches were recorded in two years old planting stock and minimum (9.40) in one year old planting stock in autumn planting. Similar trend was observed in spring planting where the same treatments gave higher values of number of branches per plant as per the pattern of autumn season. It also infers from the Table 19 that maximum number of branches per plant were recorded in H_3 (10) and minimum in H_0 (9.18) in autumn planting. Similar hydrogel levels were found to give maximum as well as minimum values with respect to number of branches in spring planting. It was further reported that the planting season showed no effect with respect to number of branches per plant to hydrogel application.

The data on individual factor means presented in Table 19 reveal that number of branches per plant were recorded maximum in autumn planting (9.46) and minimum in spring planting (9.36). It was observed that two years old planting stock gave maximum number of branches per plant (9.47) while

Table-19: Effect of planting seasons, age of planting stock and application of hydrogel on number of branches per plant of *Populus deltoides* plantations on problematic sites

Age / Hydrogel levels	Autumn Planting		Mean	Spring Planting		Mean	Factor means					
	A_1	A_2		A_1	A_2		Hydrogel levels		Age of planting stock		Planting seasons	
H_0	9.16	9.21	9.18	9.10	9.14	9.12	H_0	9.15	A_1	9.36	S_1	9.46
H_1	9.30	9.39	9.34	9.23	9.27	9.25	H_1	9.29	A_2	9.47	S_2	9.36
H_2	9.45	9.53	9.49	9.31	9.38	9.34	H_2	9.41				
H_3	9.88	10.13	10.00	9.77	9.98	9.87	H_3	9.94				
H_4	9.25	9.33	9.29	9.13	9.33	9.23	H_4	9.26				
Mean	9.40	9.51	9.46	9.30	9.42	9.36						

C.D. ($p \leq 0.05$):

H=0.02	H_0 = Control	A_1 = 1 year old	S_1= Autumn Planting Season
S =0.01	H_1 = Solid Application (3.0g/plant)	A_2 = 2 year old	S_2= Spring Planting Season
A=0.05	H_2 = 1.5 g/plant (liquid application		
H×S =0.05	H_3 = 3.0 g/plant (liquid application)		
H×A= 0.07	H_4 = 4.5 g/plant (liquid application)		
S×A=0.04			
H×A×S=0.08			

compared with one year old planting stock (9.36). Hydrogel application @ 3g/plant (H_3) gave maximum number of branches per plant (9.94) which was followed by H_2 (9.41), H_1 (9.29), H_4 (9.26) and H_0 (9.15), respectively. All the hydrogel levels were found to be statistically significant with each other with respect to the number of branches per plant.

It is evident from the Table 19 that interaction between hydrogel levels and planting seasons, hydrogel levels and age of planting stock, planting seasons and age of planting stock and the interaction between hydrogel levels, planting seasons and age of outplanting stock were found to be statistically significant with the number of branches per plant. The highest number of branches per plant was obtained in $S_1H_3A_2$ (10.13) and minimum in $S_1H_0A_1$ (9.16) in autumn planting. It was also observed that the treatment combinations like $S_1H_0A_1$ and $S_1H_0A_2$ behaved statistically at par with each other in autumn planting. The treatment combinations $S_2H_3A_2$ gave highest (9.98) number of branches per plant whereas, minimum value was observed with $S_2H_0A_1$ (9.10) in spring planting. It was also observed from the Table 19 that the age of planting stock with hydrogel application levels namely H_0, H_1 and H_2 gave statistically at par values of number of branches per plant in spring planting.

4.3.5 Effect of planting seasons, age of planting stock and application of hydrogel on leaf area per plant (cm^2) of *Populus deltoides* plantations on problematic sites

A perusal of the data given in Table 20 reveals that all the treatment combinations behaved statistically significant to each other with respect to leaf area per plant of *Populus deltoides* plantations. Two years old planting stock gave the value (889.21 cm^2) of leaf area per plant which was statistically at par with one year old planting stock (888.60 cm^2) in autumn planting. Similar trend has been observed in spring planting where both the planting stocks behaved statistically at par with respect to leaf area per plant. The hydrogel application @ 3g/plant (H_3) and 4.5 g/plant (H_4) gave the statistically at par values of leaf area per plant in autumn planting. The hydrogel applied @ 3 g/plant (H_3) gave highest

Table-20: Effect of planting seasons, age of planting stock and application of hydrogel on leaf area per plant (cm^2) of *Populus deltoides* plantations on problematic sites

Age / Hydrogel levels	Autumn Planting A_1	Autumn Planting A_2	Mean	Spring Planting A_1	Spring Planting A_2	Mean	Factor means: Hydrogel levels		Age of planting stock		Planting seasons	
H_0	886.60	887.10	886.85	885.13	885.98	885.56	H_0	886.20	A_1	887.71	S_1	888.91
H_1	888.33	888.98	888.66	886.09	886.42	886.26	H_1	887.46	A_2	888.31	S_2	887.11
H_2	889.42	889.67	889.55	887.33	887.91	887.62	H_2	888.58				
H_3	890.54	891.80	891.17	888.10	888.94	888.52	H_3	889.85				
H_4	888.10	888.52	888.31	887.42	887.78	887.60	H_4	887.96				
Mean	888.60	889.21	888.91	886.81	887.41	887.11						

C.D. ($p \leq 0.05$):

C.D.	Hydrogel levels	Age	Seasons
H=1.01	H_0 = Control	A_1 = 1 year old	S_1= Autumn Planting Season
S =0.28	H_1 = Solid Application (3.0g/plant)	A_2 = 2 year old	S_2= Spring Planting Season
A=1.00	H_2 = 1.5 g/plant (liquid application		
H×S =1.23	H_3 = 3.0 g/plant (liquid application)		
H×A= 1.38	H_4 = 4.5 g/plant (liquid application)		
S×A=1.21			
H×A×S=1.42			

leaf area per plant (891.17 cm^2) which was followed by H_2 (889.55 cm^2), H_1 (888.66 cm^2), H_4 (888.31 cm^2) and H_0 (886.85 cm^2), respectively in autumn planting. Similar results were obtained in spring planting where the highest leaf area per plant was observed in H_3 (888.52 cm^2) and minimum in H_0 (885.56 cm^2). It was also observed that the H_2, H_3 and H_4 levels of hydrogel application behaved statistically at par with each other. Although, the H_3 level gave the higher leaf area per plant as compared to the rest of the tested levels of hydrogel. The hydrogel application @ 3 g/plant (H_3) was statistically at par with the control in the plantations done in spring season.

Individual factors were evaluated to determine the best possible factor for leaf area per plant of *Populus deltoides* on problematic sites. Both the planting seasons were found to be statistically significant with each other. Highest leaf area per plant was recorded in autumn planting (888.91 cm^2) and minimum in spring planting (887.11 cm^2). It is observed from the Table 20 that two years old planting stock gave higher value of leaf area per plant (888.31 cm^2) than the one year old planted planting stock (887.71 cm^2). The hydrogel application @ 3 g/plant (H_3) recorded highest leaf area per plant (889.85 cm^2) and lowest in H_0 (886.20 cm^2) irrespective of the planting seasons and age of planting stock. It is also seen from the data presented in Table 20 that the hydrogel levels namely H_1 and H_4 behaved statistically at par with each other.

It is observed from the Table 20 that two factors interaction between hydrogel levels and planting seasons, hydrogel levels and age of planting stock, planting seasons and age of planting stock and three factors interaction among hydrogel levels, planting seasons and age of planting stock were found to be statistically significant with each other pertaining to leaf area per plant of *Populus deltoides* plantations. The treatment combination which was found to be best for leaf area per plant was $S_1H_3A_2$ (891.80 cm^2) in autumn planting. The minimum leaf area per plant was observed with treatment combination $S_1H_0A_1$ (886.60 cm^2). The data presented in Table 20 reveal that the treatment combination

$S_2H_3A_2$ gave the highest leaf area per plant but it was found to be statistically at par with the $S_2H_3A_1$, $S_2H_2A_2$ and $S_2H_4A_2$ in spring planting.

4.3.6 Correlation of physiological and quality parameters of seedlings with survival percentage and growth attributes of *Populus deltoides* plantations on problematic sites

The data presented in Table 21 indicate the correlation studies among the survival and growth attributes of plantations (plant height increment, collar diameter increment, number of branches per plant and leaf area per plant) with physiological and quality parameters (relative water content, root electrolyte leakage, shoot electrolyte leakage, root fibrosity, root volume, root length, root shoot ratio, sturdiness quotient and membrane stability index) of seedlings at the time of outplanting. The correlation was drawn by taking the survival percentage and growth attributes as dependent variables while the independent variables were physiological and quality parameters.

A perusal of the data presented in Table 21 reveals that only 7 variables of physiological and quality parameters showed positive correlation with survival percentage of *Populus deltoides* plantations. The variables namely root electrolyte leakage and shoot electrolyte leakage found to be correlated negatively to the dependent variables. The root length variable contributed 0.877 to survival percentage of *Populus deltoides* plantations whereas, root fibrosity (0.841) and sturdiness quotient (0.821). The minimum positive correlation was observed between survival percentage and membrane stability index (0.612). It was further observed that the rest of the contribution in the given correlation values was due to the factors not considered in the investigations. Root electrolyte leakage (-0.765) and shoot electrolyte leakage (-0.554) showed inverse relationship with survival and growth parameters of the plantations done on problematic site. A critical analysis of the data presented in Table 21 reveals that the value of correlation between collar diameter and root shoot ratio was found to be non-significant.

Table 21: Correlation of physiological and quality parameters of seedlings with survival percentage and growth attributes of *Populus deltoides* plantations on problematic sites

	Survival percentage	Plant height increment	Collar diameter increment	Number of branches per plant	Leaf area per plant
Relative water content	0.812^{**}	0.766^{**}	0.764^{**}	0.745^{**}	0.776^{**}
Root electrolyte leakage	-0.762^{**}	-0.654^{**}	-0.732^{**}	-0.765^{**}	-0.764^{**}
Shoot electrolyte leakage	-0.554^{**}	-0.798^{**}	-0.712^{**}	-0.786^{**}	-0.732^{**}
Root fibrosity	0.841^{**}	0.826^{**}	0.257	0.806^{**}	0.852^{**}
Root volume	0.701^{**}	0.744^{**}	0.745^{**}	0.814^{**}	0.734^{**}
Root length	0.877^{**}	0.879^{**}	0.306	0.804^{**}	0.857^{**}
Root shoot ratio	0.657^{**}	0.625^{**}	0.027	0.548^{*}	0.720^{**}
Sturdiness quotient	0.821^{**}	0.836^{**}	0.480^{*}	0.954^{**}	0.828^{**}
Membrane stability index	0.612^{**}	0.675^{**}	0.714^{**}	0.685^{**}	0.651^{**}

*significant at 5% level **significant at 1% level

The number of branches per plant and sturdiness quotient gave maximum value of correlation (0.954) and followed by plant height increment and root length (0.879) and plant height increment and sturdiness quotient (0.836), respectively. It was also observed that the plant height increment and shoot electrolyte leakage (-0.798) followed by number of branches per plant and shoot electrolyte leakage (-0.786) correlated negatively with each other.

