

**GENOTYPE AND SITE INTERACTION STUDIES
OF *Salix* CLONES IN PUNJAB**

Thesis

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

**MASTER OF SCIENCE
in
FORESTRY
(Minor Subject: Plant Breeding)**

By

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(L-2011-A-54-M)**

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CERTIFICATE I

This is to certify that the thesis entitled, “**Genotype and site interaction studies of *Salix* clones in Punjab**” submitted for the degree of M.Sc. in the subject of **Forestry** (Minor subject: **Plant Breeding**) of the Punjab Agricultural University, Ludhiana, is a bonafide research work carried out by **Kulwinder Singh (L-2011-A-54-M)** under my supervision and that no part of this thesis has been submitted for any other degree.

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

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CERTIFICATE II

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Abstract

The field trials were conducted during 2012-13 at three locations (environment 1: University Seed Farm, Ladhowal; environment 2: Badhian forest, Range and Division Dasuya and environment 3: Alamwala forest nursery, Range Malout, Division Faridkot) located in central plane zone, sub-mountain undulating zone and south-western zones of Punjab respectively. Twenty-two willow clones were planted in a randomized block design with three replications, to study the genotype and site interaction among different clones. The data for plant height and collar diameter was recorded at all the three locations and data for other parameters i.e., leaf parameters, leaf display, number of branches and insect/pest attack was recorded only at environment 1. All the characters under study at environment 1 exhibited significant differences among different clones. Differences among clones for plant height and collar diameter were significant under all three environments as well as after pooled analysis. On the basis of plant height and collar diameter, clone UHFS-13, UHFS-1 and UHFS-19 was best in environment 1, environment 2 and 3, respectively. Clone UHFS-1 and UHFS-19 showed wider adaptability. The values of genotypic variability for different traits were found between low to high and for phenotypic variability between moderate to high. Values of heritability and genetic gain were observed between low to high. On the basis of growth, number of branches leaf parameters and leaf display, clone UHFS-2, UHFS-5, UHFS-12 and UHFS-18 will be suitable for agroforestry, and clone UHFS-3, UHFS-13, UHFS-14 and UHFS-16 for biofuel or phytoremediation and Clone UHFS-10 for landscape purposes.

Keywords: Willow, Environment, Clone, Genotype and site interaction.

Signature of the Major Advisor

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Chapter I

INTRODUCTION

Crop diversification from rice-wheat rotation has attracted the attention of government and farmers of Punjab due to continuous decrease in ground water table and pollution of soil and water due to high use of agro-chemicals. To promote diversification, large emphasis is given on cultivation of maize, vegetables, flowers and short rotation tree based agroforestry. Agroforestry intercropping allows structural and functional diversification of agricultural systems through, different age structures and harvest rotation lengths. As the forest cover in Punjab is very low (6.87%) (Anonymous 2011) Government of Punjab has taken initiatives like “Green Punjab” mission to increase area under tree cover. Agroforestry besides increasing area under tree outside forest will also be of economic benefit for farmers. In Punjab main tree species used for agroforestry are *Populus*, *Eucalyptus* and *Melia*. But, an another species i.e., willow which is multipurpose, fast growing and has lots of potential in industry, phytoremediation and biomass production can be introduced for agroforestry under diverse climatic and edaphic conditions of Punjab.

Willows belong to the genus *Salix*, family Salicaceae, are light demanding, deciduous trees and shrubs, found primarily on moist soils in cold and temperate regions of the northern hemisphere. Number of species of willows have adapted to a wide range of climatic and soil conditions, from the heat of the Chinese desert to the cold, windy conditions of the South American Andes (Ball *et al* 2005). The word *Salix* is derived from classical word *sallies* (sal, "near," and lis, "water"). *Salix* is a diverse genus of about 450 species, which are classified into three groups, tree willows, shrub willows and alpine or arctic willows. There are about 32 willow species in India, of which four exotic willows namely *Salix alba*, *S. daphnoids*, *S. fragilis*, and *S. babylonica* and an indigenous willow, *S. tetrasperma* are categorized into tree willows.

Poplars and willows belong to same family *Salicaceae* and are used to be grown in mixtures with other natural forest species, in planted forests and as individual trees in the landscape (including agroforestry systems), in 70 countries. The Russian Federation, Canada and the United States have the largest reported areas of naturally occurring poplar and willows, while China, India and Pakistan have the largest planted areas. Most of the willows grow in natural forests and woodlands. The largest reported area of natural willow forests is in the Russian Federation, followed by France, China, Italy and Croatia. Willows in mixed stands, are also found in other countries like

Canada, Chile (Ball *et al* 2005). In India 137,300 ha area is reported as pure willow area, *Salix fragilis* is the most common willow species grown in the north-western Himalayas (Anonymous 2012). The global area under natural willow forests is around 3,019,000 ha, and under planted willows is 176 000 ha, from planted willow 90 000 ha has been for wood production (51%) and the remaining for environmental purposes. Few countries have established willows in agroforestry systems, except for New Zealand, whose willows were planted for river bank stabilization. In Argentina and Sweden the entire willow plantation area is for production purposes. China has the second largest area of willow planted for production (21 000 ha) and (59 000 ha) to check desertification (Ball *et al* 2005).

The wood is soft, white and light red and even-grained. Willows provide a wide range of wood products (including industrial roundwood and poles, pulp and paper, reconstituted boards, plywood, veneer, sawn timber, packing crates, pallets and furniture), non-wood products (fodder, fuelwood) and services (shelter, shade and protection of soil, water, crops, livestock and dwellings). Willows have an important role in phytoremediation (i.e. taking up heavy metals to purify polluted soils) of degraded sites, rehabilitation of fragile ecosystems (including combating desertification) and forest landscape restoration. They are often integrated with agriculture, horticulture, viticulture and apiculture. Due to their rapid growth they are effective for carbon sequestration. They provide employment opportunities, boost exports and contribute to social and economic development and sustainable livelihoods in rural areas. Willows in agroforestry systems are receiving rising attention in the United States, United Kingdom and New Zealand. In the United Kingdom, policies to encourage renewable energy by the electricity generating and supply industry have boosted the market for woodchips from short rotation coppice, which is currently dominated by willow.

It has a much wider distribution than poplars as it appears in temperate and semi-tropical climates of both the northern and southern hemispheres - generally in moist situations. Willow are well suited for establishment of special purpose plantations like biological control of soil erosion, nutrient cycling, phytoremediation, carbon sequestration and filtering of sewage and polluted water as it is able to grow over marshy, swampy, compacted acidic and saline soils provided the roots have sufficient moisture content (Verwijst 2001). Most species of willows are found on wet sites and on swamps, easy to establish from cuttings, need no fertilizer inputs and are relatively

fast growing when young and build fertility in poor and depleted soils. Another advantage over poplar cultivation is that it can be successfully cultivated in agroforestry systems with rice-wheat rotation, where the smaller leaf surface of willow allows sufficient light penetration to the crop without affecting crop yield and are able to withstand standing water in comparison to other woody species (Saini and Sharma 2001). Willow is one of the fast growing tree plants with capacity to yield 40-60 MT of wood/ha/yr when grown as short rotation crop. Willow is frequently regarded as a front-runner in the search for commercially viable perennial energy crops as it can cope with a range of soils and climatic conditions and have a long productive life of around 15–20 years in European countries (Weih 2009). But in Punjab, it can be harvested at short rotation. As the power stations using crop wastages and shrubs as a raw material to produce electricity, wood chips from willows can also acts as a new source of fuel for these thermal plants.

In Punjab agroforestry is presently dominated by poplars, eucalyptus and Melia. Plantations in Jammu and Kashmir regions were initiated to support the sports industry of Punjab at Jalandhar like cricket bat, polo balls etc.. But due to restrictions on the supply of willow wood from Jammu and Kashmir, the industry in Punjab, Delhi, and Uttar Pradesh is facing great shortage of raw material. So the introduction of willows in Punjab is also necessitated to increase the supply of raw material for sports industry. According to systematic survey of groundwater conducted by Punjab Remote Sensing Centre, 42.7 per cent area of Punjab has poor water quality (Anonymous 2010) and the willow based agroforestry can mitigate ground water related problems and address to water logging. In Punjab commercial cultivation of willow for productive uses is not known but it is present on the canal sides to control soil erosion and to maintain bunds. In 2008 -09, twenty clones collected from different parts of north India were evaluated for their morphological and physiological parameters at nursery stage in Punjab Agricultural University (Arun 2009) and ten good performing clones were selected and planted in the field for further evaluation.