4.3.7 Effect of *Populus deltoides* plantations on physico-chemical properties of soil with respect to planting seasons, age of planting stock and hydrogel application on individual factor means

The results on effect of *Populus deltoides* plantations on physico-chemical properties of soil with respect to planting seasons, age of planting stock and hydrogel application on individual factor means are presented in Table 22. A critical analysis of the data reveals that soil texture of the plantation did not change from its initial status. It was sandy loam at the time of outplanting. The initial value of bulk density was 1.40 and 1.35 g/cc in autumn and spring seasons, respectively. The values of bulk density showed a slight decrease in both the planting seasons and were found to be 1.35 and 1.34 g/cc after first growing season. It is observed from the Table 22 that bulk density did not show any change with respect to age of planting stock in autumn planting season. In spring season, it was one year old planting stock which showed higher value (1.35 g/cc) as compared to two years old planting stock (1.34 g/cc). The highest value of bulk density was observed in H_0 (1.38 g/cc) and lowest in H_3 (1.33 g/cc) in autumn season. Whereas, in spring season, the hydrogel applications H_0, H_1 and H_4 showed same value of bulk density (1.35 g/cc) and followed by H_2 (1.34 g/cc) and H_3 (1.33 g/cc), respectively. The water holding capacity was higher in the autumn planting season as compared to spring planting season. It was 53.70 percent in autumn season and 45.20 percent in spring season at the time of outplanting. Water holding capacity was 60.15 percent in autumn and 55.33 percent in spring planting season after the completion of one growing season. The Table 22 infers that water holding capacity was high in A_1 (60.57%) and low in A_2 (58.74%) while compared with each other in autumn planting season. Similar observations were reported in spring planting season. It was also observed that water holding capacity was maximum in H_3 hydrogel level (62.91%) and minimum in H_0 level (52.50%) in autumn planting season. In spring season, maximum value of water holding capacity was recorded in H_3 (65.49%) and minimum in H_0 (56.35%). The pH value was recorded high in autumn season 7.20 and somewhat lesser 7.15 in spring planting season. The pH value was observed same for both the planting stocks in autumn season and it was 7.20. Whereas, higher in A_1 (7.16) as compared to A_2 (7.14) in spring planting season. It is also recorded from the Table 22 that the highest pH value was observed in H_0 (7.20) and lowest in H_4 (7.15). The electrical conductivity showed a slight decrease from initial values and was found to be 0.20 dsm^{-1} in both the planting seasons. The value of electrical conductivity was found higher in A_1 (0.21 dsm^{-1}) and lower in A_2 (0.19 dsm^{-1}) in autumn planting season. In spring season, the electrical conductivity remained same for A_1 and A_2 i.e. 0.20 dsm^{-1}. The data from the Table 22 reveal that highest electrical conductivity was recorded in H_0 (0.23 dsm^{-1}) and lowest in H_4 (0.18 dsm^{-1}) in autumn planting season. Similar results were reported under the plantations done in spring season. The organic carbon was found to increase in both the planting seasons from their initial values. It was observed that the organic carbon was higher in autumn planting season (1.87%) and lower in spring season (1.84%). The planting stock A_2 gave high value of organic carbon (1.95%) while compared with A_1 which gave only (1.80%) in autumn planting season. Same trend was observed under spring planting season. It was found that the hydrogel level H_3 gave maximum organic carbon (2.03%) and minimum in H_0 (1.70%) in autumn planting season. In spring season, the highest value was observed in H_3 (2.00%) and lowest in H_0 (1.67%). The availability of nitrogen, phosphorous and potassium showed a decreasing trend in both the planting seasons from their initial status. The availability of nitrogen, phosphorous and potassium was observed to be 219 kg N/ha, 4.70 kg P_2O_5/ha and 304 kg K_2O/ha in autumn planting season and 210 kg N/ha, 4.70 kg P_2O_5/ha and 302 kg K_2O/ha in spring

Table 22: **Effect of *Populus deltoides* plantations on physico-chemical properties of soil with respect to planting seasons, age of planting stock and hydrogel application on individual factor means**

Parameters	Initial status		Autumn planting								Spring planting								Factor means							
	S_1	S_2	S_1	A_1	A_2	H_0	H_1	H_2	H_3	H_4	S_2	A_1	A_2	H_0	H_1	H_2	H_3	H_4	S	A_1	A_2	H_0	H_1	H_2	H_3	H_4
Soil texture	Sandy loam	Sandy loam	Sandy loom	Sandy loam	Sandy loom	Sandy loom	Sandy loam	Sandy loom	Sandy loom	Sandy Loom	Sandy loom	Sandy loom	Sandy loam	Sandy loom	Sandy loom	Sandy loam	Sandy loom	Sandy loom	Sandy loam	Sandy loom	Sandy loom	Sandy loam	Sandy loom	Sandy loom	Sandy loam	Sandy loom
Bulk density (g/cc)	1.40	1.35	1.35	1.35	1.35	1.38	1.36	1.35	1.33	1.35	1.34	1.35	1.34	1.35	1.35	1.34	1.33	1.35	1.35	1.35	1.34	1.36	1.35	1.34	1.33	1.35
Water holding capacity (%)	53.70	45.20	60.15	61.57	58.74	52.50	52.70	57.50	62.91	60.83	55.33	60.84	49.81	56.35	59.30	62.44	65.49	60.06	57.74	61.21	59.67	54.52	58.40	61.64	66.17	61.48
pH	7.36	7.32	7.20	7.20	7.20	7.26	7.23	7.20	7.18	7.15	7.15	7.16	7.14	7.21	7.18	7.15	7.12	7.10	7.18	7.18	7.17	7.23	7.21	7.17	7.15	7.12
Electrical conductivity (dsm^{-1})	0.27	0.24	0.20	0.21	0.19	0.23	0.21	0.19	0.19	0.18	0.20	0.20	0.20	0.23	0.21	0.20	0.19	0.18	0..20	0.20	0.19	0.23	0.21	0.20	0.19	0.18
Organic carbon (%)	1.55	1.48	1.87	1.80	1.95	1.70	1.78	1.90	2.03	1.97	1.84	1.78	1.91	1.67	1.76	1.90	2.00	1.90	1.86	1.79	1.93	1.68	1.77	1.90	2.01	1.93
Available nitrogen (kg N ha^{-1})	285	276	219	220	219	229	224	218	211	215	210	212	209	221	215	209	203	206	215	215	214	225	219	213	207	210
Available phosphorus (kg P_2O_5 ha^{-1})	6.04	5.90	4.70	4.81	4.72	4.88	4.81	4.75	4.68	4.73	4.70	4.72	4.67	4.78	4.73	4.67	4.63	4.68	4.70	4.77	4.70	4.83	4.77	4.71	4.65	4.71
Available potassium (kg K_2O ha^{-1})	336	325	304	306	302	312	307	303	298	302	302	303	300	309	305	301	296	299	303	305	301	311	306	302	297	300

Planting season (S) S_1=Autumn & S_2=spring

Age of planting stock (A) A_1 = 1 year old & A_2 = 2 years old

Hydrogel (H) H_0 = Control, H_1 = Solid application (3.0 g/plant), H_2 = 1.5 g/plant (liquid application), H_3 = 3.0 g/plant (liquid application) & H_4 = 4.5 g/plant (liquid application) planting season, respectively. The highest nitrogen availability was found in A_1 (220 kg N/ha) and lowest in A_2 (219 kg N/ha) in autumn season. In spring season, the nitrogen availability was highest in A_1 (212 kg N/ha) and lowest in A_2 (209 kg N/ha). The available nitrogen was observed to be highest in H_0 hydrogel level in both the planting seasons. It was also recorded from the Table 22 that available phosphorous was highest in A_1 (4.81 kg P_2O_5/ha) and lowest in (4.72 kg P_2O_5/ha) in autumn planting season. In spring season, the value was higher in A_1 (4.72 kg P_2O_5/ha) and lowest in A_1 (4.67 kg P_2O_5/ha). The Table 22 also illustrates that the highest available phosphorous was observed in H_0 (4.88 kg P_2O_5/ha) and lowest in H_3 (4.68 kg P_2O_5/ha) in autumn planting season. Similar trend was seen in spring planting season where H_0 (4.78 kg P_2O_5/ha) gave higher value as compared to other tested hydrogel levels. The available potassium was recorded highest in A_1 (306 kg K_2O/ha) and lowest in A_2 (302 kg K_2O/ha) in autumn planting season. In spring season the one year old planting stock (A_1) gave little bit high level of available potassium as compared to two years old (A_2) planting stock. It was also observed that potassium availability was highest in H_0 (312 kg K_2O/ha) and lowest in H_3 (298 kg K_2O/ha) hydrogel level in autumn planting season. Similar observations were reported in spring planting season.

Overall factor means were evaluated to determine the best possible factors which effected the physico-chemical properties of soil under poplar plantations after the completion of one growing season. The bulk density was observed to be more in A_1 (1.35 g/cc) than in A_2 (1.34 g/cc). The highest bulk density was recorded in H_0 (1.36 g/cc) and lowest in H_3 (1.33 g/cc). The Table 22 infers that the water holding capacity was little bit high in A_1 (61.21%) than in A_2 (59.67%). The maximum value for water holding capacity was observed in H_3 (66.17%) followed by H_2 (61.64%), H_4 (61.48%), H_1 (58.40%) and H_0 (54.52%). The pH value was observed to be high in A_1 (7.18) and low in A_2 (7.17). The application of hydrogel found to effect the pH value of the soil as observed after the completion of one growing season of the poplar plantations. The highest pH value was recorded in H_0 (7.23) and lowest in H_4 (7.12). The electrical conductivity was found high in A_1 (0.20 dsm^{-1}) and low in A_2 (0.19 dsm^{-1}). It is also observed from the Table 22 that the electrical conductivity showed a decreasing trend with increase in hydrogel concentration. It was H_0 (0 g/plant) which recorded highest electrical conductivity as compared to other tested levels of hydrogel. The value of organic carbon was somewhat high in A_2 (1.93%) while compared with A_1 where, it was (1.79%). The maximum organic carbon was recorded in H_3 (2.01%) and minimum in H_0 (1.68%). The available nitrogen was observed to be high in A_1 (215 kg N/ha) and low in A_2 (214 kg N/ha). It was also recorded from the data that high value of available nitrogen was reported under H_0 (225 kg N/ha) and low in H_3 (207 kg N/ha). The available phosphorous was 4.77 kg P_2O_5/ha in A_1 and in A_2 it was 4.70 kg P_2O_5/ha. The phosphorous availability was highest in H_0 (4.83 kg/ha) while it was lowest in H_3 (4.65 kg/ha). It is further recorded from the Table 22 that the potassium availability was more in A_1 (305 kg K_2O/ha) than in A_2 (301 kg K_2O/ha). The available potassium was higher in H_0 (317 kg K_2O/ha) and lower in H_3 (297 kg K_2O/ha).