The introduction of unsuitable and less productive species genotype may result into the failure of adoption by the farmers. So, before introduction of the species, the evaluation of different species/clones for adaptability and growth performance at field level under different site conditions in Punjab is essentially required. Phenotype of the plant is an outcome of an interaction between genetic as well as environmental factors. Due to genotype - environment interactions a specific genotype may give different phenotypic expressions under different

environments or different genotypes can express themselves differently under a specific environment. The genotypes with low genotype - environment interaction show stable performance over a wide range of environments, whereas genotype with high genotype - environment interactions are adapted to specific environment only. So, the identification of genotypes with relatively stable performance under different environmental conditions or a genotype for a specific environment is the main objectives of any breeding program. It is necessary to determine the stability of the response and determining the behavior of the clones in different areas selected for cultivation. It is essential to evaluate the importance and consequences of genotype-site interaction in developing breeding programmes, so that appropriate decisions can be made about testing, development and selection strategies. In addition, determining the behaviour of the clones in terms of growth and yield, it is important to assess the stability of the clones in relation to different traits in different environments.

The aim of this study was to evaluate the differences in the growth of different willow clones at an early stage at different sites, to identify the clones which display adaptive advantages in terms of both growth and response stability during the crop establishment phase. Present investigations comprising 22 different clones of *Salix* was conducted at three different sites with the following objectives:

- a. To identify the site specific clones based on their growth performance.
- b. To study the genotype and site interaction of introduced clones at different locations in Punjab.

Chapter II

REVIEW OF LITERATURE

Review of literature provides basis for preparing the research proposal and conceptualization of different ideas given by different researchers. A number of research studies have been undertaken on different aspects of willow in temperate countries, but in India very little work has been done on *Salix*. There are no published reports on the genotype and site interaction of *Salix spp.* in India. The relevant literature pertaining to different aspects of present study have been reviewed here under following two sub headings:

2.1 Growth performance

2.2 Genotype and site interactions

2.1 Growth performance

Three willow clones (*Salix dasyclados* SV1, *Salix miyabeana* SX67 and *Salix purpurea* 9882-41) were established in a field setup to compare the growth and yield of short rotation willow in an agroforestry intercropping system (consisted of 20-year-old mixed tree species) and in a conventional single variety plot system. After analyzing the data (2006-07) yields were found significantly higher in the agroforestry fields during both years of the study, with 0.8 and 0.5 odt(oven dry ton)/ha for the agroforestry and control fields respectively, in 2006, and 3.0 and 1.1 odt/ha respectively, in 2007. Results also showed that soil moisture was positively correlated with willow yield and negatively correlated with soil temperature. No significant competition for soil moisture or nitrogen was found in first two years of growth in agroforestry system (Clinch *et al* 2009).

Six genotypes of willow were planted on sites that were unsuitable for field crops in Poland to study the biomass yield and morphological traits of plants. Results of the study showed that willow biomass yield of oven-dry matter was 7.87 Mg/ha/yr, and after four years plants reached a height of 6.64 m and a diameter of 50.5 mm. The willow biomass yield obtained on peaty muck soil was significantly higher than from willow that was grown on heavy textured silt soil (Stolarski *et al* 2011). Research conducted by Christersson *et al* (1993) showed that one year rotation of willow without irrigation give yield of 8.4–11.6 odt/ha/yr in central New York, whereas, under fertilized and irrigated conditions yield was 27 odt/ha/yr in North America and 30 odt/ha/yr in Europe after three year rotation. A study on willows life cycle analysis showed that the amount of CO₂ released during the production and conversion of willow biomass into electrical energy is equal to the taken up by the growing crop (Heller *et al* 2003).

Fast growth and frost hardiness make poplars (*Populus spp.*) and willows (*Salix spp.*) suitable for intensive forestry on fertile land in temperate and boreal climates (Weih 2004).To

facilitate the choice of appropriate plant material for a given plantation site and purpose, the available plant material should be characterized in terms of biomass production under a common environmental conditions (Isebrands and Karnosky 2001). Hathaway and Kraayenoord (1979) conducted an experiment on hybrid willows in New Zealand and reported that the best clones of hybrids between *Salix matsudana* × *Salix alba* produced a dry matter of 22.6t/ha at the end of two year rotation period, whereas, Stott (1984) reported that annual dry wood production of 15, 16-22 and 10-20 t/ha from willow plantations in England, Sweden and Canada, respectively. Weih and Nordh (2002) characterized fourteen willow clones in terms of growth, nitrogen and water-use efficiency under different irrigation and fertilization treatments. Significant differences between clones were found in nearly all parameters measured and the clones varied in the response to the experimental treatments. Further, it was emphasized that the growth-physiological characterization of young willows in the short term (several months) can be regarded as a suitable approach for pre-selection for promising clones prior to extensive field evaluation.