4.4 Relative economics of plantations

The present work on economic analysis of *Populus deltoides* plantations done on problematic sites in temperate region of North Western Himalayas was carried out in Faculty of Forestry, Sher-e-Kashmir University of Agricultural Sciences and Technology of Kashmir, Jammu and Kashmir. The data pertaining to relative economics of plantation operations and tentative expected outcome are presented in Tables 23 and 24. The actual data for cost and benefit were obtained for one growing season and expected data was calculated by adopting the proper methodology after consulting economists and timber traders to obtain total benefits for eight years rotation cycle. Profitability analysis of plantation was carried out to calculate the economics of *Populus deltoides* on problematic sites. The total plantation area was 0.25 hectare (5 kanals). The average input cost of plantation was found to be Rs. 1,10,361.00 for 8 years while gross return would be of Rs. 9,32,300.00. The total variable cost was found to be Rs. 97,086.00 which included labours, fertilizers, planting material, mulching materials and transport cost. Maximum expenditure of Rs. 30,000.00 (30.90%) was incurred upon planting material. Planting operations and transport cost ws to be claimed of Rs. 20,000.00 (20.60%), labor cost and lopping of branch wood and timber Rs. 38,000.00 (39.14%), fertilizers and mulching materials Rs. 5000.00 (5.15%). Minimum amount was incurred on purchase and maintenance of miscellaneous expenditures Rs. 4086.00 (4.20%). The total fixed cost was Rs. 13,275.00 in which land rent and depreciation cost of implements was included. The amount claimed to be land rent would be Rs. 11,500.00 (86.62%) and depreciation cost of implements was Rs. 17275.00 (13.38%). Net return (GR-TC) of the plantation was calculated and found to be Rs. 8,21,939.00. Maximum income i.e. Rs. 7,90,000.00 (96.11%) was generated by timber in 8 years rotation cycle. Fuelwood and branch wood contributions would be Rs. 31,939.00 (3.89%). Return over variable cost (GR-TVC) and return over fixed cost (GR-TFC) were also calculated which would be found to be of Rs. 8,35,214.00 and Rs. 9,19,025.00, respectively. Net Present Value (NPV) of total cost (@ 10%) and Net Present Value (NPV) of return (@ 10%) was estimated and found to be of Rs 72,071.54 and Rs 4,37,488.88. Net Present worth of plantation was Rs 3,65,417.30. The estimated benefit cost ratio of *Populus deltoides* plantations done on problematic site would be of Rs 6.07.

Table-23: Estimated cost and expected return of *Populus deltoides* plantations on problematic sites

	Years of Production							
Particulars (in Rupees)	**I^st^**	**2^nd^**	**3^rd^**	**4^th^**	**5^th^**	**6^th^**	**7^th^**	**8^th^**
Total variable cost	34936	450	700	0	7500	5000	8000	40500
Total fixed cost	2090	1580	1605	1500	1500	1690	1500	1810
Total cost	37026	2030	2305	1500	9000	6690	9500	42310
Production (qt.)	0	0	25	0	50	65	95	4544(ft^3)
Gross return	0	0	2500	0	5000	6500	9500	908800

Table-24: Profitability analyses

S. No.	Particulars	Amount (in Rupees)
1	Total variable cost	97086
2	Total fixed cost	13275
3	Total cost	110361
4	Gross return	932300
5	Net return (GR-TC)	821939
6	Return over variable cost (GR-TVC)	835214
7	Return over fixed cost (GR-TFC)	919025
8	Net present value of total cost (@ 10 %)	72071.54
9	Net present value of return (@ 10 %)	437488.88
10	Benefit of return (B/C)	6.07
11	Net present worth	365417.3

Chapter – 5

DISCUSSION

Diverse edapho-climatic conditions prevalent in India support a vast diversity of flora and fauna especially of forest tress. However, the diversity of forest trees in our country is under threat due to various reasons such as change in climate, rise in population, increase in area under agriculture, rapid urbanization, natural calamity, etc. Besides this, the recent thrust on reverting to natural products has led to various pressures on the natural resources especially timber and other products. This has led to over exploitation and unsystematic extraction of various commercially demanding tree products. The unplanned, unscientific and over-exploitation of such resources have led to the situation where in, a number of these trees have figured in the endangered/threatened/extinction list of species.

Wood scarcity associated with continued decline in forest cover is a serious matter of concern. Forest cover in India is far less than the national target of 33 percent as envisaged in Indian Forest Policy, 1988. Loss of tree cover leads to desertification, loss of biodiversity and ecological imbalance including socio-economic crises. Trees are undoubtedly a viable source of energy and construction option for the country. Therefore, there is an urgent need to expand afforestation programme particularly on lands which are devoid of trees because of their wasteland nature. These lands can not be put directly for plantation programme as per the traditional planting techniques because of inhospitable conditions for the plants.

Extensive work has been done for plantation of trees on sub-standard sites for improving their productivity through silvicultural and tree improvement interventions which found to ameliorate fertility status of the soil. However, in recent years the concept of plantation technology has gained immense significance in order to combine and utilize the land, labour and water resources for meeting immediate requirements of communities for timber, wood fuel, fodder and other minor products efficiently. The study area falls in the temperate and hilly zone where the tree diversity is very less as compared to the other agro climatic zones of the country. The land holding of the inhabitants is also very low due to physiographic limitations of the area. The available lands are put to use for agriculture, horticulture and other purposes but not for tree plantations. The lands available for tree plantations are challenging and/or harsh. Therefore, there is need to device the plantation technology in consonance with such lands for making the successful plantation programme. Willows and poplars are the two social forestry trees on which the economy of local inhabitants of Kashmir is based. Willows can be grown in the areas where water is abundant but poplar can be grown on the sites which are moisture deficit. Keeping in view, the land and social factor, poplar trees were purposively selected to standardize the plantation technology for problematic site of the region to feed the inflated population in climate changing scenario. *Populus deltoides* is abundant in availability and multifarious purposes in the region are also the strong evidence for its selection in the study. The present investigations have been undertaken with the objectives to standardize the out planting techniques, to determine the best physiological attributes of out planting stock, to elucidate the effect of nitrogen fertilizer on establishment and growth of plantations, to suggest suitable moisture conservation measures for problematic sites and to work out the relative economics of plantations. The results obtained during the present investigations on "Plantation Techniques of *Populus deltoides* Bartr. for Problematic Sites in Temperate Region of North Western Himalayas" have been discussed here by establishing a cause and effect relationship wherever necessary or feasible in the light of available evidences under the following heads:

5.1 Effect of planting seasons with intervals and nitrogen fertilizer on establishment & growth of *Populus deltoides* plantations on problematic site

One of the most important approach for the successful establishment and growth of *Populus deltoides* plantations lies under the selection of best planting season with intervals and nitrogen application. The *Populus deltoides* Plantations done on problematic sites will help in rehabilitation of unserviceable lands which results in increasing the tree cover. This is certainly helpful in reducing the pressure on natural forests to meet the bonafide needs of local populace.

In this context, two planting seasons, three intervals and four nitrogen levels were tested to find out the suitable best possible factor responsible for establishment and growth of poplar plantations on problematic sites in temperate region of North-Western Himalayas.

5.1.1 Establishment of plantations

Exposition of Table 2 reveals that both the planting seasons with intervals effected survival percentage significantly. The planting interval I recorded highest survival percentage followed by planting interval II and planting interval III in both the planting seasons. The highest survival percentage of plantation under planting interval I in both the planting seasons is attributed to favorable climatic conditions and availability of more time duration as compared to other two planting intervals. Similar results were found by Cecek *et al.* (2010) for *Fraxinus angustifolia* in Adapazari, Turkey. Survival percentage of *Populus deltoides* increased with increase in nitrogen dosages from N_0 (control) to N_2 (150 kg N/hectare) and then decreased in both the seasons. Similar findings were recorded by Gilman *et al.* (2000) for *Magnolia* and *Oak* in sandy landscape where they reported that the increase in nitrogen concentration in soil resulted in increase in survival percentage upto certain limit and then found to decrease.

Factor means revealed that autumn planting gave higher survival percentage (76.38%) than spring planting (66.66%). The higher survival in autumn planting was because of the reason that the plantation area falls in the temperate region which get precipitation in the form of snow right from November to February every year. This may result in the availability of sufficient moisture in the soil. Tomar *et al.* (2003) have also reported the similar observations in *Acacia auriculiformis* and *Acacia nilotica* plantations done on calcareous soils in Bir reserved forest Hisar. Planting interval I with survival percentage of 77.07 percent was best for poplar plantation than other two planting intervals. It is due to the reason that planting interval I got more time for establishment of seedlings as compared to planting interval II and Planting interval III. These results are in conformity with the earlier findings of Pal and Sharma (2001). Nitrogen level of N_2 (150 kg N/ha) gave highest survival percentage (86.35%), while compared with N_1 (72.21%), N_0 (63.88%) and N_3 (63.68%). The decrease in survival percentage of plantations from N_2 to N_3 is due to toxicity of soil. High fertilizer concentrations in the soil from high fertilizer rates can damage the root system of seedlings which results in the low rate of survival. Same trend was recorded by Esen *et al*. (2012) for *Prunus avium* seedlings in Duzce. The overall interaction between three factors was found non-significant. Survival percentage of *Populus deltoides* plantations on problematic site was found highest with treatment combination $S_1I_1N_2$, 100 percent (Autumn planting × Planting interval I × 150 kg N/ha).

5.1.2 Growth of plantations

Planting interval I gave better expression of growth attributes plant height increment, collar diameter increment, number of branches per plant and leaf area per plant of plantations as compared to planting interval II and planting interval III in both the planting seasons. The higher growth of plantations in planting interval I was due to the early establishment and availability of enough time for growth of plantations than other two planting intervals. These findings are in conformity with the results of Bowersox *et al*. (1991) and Goel and Behl (2004) where they reported that the seedlings planted in planting interval I (PI_1) got maximum time for establishment as compared to other planting intervals which resulted in higher growth rates. Maximum growth of seedlings was recorded under nitrogen level N_2 (150 kg N/ha) and minimum under N_0 (control) in autumn planting. Same trend was observed in spring planting with maximum growth under N_2 and minimum under N_0. The maximum growth of plantations under N_2 (150 kg/ha) application may be due to the easy availability of nitrogen in the soil. The nitrogen is considered as an essential element for the growth of trees especially in problematic sites. These findings are in conformity with the outcomes of the investigations carried on larch seedlings by applying urea fertilizer by Okarsson *et al.* (2006). The most recognized role of nitrogen in the plants is its presence in the structure of protein molecules as purines, pyrimidines, porphyrins and enzymes. The porphyrin is found in such metabolically important compound such as chlorophyll pigments and the cytochromes essential in photosynthesis and respiration. These molecules are often related with the process of plant growth. Nitrogen application beyond 150 kg/hectare showed a decrease in growth of plantations which may be due to nitrogen toxicity in roots. Similar findings were recorded by Khamis *et al*. (2013) for *Melia azedarach* and *Populus euphratica* in Wadi el Natrun, Egypt.

Evaluation of factor means reveal that autumn planting came out to be the best season for plantation growth (plant height increment, collar diameter increment, number of branches per plant and leaf area per plant) on problematic site as compared to spring planting. This is due to the reason that seedlings planted in autumn had enough time to get established and then growth of outplanted seedlings as compared to spring planting. Similar results were recorded by Barnett *et al*. (1988) for *Eucalyptus camaldulensis* in Zomba, Malawi. Planting interval I (PI_1) recorded highest growth of plantations followed by planting interval II (PI_2) and planting interval III (PI_3). Similar findings were recorded by Ballard (1978) in New Zealand for *Eucalyptus* plantation and reported that planting interval I showed higher growth as compared to other intervals due to early establishment of plantations. Individual dosages of nitrogen fertilizer have significantly increased the plant growth over control upto N_2 (150 kg N/hectare) and then decreased. Similar observations were recorded by Xu *et al.* (2000) where they reported that the best growth increments from the application of N fertilizer up to 150 kg/ha to increase N addition which resulted in maintaining the growth improvements. The high concentration of nitrogen found to increase leaf cell number and cell size with an overall increase in number of branches and leaf production (Mortan and Watson, 1948) and contrary to this, the low nitrogen availability cause a decrease in protein synthesis which subsequently show an inverse effect on plant growth (Njoku, 1957). The effect of interactional combination of the treatments namely planting seasons, intervals and fertilizer application on plant growth reveal that the treatment combination $S_1I_1N_2$ (autumn season × planting interval I × 150 kg/ha) out performed over rest of the tested combinations. This might be due to the reason that climatic conditions in autumn season under temperate conditions with appropriate nitrogen dosages are favorable for growth of poplar plantations on problematic sites.

5.1.3 Correlation of physiological and quality parameters of seedlings with survival percentage and growth attributes of *Populus deltoides* plantations on problematic sites

Simple correlation does not provide the true associations of traits with each other as these attributes are interrelated among themselves and considerably influence each other. Due to mutual relationship among different traits which may be positive or negative, these correlations are partitioned into direct and indirect effects. The survival and growth in a plant is effected by several physiological & quality variables and environment. In the present study, the survival percentage and growth attributes (plant height increment, collar diameter increment, number of branches per plant and leaf area per plant) were taken as dependent variables whereas, physiological and quality parameters were taken as independent variables for correlation studies. Table 7 reveals that out of the nine independent variables, only 7 variables had direct positive effect on survival percentage of *Populus deltoides* plantations. Root electrolyte leakage and shoot electrolyte leakage correlated negatively to the dependent variables. Relative water content (0.813) exhibited the maximum contribution on survival percentage of *Populus deltoides* plantations followed by root fibrosity (0.810) and root length (0.803).

The lowest positive correlation was observed between survival percentage and membrane stability index (0.653). Root electrolyte leakage (-0.831) and shoot electrolyte leakage (-0.776) had direct correlation with survival percentage but with negative sign. The reason might be that greater electrolyte leakage leads to desiccation of plant parts finally resulted in low chances of survival of the plantations. Similar results were reported by Mckay (1998) in spruce and larch. The correlation of root shoot ratio with survival percentage was statistically non-significant. These findings are in consonance with the recommendations of Davis and Jacobs (2005) for northern red oak.

The leaf area per plant and sturdiness quotient have maximum direct positive correlation (0.970) which was further followed by plant height increment and sturdiness quotient (0.941) and number of branches per plant and sturdiness quotient (0.903), respectively. This might be due to the reason that seedlings with greater leaf area have greater photosynthetic rate and hence higher growth of different parts. Similar results were observed by Grossnickle and Folk (1993) for larch plantations that there was strong correlation between leaf area plant and sturdiness quotient. The number of branches per plant gave highest negative correlation with root electrolyte leakage (-0.876) and shoot electrolyte leakage (-0.854). The reason for this negative correlation might be more the electrolyte leakage less will the performance of seedlings on problematic site. The findings reported in the investigation proved to be in consonance with the conceptual base of the mechanism.

5.1.4 Effect of *Populus deltoides* plantations on physico-chemical properties of soil with respect to planting seasons, planting intervals and nitrogen fertilizers on individual factor means

The soil texture of the plantation site did not show any change due to short span of time of the study. Similar findings were reported by Khamis *et al*. (2013) that physical soil parameters cannot be altered much after one or two years of plantations. The values of bulk density showed a slight change under both the planting seasons from their initial values. It was also observed that planting intervals and nitrogen fertilizers found to effect bulk density under poplar plantations. Similar results were observed by Alle *et al*. (2014) in *Hevea brasiliences* that under different planting intervals and nitrogen levels bulk density varies. Water holding capacity of the plantation site showed increase after first growing season. Maximum water holding capacity was found in PI_1 (60.02%) and N_2 fertilizer level (58.17%) in both the seasons. The higher water holding capacity under said treatments may be attributed to greater retention of water by the roots of plantations in the soil. The pH of soil showed a slight decrease over the initial value after first growing season. The pH value was recorded higher in autumn season (7.25) as compared to spring season (7.21). In both the planting seasons, the highest pH was reported in PI_1 and N_0 nitrogen level (7.29). Similar findings were observed by Bolu and Polle (2004) that pH was observed higher in autumn season under treatments that were without fertilizer application in poplar species. Electrical conductivity showed a minor decrease from initial value and was found to be 0.23 dsm^{-1} in both the planting seasons and in all the three planting intervals. It was also found that the electrical conductivity showed a decline from its initial value with the application of nitrogen fertilizers. Similar findings were observed by Cicek *et al.* (2010) that application of urea found to decrease pH and electrical conductivity on degraded plantation site. The organic carbon was found to increase in both the planting seasons from their initial values. The organic carbon was higher in autumn season (1.81%) and low in spring season (1.78%). It was found that N_2 nitrogen level gave better results pertaining to organic carbon in both the planting seasons. The increase in organic carbon is due to metabolic activities of microorganisms inside the soil. This finding is in agreement with the results of Miles *et al.* (1999) that greater the activity of organisms inside the soil more will be the organic carbon. The highest nitrogen availability was found in PI_1 and N_2 nitrogen level in both the planting seasons. This may be due to the reason that addition of nitrogen found to increase nitrogen content of soil and hence reflected in the growth of poplar plantations. The available phosphorous was highest in PI_3 (5.06 kg P_2O_5/ha) in both the planting seasons. Plants absorb more nutrients in planting intervals PI_1 and PI_2 as compared to PI_3 due to the more time duration. The available potassium was found highest in PI_2 (311 kg K_2O/ha) and lowest in PI_3 (307 kg K_2O/ha. The higher value of available potassium in planting interval II (PI_2) in autumn season may be due to the cessation of growth in winter which ultimately decrease the absorption of nutrients.

The factor means were also evaluated to determine the best individual factor which effect the physico-chemical properties of soil under poplar plantations. It was observed that bulk density decreased from initial value and was found to be 1.36 g/cc at the time of completion of first growing season. The reason may be attributed to increase in organic matter which loosens the soil in plantations and decrease density. These findings are in agreement with the results of Kumar (2008) that addition of organic matter decreases bulk density of soils. The highest bulk density was recorded under N_3 nitrogen level (1.39 g/cc) and lowest under N_0 (1.35 g/cc). The addition of chemical fertilizer found to increase the compactness of soils under limited moisture conditions and hence increase the value of bulk density. This is true to the findings of the present investigation. The maximum water holding capacity was found under PI_1 (57.09%) and lowest under PI_3 (50.13%). The maximum value of water holding capacity was observed under N_2 (54.51%) dosage of nitrogen fertilizer. Due to early establishment of seedlings in PI_1 growth parameters showed early response and adds more organic carbon to the soil as compared to plants planted in other planting intervals thereby, increasing the water holding capacity. It was also observed from the present investigation that growth parameters showed higher values under N_2 (150 kg N/ ha) nitrogen level, because of release of more organic matter and thereby enhance the value of water holding capacity of the soil. Similar finding was reported by Melo *et al.* (2004) that in *Eucalyptus camaldulensis* plantations higher rates of nitrogen dosages increased the growth of plants and water holding capacity of soils. The pH value was observed to be highest in PI_1 (7.27) while lowest in PI_3 (7.19). The early establishment and growth in PI_1 increased the microbial activity in soils and thus increase the pH value. It was also reported that organic carbon was maximum in PI_1 (1.83%) and under N_2 (1.84%) nitrogen level. The reason may be increase in growth of plantations which ultimately increase the organic carbon in the soils. These findings are in agreement with the results of Moscatelli *et al.* (2008) that increase in organic carbon was due to addition of nitrogen fertilizer in the soil. It was also recorded that highest nitrogen was available under N_2 (150 kg N/ha) while it was lowest under N_0 (0 kg/ha). The reason may be addition of fertilizer in soils resulted in increase its availability after absorbing by the plants.

5.2 Effect of planting seasons, pit shapes, pit sizes and moisture conservation measures on establishment & growth of *Populus deltoides* plantations on problematic site

The main aim of establishing *Populus deltoides* plantations on problematic sites by using different pit shapes, sizes and moisture conservation measures was to standardize the out planting techniques with planting seasons in problematic sites existing in temperate regions. For this purpose, two planting seasons, three pit shapes and sizes including mulching measures (paddy straw and polythene mulch) were taken to find out the best treatment as per the site specification and species requirement.