Twenty clones were introduced in Punjab for evaluation on the basis of various growth, biomass, physiological and wood traits at nursery stage (Arun 2009). Significant differences were found among the clones for all traits under study. Results also showed that the correlation between growth and biomass traits was highly positive and significant. On the basis of performance ten clones were selected for field trials and all the plants survived in field and showed excellent growth. Similar large amount of inter-specific and inter-clonal variation for growth and wood characteristics have been studied in short rotation energy plantations of *Salix* by Ager *et al* (1986).

To compare the growth, insect and disease resistance of twelve clones of fast growing trees (willow and poplar), plantation was established in 1999 under short-rotation intensive culture (SRIC) on an abandoned farmland in southern Quebec. The plantation was established at a density of 18,000 trees per hectare from stem cuttings and no fertilizer and irrigation were applied. Regular analysis of the trees performance for four growing seasons showed statistically significant differences between the clones. Poplar clones registered the highest aboveground biomass yield after 4 growing seasons (from 66.48 to 72.20 ton dry matter (tDM)/ha). The best willow biomass productivity was obtained from clones SX64 (67.58 tDM/ha) and clone SX61 (62.34 tDM/ha). The results proved that some clones of *S. miyabeana* and *S. sachalinensis* were more productive and more resistant to insect and disease damage than *S. viminalis* (Labrecque and Teodorescu, 2005).

The existence of genotypic differences among white willow populations offer good opportunities for improvement through clonal screening and inter-provenance crosses in terms of

rate of growth, straightness of trunk, length of growing season, rooting capacity, morphological leaf characteristics, seed production and branching (Kristinic 1979). It indicates that there are genotypic variations among the white willow population in Yugoslavian territory as a result of development of local races. Short-rotation coppice *Salix* genotypes of differing biomass yields were studied over two growing seasons with the long-term aim of identifying traits definitive of high yield for the breeding of elite energy crops by Robinson *et al* (2004). Increase in the maximum stem heights and stem diameters with biomass yield was observed in the study. The results of the study also suggest that leaf extension rate, final leaf size and cell number per leaf may be indicative of yield, and may be useful as selection criteria for potentially high-yielding hybrids for biomass use.

One year old cuttings from sixteen clones of seven willow species were studied for successive years by Kueizone *et al* (1983) to evaluate plant type variability. The weights of leaves, branches and stems at different heights of the trunk were taken as plant type variables. Twenty morphological and growth characters were chosen by means of variance analysis. Result of the study shows that the high yielding plants should have rapid increment in trunk biomass, stem should be cylindrical and its crown should be narrow and dense. Number of morphological and physiological characters like plant height, leaf area, total leaf areas of individual plant, length of branch, dry weight of stem, net photosynthetic rate and dry matter productivity of each plant, etc. were measured from annual cuttings of twenty clones of ten willow species (Tu and Pan 1984). Result show that there were large genetic variations for photosynthetic characteristics among species and clones. Correlation between the total leaf areas and plant height was greatest, so this is an important factor for breeding strategies to increase timber production.

Cuttings of eight willow clones were planted on an abandoned farmland near Sendai (Japan) in March 2006 to select willow (*Salix* spp.) clones with a high potential for use as biomass energy crops. Clones grew throughout the year and were cut back in late December 2006 to re-sprout from the remaining stools in March 2007. The biomass yield in December 2007, after the first growing season, was highest in clone KKD, followed by clone FXM and clone SEN. The average annual yield of dry mass for top four clones after the second growing season was 3.09, 2.58, 2.17 and 1.85 kg DM(dry matter)/plant. Plant growth form differed among the clones. Clones FXM and SEN had several shoots of almost uniform base diameter, whereas clones KKD and HB471 showed plagiotropic growth with one thick and several thin shoots. The calorific values of dried stem segments were similar among clones, ranging from 18.7 - 19.1 kJ/g (Mitsui *et al* 2010).