5.2.1 Establishment of plantations

It was observed that PT_2 (saucer pit) gave higher survival percentage which was followed by PT_1 (ordinary pit) and PT_3 (ring pit) in both the planting seasons. The reason might be that on sloppy plantation sites saucer pits conserve more moisture as compared to other tested pit types. The configuration of the saucer pit that does not allow the precipitation to go as runoff was reported to be responsible for giving more moisture over the rest of the two tested pits. The findings are in conformity with the observations made by Mehta (1989) for *Acacia* plantations on alkali soils in Haryana state. Pits of different sizes found to effect the survival percentage of *Populus deltoides* plantations done in both the planting seasons. It was found that PS_3 (60×60 cm^3) recorded highest survival percentage followed by PS_2 (45×60 cm^3) and PS_1 (30×45 cm^3). The reason being pits of larger sizes store enough water during rains as compared to pits of smaller sizes which is thought to be essential for the establishment of plantations. Therefore, the results pertaining to survival percentage has equally proven the statement beyond any doubt. These results are in agreement with Singh *et al.* (1992) that large sized pits store more water for establishment of tree plantations done on highly alkaline soils. Highest survival percentage was recorded for M_2 (black polythene) and lowest in M_0 (control) in both the planting seasons. Black polythene mulches were found to evaporate less moisture from pits compared to ordinary mulch (paddy straw) and control where no mulch was used. Similar results were recorded by Porfit and Scott (1984) that under black polythene mulch survival of poplar seedlings was higher as compared to other tested bio mulches.

Factor means were evaluated to determine the best possible input factor responsible for enhancing the survival percentage of poplar plantations on problematic sites. The seedlings planted in autumn season found to establish better in terms of number while compared with spring planting season. The 76.53 percent survival percentage was observed in autumn and 67.88 percent in spring planting. This may be due to the reason that seedlings planted in autumn season got enough time period as compared to seedlings planted in spring season for their roots to establish. Moreover, the seedlings planted in autumn season lies dormant and this would be the reason that the seedlings sufficiently bear the transplanting shock before initiation of the growth that is evident in the spring season especially in temperate regions. On the other hand, the time period between two planting seasons is almost three months which may be considered as sufficient time for establishment of roots. Similar results were observed by Lahiri and Mazumdar (1993) in *Eucalyptus hybrid* and *Eucalyptus tereticornis* plantations in wasteland of Burdwan District, West Bengal. Highest survival percentage was recorded in M_2 (81.47%) and lowest in M_0 (62.95%). Applying black polythene mulch around the base of tree has been associated with increased growth and survival as compared to ordinary mulch (paddy straw) and control (no mulch). This observation is in concurrence with finding of Watson (1988) who reported higher survival of *Populus deltoides* plantations was under black polythene mulch. Saucer pit (PT_2) recorded highest survival percentage (77.85%) followed by PT_1 (70.36%) and PT_3 (68.50%). Similar results were recorded by Meena *et al*. (1995) that saucer pit is the main water conserving method under degraded sloppy sites for better survival of plantations. Highest survival percentage was recorded for PS_3 (85.26%) which was followed by PS_2 (70.36%) and PS_1 (61.10%). The reason being greater the pit size more is the rain water storage. Similar results have also been reported by Dagger *et al.* (1993) for *Prosopis* species in salt effected soils. The interactional treatment combinations namely $S_1M_2PT_2PS_3$, $S_1M_1PT_2PS_3$, $S_1M_2PT_3PS_3$ and $S_2M_2PT_2PS_3$ gave 100 percent survival of poplar plantations. The pit type, pit size and mulching in each of these treatment combinations is playing their role in conserving water for higher survival of plantations on problematic sites.

5.2.2 Growth of plantations

The maximum plantation growth (plant height increment, collar diameter increment, number of branches per plant and leaf area per plant) was recorded for PT_2 (saucer pit) followed by PT_1 (ordinary pit) and PT_3 (ring pit) in both the seasons. Similar observations were reported by Agnihotri *et al.* (1989) that under barren and sloppy sites saucer pits store rain water which is essential for nutrient mobilization and growth of *Eucalyptus hybrid* plantations. PS_3 (60×60 cm^3) recorded maximum plant growth and minimum in PS_1 (30×45 cm^3) in both the planting seasons. This might be due to the reason that roots of seedlings proliferate more rapidly in large sized pits as compared to smaller sized pits. The growth of roots is directly related to plant growth. The results are in agreement with the finding of Barnett *et al.* (1988) where they reported the maximum plant growth in larger sized pits under problematic sites. Maximum growth of plantations was recorded under M_2 (black polythene) which was followed by M_1 (paddy straw) and M_0 (control). The primary benefit of black poly mulch was reduction in vegetative competition and benefit related to the improvement of edaphic environments. Such conditions are undoubtly helpful in enhancing growth of plantations done on moisture stressed sites. Similar results were reported by Davis (1988) that weed growth was found to be less under black polythene mulch as compared to other mulching materials.

Individual factors were also evaluated to determine the best individual factor for plantation growth on problematic sites. Maximum growth of plantations was recorded in autumn planting and minimum in spring planting. The higher survival in autumn planting might be due to the reason that seedlings planted develop earlier and better root system as compared to seedlings planted in spring season. Root growth is directly related to plant growth. These results are in agreement with Singh *et al*. (1989) who reported the earlier growth in autumn planting as compared to spring planting in Mesquite on highly problematic soils. PT_2 recorded highest plantation growth (plant height increment, collar diameter increment, number of branches per plant and leaf area per plant) followed by PT_1 and PT_3. This might be due to the reason that PT_2 (saucer pit) conserves more moisture on sloppy lands compared to ordinary and ring pit. These results are in agreement with findings of Pandalai and Chacko (1987) where they observed that saucer pits are efficient moisture conservation measures on sloppy sites. Maximum growth of plantations was observed in PS_3 and minimum in PS_1. The reason for this might be efficient root growth and development in large sized pits resulted in higher plantation growth. Similar findings were reported by Singh *et al*. (1992) in *Gliricidia sepium*. The maximum growth of plantations was recorded under M_2 (black polythene) followed by M_1 (paddy straw) and M_0 (control). Polythene mulch act as barriers to water and air movements escaping from plant basin encourage the root and plantation growth. These findings are in agreement with Appleton *et al.* (1990) where they reported that black poly mulch enhanced tree growth by reducing evaporation and temperature. The interactional treatment combination namely $S_1M_2PT_2PS_3$ produced the highest growth of poplar plantations on problematic site. The seedlings planted in saucer and large sized pits under black polythene mulch conserves enough moisture and reduce weed growth which resulted in highest growth of poplar plantations on problematic sites.

5.2.3 Correlation of physiological and quality parameters of seedlings with survival percentage and growth attributes of *Populus deltoides* plantations on problematic sites

Significant correlation may or may not be proof of very direct causal relationship. Again when more variables are considered in the correlation study, the association becomes more complex, less obvious and sometimes confusing. At this point, it appears appropriate to employ a method of analysis which will take into account the knowledge that we have with regard to the causal relation between the characters of correlation.

A perusal of the data from Table 14 reveals that out of the nine independent variables, only 7 variables had direct positive effect on survival percentage of *Populus deltoides* plantations. Root electrolyte leakage and shoot electrolyte leakage correlated negatively to the dependent variables. Relative water content (0.825) exhibited the maximum contribution on survival percentage of *Populus deltoides* plantations followed by root fibrosity (0.822) and root length (0.811). The lowest positive correlation was observed between survival percentage and membrane stability index (0.632). Root electrolyte leakage (-0.822) and shoot electrolyte leakage (-0.764) had direct correlation with survival percentage but with negative sign. The reason might be more the electrolyte leakage from roots and shoots poor is the growth performance of seedlings. Similar finding were reported by Mckay and White (1997) in fir seedlings under temperate conditions.

The number of branches per plant and sturdiness quotient have maximum direct positive correlation (0.963) followed by collar diameter increment and sturdiness quotient (0.905) and number of branches per plant and root length (0.858), respectively. The findings of the study undoubtly are in line with the earlier outcomes of Long and Hallgren *et al.* (1993) where they reported strong correlation between number of branches and collar diameter with sturdiness quotient. It is also observed from the data that number of branches per plant gave highest negative correlation with root electrolyte leakage (-0.851) and shoot electrolyte leakage (-0.832). These findings are in agreement with the study of Dunsworth (1997) who reported the strong positive correlation between number of branches per plant and other growth attributes (plant height, diameter increment and number of branches per plant) in case of cedar seedlings.

5.2.4 Effect of *Populus deltoides* plantations on physico-chemical properties of soil with respect to planting seasons, pit shapes, pit sizes and moistures conservation measures (mulching) on individual factor means

The initial soil texture of the plantation was sandy loam and was not affected by *Populus deltoides* plantation after one growing season. Similar results were reported by Gilman *et al.* (2000) that soil structure and texture is not effected by one year of plantation. The values of bulk density showed a slight change in both the planting seasons and were found to be 1.35 and 1.36 g/cc after first growing season. The highest value of bulk density was found in PS_1 than PS_2 and PS_3 in both the planting seasons. The reason might be less growth and microbial activity in pit size I (PS_1) which increases the density of soil in plantations as compared to PS_2 and PS_3. Water holding capacity was found to be maximum in autumn planting (57.17%) as compared to spring season (56.42%) after first growing season. The higher growth in autumn planting adds more organic matter to the soil and increases water holding capacity of plantation site. Similar finding were recorded by Hodge (1995) that organic matter increases water holding capacity under plantations. It was also observed that water holding capacity was maximum in PS_3 (60.61%) and under mulching material M_2 (60.29%) in both the planting seasons. In both the situations growth of plantations enhanced due to release of organic matter and resulted in increased value of water holding capacity. Similar results were reported by Klimek *et al.* (2011) that higher water holding capacity was seen under black polythene mulches. The pH value was higher in autumn season (7.23) as compared to spring season (7.22). The higher growth of autumn season plantations may be due to the early establishment which found to enhance the microbial activity and resulted in increase in pH value of soil. Similar findings were reported by Arthur and Wang (1999) that pH value of soil under Christmas tree plantations showed an increase due to microbial activity in soil. The effect of mulching on pH was similar in both the planting seasons with M_2 performed better as compared to other tested mulching materials. Black polythene mulch enhance the temperature and decomposition under tree plantations and found to increase pH value of the soils. These findings are in agreement with the results of Byard *et al.* (1996) that increase in pH value under black polythene mulch was due to elevated temperature which enhance microbial activity of the soil. The electrical conductivity showed a minor decrease from its initial value and was found to be same for both the planting seasons (0.21 dsm^{-1}). Electrical conductivity was found highest in PT1 (0.22 dsm^{-1}) and lowest in PT_2 (0.19 dsm^{-1}) in both the planting seasons. The electrical conductivity showed a minor decrease from initial values and was found to be same for both the planting seasons (0.21 dsm^{-1}). The highest electrical conductivity was observed under M_0 (0.22 dsm^{-1}) in both the planting seasons. The organic carbon was higher in autumn season (1.81%) and lower in spring season (1.78%). It was found that the PS_3 gave better results pertaining to organic carbon in both the planting seasons. The highest organic carbon was found under M_2 and lowest under M_0 in both the planting seasons. The reason may be increase in microbial activity under black polythene mulch in poplar plantations which release more organic carbon compared to ordinary mulch (paddy straw) and control (no mulch). Similar findings were reported by Jiang *et al.* (2002) that under black polythene mulch organic carbon showed an increase in bamboo plantations as compared to other tested mulches. The availability of nitrogen, phosphorous and potassium observed to be 226 kg N/ha, 4.61 kg P_2O_5/ha and 295 kg K_2O/ha in autumn season and 215 kg N/ha, 4.51 kg P_2O_5/ha and 294 kg K_2O/ha in spring planting season, respectively. Similar decreasing trend of nutrients with respect to planting seasons was reported by Mishra *et al.* (2003) in *Eucalyptus tereticornis.* The available nitrogen, phosphorous and potassium was observed to be highest in pit size I (PS_1) and under M_0 where no mulching was done (control). The reason might be poor growth and establishment under these treatments leads to poor absorption from soil and enhance their level at plantation site. These findings are in agreement with the results of Meena *et al.* (1995) that availability of nutrients is more on places where absorption by plantation is less.

The factor means were evaluated to determine the best possible factor which could be responsible to effect the physico-chemical properties of soils under poplar plantations done on problematic site. It was observed that bulk density decreased from initial value and was found to be 1.36 g/cc. The highest bulk density was observed in PT_1 (1.36 g/cc) and minimum in PT_3 (1.34). The pit size PS_1 (1.37 g/cc) gave higher bulk density as compared to other tested pit sizes. The mulching treatment M_0 (1.37 g/cc) was observed with higher bulk density than other mulching materials. The poor growth of seedlings under these treatments may lead to decrease in addition of organic matter and increase the density of the soils. The maximum water holding capacity was found in PS_3 (61.11%) and with M_2 (59.98%) mulching treatment. The reason may be increase in microbial activity which enhance the organic carbon and water holding capacity of soil on plantation site. The similar findings were observed by Pazhanivelan *et al.* (2009) who reported the influence of planting techniques and performance of tree species in rainfed alkali soils. The available nitrogen was observed highest in PT_1 (234 kg N/ha), PS_1 (224 kg N/ha) and under M_0 (224 kg N/ha) treatments. Similar trend was also recorded with phosphorous and potassium. The reason may be poor performance of seedlings under these treatments lead to increasing availability of nutrients on plantation site. These findings are in agreement with the results of Sardar (1992) who reported the effect of pit type, pit size and mulching on fodder trees.

5.2.5 Effect of different moisture conservation measures on moisture regimes of soils in poplar plantations done on problematic sites

The establishment and growth of seedlings on plantation site was mainly associated with moisture present in the soil. The moisture percentage of soil under different moisture conservation measures was measured by using moisture meters.

The mulching materials (control, ordinary mulch and black polythene) were found to vary in moisture percentage under poplar plantations. Moisture percentage under black polythene was more as compared to ordinary mulch and control in both the planting seasons. The reason might be low weed growth under black polythene mulch which resulted in increased moisture in the site. Similar results were recorded by Cregg *et al.* (2009) in Fraser fir and blue spruce. The highest percentage of moisture was found in P4 (16-28th February) and lowest in P15 (1st-15th august) in autumn season. The reason behind this drastic variation is that precipitation in the form of snowfall in winter found to increase moisture availability in soils. On contrary to this, the occurrence of high temperature in summer found to decrease the same (P15). In spring planting, the highest percentage of moisture was reported in P2 interval (16-30th April) and lowest in P9 interval. The highest moisture percentage in P2 was due to rainfall that occurred in the month of March and April in the plantation site which falls under the temperate conditions of North West Himalayas. Moreover, the area experiences rainy season immediately after the winter season because of monsoon shadow effect in Kashmir valley.

The pits of different shapes were found to vary in moisture percentage under the poplar plantations site. The graphical representation of fortnight intervals with moisture percentage showed that among the three pit types, saucer pit gave highest percentage of moisture which was further followed by ring pit and ordinary pit. This might be due to the reason that saucer pits on sloppy sites did not allow to drain out single rain drop because of its shape. The highest percentage of moisture was recorded in P2 (15-31st January) and lowest in P20 (15-31st October) in autumn planting. The highest moisture percentage was found in interval P1 (1st-15th April) and lowest in P14 (16-31st October) in spring planting. The reason might be high rainfall and low temperature in the month of April and low rainfall in October.

Highest moisture was found under large sized pits 60×60 cm^3 which was followed by 45×60 cm^3 and 30×30 cm^3 in both the planting seasons. The reason being, more the pit size more is the moisture present. The percentage of moisture was also recorded after every 15 days and it was found that highest percentage was observed in P1 (1st-15th January) and lowest in P20 (15-31st October) in autumn planting. In general moisture percentage showed a declining trend from P1-P20. The reason might be snowfall in interval 1 (P1) and dry weather in spring and extended to summer seasons. Similar trend was also reported during spring planting. The results are in agreement with the findings of Kotze and Joubert (1992) that moisture conservation takes place more in winter as compared to summer season.

5.3 Effect of planting seasons, age of planting stock and hydrogel application on establishment & growth of *Populus deltoides* plantations on problematic sites

5.3.1 Establishment of plantations

The main purpose of evaluating treatments/inputs namely planting seasons, age of out planting stock and hydrogel levels to find out the best treatments and their interactions which found to influence the establishment and growth of *Populus deltoides* plantations. The survival of two years old planting stock (A_2) was more than the one year old planting stock (A_1). The higher survival of two years old planting stock may be because of the large root volume which found to absorb moisture and nutrients more efficiently than the one year old planting stock on problematic plantation sites. These findings are in agreement with Snellgrove and Mayhead (1995) that *Juglans regia* seedlings with higher root volume survive better as compared to one having less root volume. Higher survival percentage was obtained in H_3 (liquid application @ 3 g/plant) and minimum in H_0 (control) in both the planting seasons. The liquid application of hydrogel at the rate of 3 g/plant forms a film around roots and absorb sufficient moisture in rainy season as compared to solid application. This absorbed moisture is then released by the roots during water deficit period for plant growth functions. Similar findings were reported by Viero *et al*. (2000) that liquid hydrogel absorbs moisture in rainy season and release the same during drought conditions in *Eucalyptus grandis* × *camaldulensis* clones in Zululand.

Factor means analysis revealed that autumn planting gave better survival percentage (70.99%) than spring planting (69.99%). Similar findings were reported by Sardar (1992) for *Leucaena leucocephala* plantations done on degraded sites in Peshawar, Pakistan that autumn planting season is better for survival of seedlings with respect to the moisture present in soil. Two years old planting stock (79.99%) gave survival percentage which was better than one year old planting stock (69.99%). This might be due to the reason that two years old planting stock had greater root length and volume to overcome the water stress compared to one year old planting stock. H_3 (liquid application @ 3 g/plant) gave highest survival percentage (95.83%) which was followed by H_2 (79.16%), H_4 (79.16%), H_1 (66.66%) and H_0 (54.16%). These results are in conformity with Parrotta *et al*. (1997) that maximum water storage was seen in pits of eucalyptus plantations done on degraded sites where liquid hydrogel applied @ 3 g/plant. It was also observed that survival percentage of *Populus deltoides* plantations on problematic site was found 100 percent with interactional treatment combination of $S_1H_3A_2$ 100 percent (autumn season × hydrogel level 3 g/plant liquid application × two years old planting stock). The reason might be that in winter season appropriate level of hydrogel and better planting stock can absorb enough moisture for its survival during moisture stressed period.

5.3.2 Growth of plantations

The present investigation reveals that plantation growth (plant height increment, collar diameter increment, number of branches per plant and leaf area per plant) found to influenced by planting seasons, age of out planting stock and five levels of hydrogel application significantly. Maximum growth of plantations was recorded in two years old planting stock as compared to one year old planting stock in both the seasons. The reason may be higher moisture and nutrient absorption by two years old planting stock whose roots are more developed as compared to one year old planting stock. Similar results were reported by Cicek (2010) that increased plantation growth is related directly to the use of high quality and larger-size planting stock. Maximum growth of plantations was observed under H_3 (liquid application @ 3 g/plant), followed by H_2 (liquid application @ 1.5 g/plant), H_4 (liquid application @ 4.5 g/plant), H_1 (solid application @ 3 g/plant) and H_0 (control). These results are in conformity with findings of Aide *et al*. (1995) where they reported that liquid application of hydrogel at the rate of 3 g/plant gave higher growth increments including number of branches per plant and leaf area per plant as compared to solid applications.

Individual factor means revealed that plantation growth was better in autumn planting than in spring planting. The reason might be the availability of abundant moisture in autumn planting which is responsible for early seedling establishment as compared to spring planting. I.e irrigation requirement in autumn planting is far less than spring planting. Maximum growth of plantations was recorded in two years old planting stock and minimum in one year old planting stock. The reason might be better establishment and growth of two years old planting stock whose long tap root found to absorb moisture and nutrients more efficiently from deeper soil layers as compared to one year old planting stock. More the absorption more is the height increment. The H_3 hydrogel level (liquid application @ 3.0 g/plant) gave maximum growth of plantations than other tested hydrogel levels. These findings are in agreement with Viero *et al*. (2000) that better plantation growth was observed in *Eucalyptus species* at different concentrations of liquid hydrogel application as compared to solid application and control. It was observed that best interactional treatment combination for growth of plantations on problematic sites was $S_1H_3A_2$. The two years old seedlings planted in autumn season under hydrogel level 3.0 g/plant gave maximum growth pertaining to higher absorption of moisture and nutrients.

5.3.3 Correlation of physiological and quality parameters of seedlings with survival percentage and growth attributes of *Populus deltoides* plantations on problematic sites

The survival and growth of plantations is throughout to be the cumulative effect of several survival and growth related components and environment. In the present study, the survival percentage and growth attributes (plant height increment, collar diameter increment, number of branches per plant and leaf area per plant) were taken as dependent variables while physiological and quality parameters were taken as independent variables for correlation studies.