Thirty-seven different native and exotic willow varieties were grown under controlled environment conditions on soils of varying salinity to check the relative tolerance of varieties (Hangs *et al* 2011). Most willow varieties tested in this study were able to tolerate moderately saline conditions ($EC \leq 5.0$ dS/m). There were also some varieties which could tolerate severe salinity ($EC \leq 58.0$ dS/m). These results indicate that some willow varieties are quite salt tolerant and suitable for establishment on salt-affected soils. Eight *Salix viminalis* cultivars and one *Salix alba* cultivar were analyzed to determine selected *Salix* clones' capacities for biomass production and accumulation of heavy metal ions. The results have revealed significant differences among clones. *S. alba* var. *chermesina* and *S. viminalis* '1056' had the greatest biomass production i.e. 6.8 and 4.3 kg of fresh mass per shrub per year, respectively. The clones most effective in accumulating all five heavy bio-metals were *S. viminalis* '1154' and '1054' (Mleczek *et al* 2010).

Forty families of *Salix viminalis* were grown in contrasting environment to study the genetic variation in number of sylleptic shoots, wood density, dry matter content, flower production, bud break, growth cessation, insect susceptibility and rust susceptibility and the relationships of these characters with other growth characters. No genotype-environment interaction was measured between sites. Negative correlation between insect susceptibility on both the sites and for rust susceptibility on sandy environment was observed. The highest negative correlation between number of days to sprouting of leaves and weight was also recorded (Ronnberg-Wastjung and Gulberg 1999). The existence of genetic variation for dry matter production has also been proved in studies conducted by Vihera-Aarnio (1988) and Gullberg (1989).

Nine month old fifty-one progenies of *Melia azedarach* from Punjab, Haryana and Uttaranchal was observed for height and diameter growth. Results of analysis of variance for height, diameter at breast height, collar diameter, crown diameter and clear bole height were found to be highly significant at 1% level of probability. Phenotypic and genotypic coefficient of variation indicated that height and diameter traits can be relied upon early selection for tree improvement (Luna *et al* 2006). Twenty poplar clones (*Populus deltoides* Bartr.) were evaluated for the growth performance under semiarid conditions of Punjab at age of four years (Singh *et al* 2008). After data analysis, clones showed significant differences among themselves for diameter, plant height and volume. The phenotypic and genotypic variations were highest for volume (36.51 and 24.64%, respectively) and the minimum for tree height (14.36 and 9.61%, respectively).

Biomass potential of poplar and willow plantations at different spacing was tested by Benea and Savulescu (2000) in the Danube Delta. Average annual yield of above ground biomass

of *Salix alba* ranged between 27.9 t/ha to 42.0 t/ha as compared to the *Populus* clones, which ranged from 16.3 t/ha to 32.3 t/ha. Results also showed that two year rotation is more favorable than one year rotation for both the species. To study the genetic structure of *Salix viminalis* for different growth traits and bud flush, two incomplete factorial crossings with parental clones originating from Poland and Sweden were used by Ronnberg-Wastjung (2001). Results showed that there were significant differences in the genetic makeup of clones from different origin for three of the nine traits. Bud flushes showed high additive genetic variance in contrast to the growth traits. Growth traits also showed a high amount of dominance genetic variance independent of parental origin.

Three *Salix* clones and four diameter classes were evaluated for growth and survival under Tarai conditions of Pantnagar in a nursery experiment. Maximum collar diameters (2.07 cm and 2.18 cm) were recorded in S1 clone and D4 diameter class, respectively. Similarly maximum heights (258 cm and 233 cm) were observed in S3 clone and D4 diameter class, respectively. Plant height, collar diameter and survival were also higher at Pantnagar as compared to Srinagar source (Saini *et al* 2002). To compare the growth performance and nutrient movements, two species of willow, *Salix discolor* and *S. viminalis*, were grown over two abandoned farmlands under different edaphic condition (sandy and clay sites) by using fertilizers and sludge wastewater as treatments (Labrecque and Teodorescu 2003). After three years, height, diameter and aboveground biomass was greater for *S. viminalis* than for *S. discolor* on all fertilized plots. The best growth performance of two willow species was obtained on the clay site. The application of wastewater sludge was not enough to satisfy all nutritional requirements of willows for the period of growth.

Variation in eleven morphological traits among thirty willow clones at the end of a 3-year rotation was analyzed to determine its relationship to biomass production (Tharakan *et al* 2005). Significant differences ($p = 0.001$) were found among the thirty clones in all traits. Data analysis revealed that high-yielding clones could be separated into two distinct "functional types" characterized by alternate growth strategies. One set of clones was characterized by a large number of small diameter stems, relatively low leaf area index and specific leaf area, but high foliar nitrogen and wood specific gravity. The other was characterized by a small number of large diameter stems, high leaf area index and specific leaf area, but low foliar nitrogen and wood specific gravity. These results suggest that multiple ideotypes need to be incorporated into willow breeding and selection efforts and in the management of willow biomass crops.