Out of the nine independent variables, only 7 variables had direct positive effect on survival percentage of *Populus deltoides* plantations. Root electrolyte leakage and shoot electrolyte leakage are correlated negatively to the dependent variables. Root length (0.877) exhibited the maximum contribution on survival percentage of *Populus deltoides* plantations followed by root fibrosity (0.841) and sturdiness quotient (0.821). The lowest positive correlation was observed between survival percentage and membrane stability index (0.612). Root electrolyte leakage (-0.765) and shoot electrolyte leakage (-0.554) had direct correlation with survival percentage but with negative sign. The value of correlation between collar diameter and root/shoot ratio was found to be non-significant. Similar results were observed by Davis and Jacobs (2005) while quantifying root system quality of seedlings to outplanting performance. Root and shoot electrolyte leakage exhibits negative correlation with survival percentage.

The reason for negative correlation might be poor performance of outplanting stock under high electrolyte leakages.

The number of branches per plant and sturdiness quotient have maximum direct positive correlation (0.954) followed by plant height increment and root length (0.879) and plant height increment and sturdiness quotient (0.836), respectively. The highest negative correlation was seen between plant height increment and shoot electrolyte leakage (-0.798) followed by number of branches per plant and shoot electrolyte leakage (-0.786). The reason might that activity of roots is directly related to growth performance of above grounds plant parts. The greater root length helps in absorption of nutrients from deep soil layers in problematic sites and results in more height increment of seedlings. These results are in conformity with the findings of Mattson (1997) that plant height increment, root length and number of branches per plant and sturdiness quotient have strong correlation.

5.3.4 Effect of *Populus deltoides* plantations on physico-chemical properties of soil with respect to planting seasons, age of planting stock and hydrogel application on individual factor means

There was no change in soil texture under *Populus deltoides* plantations after first growing season. It is well proven that soil properties such as texture cannot be altered by one year of plantations. Similar findings were reported by Kumar (2008) that texture of soils cannot be altered by short rotation plantations. The value of bulk density showed a slight change in both the planting seasons and found to be 1.35 and 1.34 g/cc after first growing season. Water holding capacity was maximum in autumn season (60.15%) and minimum in spring season (55.33%) after first growing season. The maximum water holding capacity was found in A_1 (60.57%) and H_3 hydrogel level (62.91%). The reason may be the better expression of the growth parameters of plants under these treatments found to enhance water holding capacity. The microbial decomposition may also found to be responsible in increasing pH of the soil on plantation site. The value of electrical conductivity was found higher in A_1 (0.21 dsm^{-1}) and lower in A_2 (0.19 dsm^{-1}) in autumn season. In spring season, the electrical conductivity remained same for A_1 and A_2 (0.20 dsm^{-1}). Similar findings were reported by Nasim *et al.* (2007) under *Eucalyptus camaldulensis* plantations. The organic carbon was found to increase in both the planting seasons from their initial values. The organic carbon was higher in autumn season (1.87%) and lower in spring season (1.84%). The two years old planting stock A_2 (1.95%) and hydrogel level H_3 (2.03%) recorded higher value of organic carbon. The higher growth of plants under these treatments may lead to increase in microbial activity under soil and hence increase the organic carbon of soil. Similar results were reported by Gan *et al.* (2004). The availability of nitrogen, phosphorous and potassium showed a decreasing trend in both the planting seasons from their initial value. The reason may be absorption of nutrients by plantations. These results are in agreement with the findings of Brown and Driessche (2005) that decrease in soil nutrients after first growing season under degraded sites was due to absorption by plantations. The available nitrogen, phosphorous and potassium was observed to be more under one year old planting stock (A_1) and hydrogel level (H_0) in both the planting seasons. The reason might be that one year old planting stock required less nutrients as compared to two years old planting stock which resulted in their abundant availability in soil. These results are in agreement with the findings of Paul *et al.* (2000) that one year old planting stock absorb less nutrients as compared to two years old planting stock in *Eucalyptus camaldulensis* plantations. The hydrogel level H_0 (0 g/plant) may not hold as much water in the soil and decreased nutrient absorption in turn while compared with other hydrogel levels.

The factor means analysis revealed that the highest bulk density was observed in planting stock (A_1) and hydrogel level (H_0). The microbial activity is low under these treatments which thought to result in poor decomposition and results in increase in density of soils. Similar results were reported by Viero *et al.* (2000) in *Eucalyptus grandis* × *camaldulensis* clones. The maximum water holding capacity was found in planting stock A_1 (61.21%) and hydrogel level H_3

(66.17%). The reason for this may be the increase in organic carbon which enhances the water holding capacity of soils under plantations. Similar results were reported by Quirk and Schofield (1995) that the age of planting stock and hydrogel concentrations effected the soil water absorption. The values of available nitrogen, phosphorous and potassium were highest in A_1 (one year old planting stock) and under H_0 (0 g/plant). The reason may be low absorption of nutrients in one year old planting stock as compared to two years old planting stock. Similarly, absorption of moisture and nutrients was negligible in H_0 when compared with other tested hydrogel levels.

5.4 Relative economics of plantations

Economic evaluation is one of the most important parts of forest planning for considering which pattern of afforestation will be used. Results from calculation of outplanting operations, tending, timber production and other miscellaneous costs show that the plantation of poplar on problematic sites is a profitable venture when managed on scientific lines. The data pertaining to relative economics of plantation operations are presented in Tables 23 and 24. The actual data for cost and benefit were obtained for one growing season and expected data was calculated after consulting economists and timber traders to obtain total benefits for eight years rotation cycle. Profitability analysis of plantation was carried out to calculate economics of *Populus deltoides* on problematic sites. The total plantation area was 0.25 hectare. Average cost of plantation was found to be Rs. 1,10,361.00 for 8 years. This includes total variable cost (labor, transport, mulching, hydrogel, fertilizer, etc) and total fixed cost (land rent and depreciation of implements). Maximum expenditure of Rs. 30,000.00 (30.90%) was incurred upon planting material. Planting operations and transport cost claimed Rs. 20,000.00 (20.60%), labor cost and felling of branch wood and timber Rs. 38,000.00 (39.14%), fertilizers and mulching materials Rs. 5000.00 (5.15%). Minimum amount was incurred on purchase and maintenance of miscellaneous expenditures and were Rs. 4086.00 (4.20%).Similar results were reported by Anjum *et al* (2013) for raising the Kamalia irrigated plantations, Pakistan. The gross return after a rotation of eight years was Rs. 9,32,300.00. This was estimated by taking thinning, lopping and clear cutting of trees at the end of rotation age. Maximum income i.e. Rs. 7,90,000.00 (96.11%) would be generated by timber in 8 years rotation cycle. Fuelwood and branch wood contributed Rs. 31,939.00 (3.89%). Maximum income obtained from timber is due to the reason that the plantation was basically managed for timber production of high quality. These results agree to the findings of Sathish *et al.* (2007) where they found that maximum income in coffee based Agroforestry system was contributed by timber. Net return (GR-TC) of the plantation was calculated and found to be Rs 8,21,939.00. Return over variable cost (GR-TVC) and return over fixed cost (GR-TFC) were also calculated which would be found of Rs 8,35,214.00 and Rs 9,19,025.00 respectively. Net Present Value of total cost (@ 10%) and Net Present Value of return (@ 10%) was estimated and found to be Rs 72,071.54 and Rs 4,37,488.88. The amount was calculated by predicting the value of rupee after eight years. Net Present Worth of plantation was Rs 3,65,417.3. The estimated benefit cost ratio of *Populus deltoides* plantations done on problematic site might be Rs 6.07. Similar results were recorded by Salek and Sloup (2012) where they reported that benefit cost ratio of pure stands increases with increase in rotation age.

Chapter – 6

SUMMARY AND CONCLUSION

The present investigation entitled "Plantation Techniques of *Populus deltoides* Bartr. for Problematic Sites in Temperate Region of North Western Himalayas" was conducted at Faculty of forestry, Sher-e-Kashmir University of Agricultural Sciences and Technology of Kashmir, Benihama, Watlar, Ganderbal, Jammu and Kashmir. The basic purpose of this study was to standardize the out planting techniques with intervals including Pit type and size in problematic sites existing in temperate region particularly in Kashmir province. Identification of best physiological attributes of out planting stock for getting better establishment and growth. In addition to this, the present investigation was also focused to elucidate the effect of nitrogen fertilizer along with the exploring of suitable moisture conservation measures for problematic sites. Experiments were laid out in Randomized Block Design (factorial) with two replications. The salient features of the investigation are summarized here as below:

- The experiment on effect of planting season, interval and nitrogen fertilizer levels on establishment & growth of *Populus deltoides* included two planting seasons: autumn planting (S_1) and spring planting (S_2), three planting intervals, planting interval I (PI_1), planting interval II (PI_2) and planting interval III (PI_3) and four nitrogen levels, control (N_0), 100 kg/hectare (N_1), 150 kg/hectare (N_2) and 200 kg/hectare (N_3). Among the two seasons, autumn planting (S_1) was found as best compared to spring planting (S_2). Out of three planting intervals, planting interval I (PI_1) was observed better followed by planting interval II (PI_2) and planting interval III (PI_3), respectively. It was also recorded that growth and survival of seedlings increased with increasing nitrogen levels upto certain limit and then decreases. The nitrogen level N_2 (150 kg/hectare) was found better compared to other three nitrogen levels. The treatment combination $S_1PI_1N_2$ (autumn [planting × planting interval I × 150 kg nitrogen/hectare) recorded highest survival and growth over the rest of treatment combinations.

- The experiment on effect of planting season, pit shape, size and moisture conservation measures on establishment & growth of *Populus deltoides* included two planting seasons: autumn planting (S_1) and spring planting (S_2), three pit types, ordinary pit (PT_1), saucer pit (PT_2) and ring pit (PT_3), three pit sizes, 30×45 cm^3 (PS_1), 45×60 cm^3 (PS_2) and 60×60 cm^3 (PS_3) and three mulching treatments, control (M_0), ordinary mulch (M_1) and black polythene (M_2). Autumn planting season (S_1) was observed to be best. Among the three pit types, PT_2 (saucer pit) recorded highest survival and growth. It was also found that among three pit sizes, PS_3 (60×60 cm^3) recorded higher survival and growth of seedlings compared to PS_1 (30×45 cm^3) and PS_2 (45×60 cm^3). Black Polythene Mulch (M_2) gave higher survival and growth over the rest of the moisture conservation treatments. The treatment combination $S_1M_2PT_2PS_3$ (autumn planting × black polythene mulch × pit type II × pit size III) recorded highest survival and growth. The moisture regime of soil was measured under different moisture conservation measures. Moisture percentage under black polythene was more as compared to ordinary mulch (paddy grass) and control. Saucer pit gave highest percentage of moisture which was further followed by ring pit and ordinary pit. The highest moisture was found under 60×60 cm^3, followed by 45×60 cm^3 and 30×30 cm^3 in both the planting seasons.

- The experiment on effect of planting season, age of planting stock and hydrogel on establishment & growth of *Populus deltoides* included two planting seasons, autumn planting (S_1) and spring planting (S_2), two planting stocks, 1 year old (PS_1) and 2 year old (PS_2) and five hydrogel levels, control (H_0), solid application 3.0 g/plant (H_1), 1.5 g/plant Liquid application (H_2), 3.0 g/plant liquid application (H_3) and 4.5 g/plant liquid application (H_4). Autumn planting was observed to be best. Among the two planting stocks studied, PS_2 (2 year old) was found better compared to PS_1 (1 year old). It was also recorded that among five levels of hydrogel, H_3 (3.0 g/plant liquid application) was found better compared to other four hydrogel levels applied. The interactional treatment combination $S_1PS_2H_3$ (autumn planting × planting stock II × hydrogel level 3 g/plant) recorded highest survival and growth in *Populus deltoides*.

- The effect of different treatments on soil was also recorded under poplar plantations on problematic sites. The soil physico-chemical parameters were found to vary with different treatments under temperate conditions. The economic valuation of poplar plantations done on problematic site in temperate conditions is of beneficial venture as per the outcomes of the investigations. The B/C ratio was calculated by taking the 8 years rotation age of the poplar plantation and it was worked out to be 6.07.

CONCLUSIONS

- Autumn Planting is found to be best over spring planting with respect to plantation survival and growth of *Populus deltoides* on problematic site in temperate region.
- The planting interval (15^{th}-30^{th} Nov.) in autumn planting and (16^{th}-28^{th} Feb.) in spring planting is found to be best in both the seasons. This is the first interval in both the planting seasons.
- Nitrogen fertilizer in the form of urea applied at four levels and N_2 outperformed over the rest of the levels including control with respect to the poplar plantations.
- PT_2 (Saucer Pit) plantation is ideal for establishment and growth of poplar as compared to other types pits on problematic site.

- PS_3 (60×60 cm^3) gave better survival and growth of poplar on problematic sites as compared to the other tested pit sizes.
- Black Polythene mulch (M_2) performed better than ordinary mulch (paddy straw) for survival and growth including moisture regimes under poplar plantations.
- Moisture percentage under black polythene was found highest as compared to ordinary mulch and control in both the planting seasons.
- Among the three pit types saucer pit was recorded with highest percentage of moisture which was further followed by ring pit and ordinary pit in both the planting.
- The highest moisture was observed under 60×60 cm^3 followed by 45×60 cm^3 and 30×30 cm^3 in both the planting seasons.
- Age of planting stock significantly effected the survival and growth of poplar plantations on problematic site. The study advocates that two years old planting stock was found better over the first year old planting stock with respect to the success of the plantation program.
- Hydrogel application @ 3.0 g/plant in liquid form gave better survival and growth of out-planted seedlings than the other hydrogel concentrations like 3.0 g/plant (solid form), 1.5 g/plant (liquid form) and 4.5 g/plant (liquid form).
- The initial trend of physico-chemical properties of soil did not vary much but the availability of the nutrients showed somewhat declining trend.
- The study advocates that the plantation on problematic site is profitable venture as shown by the B/C ratio calculated by taking the 8 years rotation age of the poplar plantation on problematic site and it is worked out to be 6.07.

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Appendix-1

Average weather conditions of the plantation site for the year 2013-2014

Weather parameters	**Nov. (2013)**	**Dec. (2013)**	**Jan. (2014)**	**Feb. (2014)**	**Mar. (2014)**	**Apr. (2014)**	**May (2014)**	**Jun. (2014)**	**Jul. (2014)**	**Aug. (2014)**	**Sept. (2014)**	**Oct. (2014)**
Temperature (^{o}C)	19.5	11.6	-1	8.8	16.8	18.5	25.4	27.9	32.5	31.5	28.6	21.4
Rainfall (mm)	217.5	281.8	460.5	481.6	462.8	367.9	485.6	230.7	230.5	210.5	205	198.8
Relative humidity (%)	37.1	39.7	67.8	67	65.4	38.8	43.5	34.5	36.9	39.8	45.8	42.5

Appendix-II

Effect of different mulching materials on moisture regimes of soils in poplar plantations done on problematic sites in autumn season

Pit types	Fortnightly intervals (1st January to 31st October)																			
	P1	P2	P3	P4	P5	P6	P7	P8	P9	P10	P11	P12	P13	P14	P15	P16	P17	P18	P19	P20
Ordinary pit	44.71333	44.71333	57.07667	63.43333	60.93333	45.38	37.4	38.66667	35.56	36.05	29.54	28.53667	27.65333	21.78667	20.53667	30.02	29.16	31.44	33.41333	31.44667
Ring pit	47.84667	47.84667	62.54	63.08667	65.35	47.71667	40.81667	41.3	36.18333	39.49	32.86333	31.34667	29.88	23.15667	21.81	29.96667	33.23667	35.26	38.83333	34.11333
Saucer pit	48.69	48.69	64.41333	71.81667	65.87667	51.04	44.83667	44.71667	41.73333	39.80667	37.17667	31.98667	34.29667	26.05	27.50333	39.38	34.98333	40.75	39.40333	38.7

Appendix-III

Effect of different pit shapes on moisture regimes of soils in poplar plantations done on problematic sites in autumn season

Pit types	**Fortnightly intervals (1st January to 31st October)**																			
	P1	**P2**	**P3**	**P4**	**P5**	**P6**	**P7**	**P8**	**P9**	**P10**	**P11**	**P12**	**P13**	**P14**	**P15**	**P16**	**P17**	**P18**	**P19**	**P20**
Ordinary pit	31.96333	44.34667	35.18333	43.33	41.23667	44.4	40.96333	43.09667	38.74667	25.73	25.73	24.10333	25.12333	21.47	18.98333	24.63667	22.62333	24.81	21.47	15.60667
Ring pit	41.76333	58.31333	53.46	51.88333	43.03333	46.98333	41.26333	45.32333	39.46	28.56333	26.66667	27.41	23.37333	24.16667	19.81333	26.66667	27.41	23.37333	24.16667	19.34667
Saucer pit	45.18333	62.44	49.83667	51.99	45.74	49.42667	47.34	46.02667	42.96667	29.79333	29.79333	29.39333	26.28667	27.45333	23.50667	28.95333	28.5	26.28667	27.45333	21.59

Appendix-IV

Effect of different pit sizes on moisture regimes of soils in poplar plantations done on problematic sites in autumn season

Pit sizes	Fortnightly intervals (1st January to 31st October)																			
	P1	P2	P3	P4	P5	P6	P7	P8	P9	P10	P11	P12	P13	P14	P15	P16	P17	P18	P19	P20
30×45 cm^3	67.06	60.07667	58.06667	55.55	54.6	35.97667	36.99	31.42	34.14	36.60667	25.73	24.10333	25.12333	21.47	18.98333	24.63667	22.62333	24.81	21.47	15.60667
45×60 cm^3	72.33	61.52	58.98333	60.36667	61.47333	35.75	40.01667	33.11667	36.91	38.26333	26.66667	27.41	23.37333	24.16667	19.81333	26.66667	27.41	23.37333	24.16667	19.34667
60×60 cm^3	80.04	61.35	65.19	61.91333	66.83	39.96333	40.58	39.05333	40.75333	39.20333	29.79333	29.39333	26.28667	27.45333	23.50667	28.95333	28.5	26.28667	27.45333	21.59

Appendix-V

Effect of different mulching materials on moisture regimes of soils in poplar plantations done on problematic sites in spring season

Mulching materials	Fortnightly intervals (1st April to 31st October)													
	P1	P2	P3	P4	P5	P6	P7	P8	P9	P10	P11	P12	P13	P14
Control	39.43	38.66667	35.56	36.05	29.54	29.67	27.65333	21.78667	20.53667	30.02	29.16	31.44	33.41333	31.44667
Ordinary mulch	40.81667	41.3	38.76	39.49	32.86333	31.34667	28.08	23.15667	24.45	29.96667	33.23667	35.26	35.47	34.11333
Black polythene	42.45	44.71667	41.73333	40.12	37.17667	31.98667	34.29667	26.05	27.50333	40.32	34.98333	40.75	39.40333	36.95

Appendix-VI

Effect of different pit shapes on moisture regimes of soils in poplar plantations done on problematic sites in spring season

Pit types	Fortnightly intervals (1st April to 31st October)													
	P1	**P2**	**P3**	**P4**	**P5**	**P6**	**P7**	**P8**	**P9**	**P10**	**P11**	**P12**	**P13**	**P14**
Ordinary pit	38.58	43.09667	38.74667	25.73	25.73	26.55	25.12333	21.47	18.98333	24.63667	22.62333	24.81	21.47	15.60667
Ring pit	41.26333	45.32333	40.55	28.56333	26.66667	27.41	23.37333	24.16667	19.81333	26.66667	27.41	23.37333	24.16667	19.34667
Saucer pit	45.46	45.35	42.96667	29.79333	29.79333	29.39333	26.28667	26.98	23.50667	28.95333	28.5	26.28667	27.45333	20.85

Appendix-VII

Effect of different pit sizes on moisture regimes of soils in poplar plantations done on problematic sites in spring season

Pit sizes	Fortnightly intervals (1st April to 31st October)													
	P1	**P2**	**P3**	**P4**	**P5**	**P6**	**P7**	**P8**	**P9**	**P10**	**P11**	**P12**	**P13**	**P14**
30×45 cm^3	38.75	31.42	34.14	36.60667	25.73	24.10333	25.12333	21.47	18.98333	24.63667	22.62333	24.81	21.47	15.60667
45×60 cm^3	40.01667	33.11667	36.91	38.26333	26.66667	27.41	23.37333	24.16667	19.81333	26.66667	27.41	23.37333	24.16667	19.34667
60×60 cm^3	40.58	39.05333	40.75333	39.20333	29.79333	30.85	26.28667	27.45333	23.50667	28.95333	28.5	26.28667	27.45333	18.55

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Certificate

Certified that all the corrections/amendments as suggested by External Examiner Prof. S.D. Bhardwaj, Former Dean, College of Forestry, Dr. Y.S. Parmar University of Horticulture & Forestry, Solan during Viva-Voce examination held on October 28, 2015 have been incorporated in the manuscript entitled **"Plantation Techniques of *Populus deltoides* Bartr. for Problematic Sites in Temperate Region of North Western Himalayas**" submitted by **Tahir Mushtaq (Regd. No. 2012-430-D).**

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