Twenty four clones of teak (*Tectona grandis*) derived from three provenances were studied in a 19 year old Clonal Seed Orchard (CSO) in Karnataka for vegetative phenology

(Rajesh and Vasudeva, 2003). Statistically significant differences were found among clones for three vegetative phenophases *viz.* leaf flushing, leaf shedding initiation and duration of leaf expansion. Strong influence of provenance was observed for time of leaf flushing and duration of leaf expansion. Clone derived from northern provenance of Karnataka initiated their leaves late in the season, however, possesses lesser duration of leaf expansion compared to those from central and Southern provenance which initiate leaf flush early. This concludes that the duration of leaf lessness did not significantly vary among the clones.

Growth and water-use parameters of four willow clones grown in a moderate drought regime and with ample water supply were determined to characterize their water-use efficiency (WUE), drought resistance and capacity for drought acclimation. After data analysis at the end of the 10-week, outdoor pot experiment, clonal differences were observed in water-use efficiency of aboveground biomass production, resistance to xylem cavitation, stomatal conductance to leaf-specific and whole-plant hydraulic conductance ratio. Across clones and regimes, WUE was positively correlated with the assimilation rate to stomatal conductance ratio. Both of these water-use efficiency indicators were generally higher in drought-treated trees compared with well-watered trees. It is concluded that WUE and drought resistance traits are inter-linked and that both may be enhanced by selection and breeding (Wikberg and Ogren 2007).

In a project related to phytoremediation of soil two approaches were conducted on the site of a former oil refinery in the Montreal region, Quebec, Canada (Guidi *et al* 2012). The first approach was conceived as remedy to a deep, polluted plume contaminated mainly by organics, in the sector called EDC-VCM. The second dealt with decontamination of shallow soil (GERLED) polluted by a mixture of organics and heavy metals. Project failed in the first approach due to high mortality during establishment phase. But at the second site results were significant in terms of growth and survival and soil under willow plants showed a significantly lower concentration of both organic and heavy metal contaminants. It represents a very positive and encouraging result after a single growing season.

Eighty-eight hybrid poplar clones obtained from the intraspecific and interspecific crosses of eastern cottonwood and black poplar and two control clones “I-214” and “Samsun” were tested at Izmit nursery in Turkey. Genetic variation on growth trends and some morphological characteristics was taken into consideration for preliminary selection of the best clones at nursery stage. Significant clonal differences were observed regarding height, diameter, volume index and survival rate. Ten intraspecific crosses had significantly better growth performances than control clones “Samsun” and “I-214” based on volume index values, but most of the clones showed poor survival rates in comparing control clones (Ozal *et al* 2010).

2.2 Genotype and site interactions

According to Sprague (1966) genotype-environment interactions constitute an important limiting factor in the estimation of variance components and in the efficiency of the selection programmes. There is large number of factors, which contributes these interactions and under field conditions it is almost impossible to control these environmental factors. Genotype of plant is affected by two types of environments i.e. macro-environment and micro-environment. Comstock and Moll (1963) defined the micro-environment as the environment in the close periphery of a single organism as opposed to that of another growing at the same time and in almost the same place. This includes the type of soil in which the plant grows, temperature, humidity, distribution and quality of solar radiations, insect and pathogens to which the plant is exposed. Macro-environment is the environment, which remains stable over a large area for a long period like weather and climate of that area. Allard and Bradshaw (1964) classified the environmental variation into predictable and unpredictable types. Predictable variation are those which we can predict well in advance, such as climate, soil type, day length, planting dates, sowing density, methods of harvest and other agronomic practices. Unpredictable variations are those which we cannot predict in advance like fluctuations in weather, such as amount and distribution of rainfall and temperature.

A major concern now becoming generally recognized is, how the best species, sources or even the best individual genetic selections that have been obtained will perform, when grown in different environments (Squillance 1970, Matheson 1974 and Zobel and Kellison 1978) or how stable a given genotype is when grown in quite different environments (Hanson 1970). Phenotypic plasticity is understood as the ability of a genotype to produce different phenotypes in response to differences in environmental conditions (West-Eberhard 2003). Sultan (1995) distinguished between passive or inevitable plasticity, observable through describing the morphological and/or physiological changes, as opposed to adaptive phenotypic plasticity, which has potential for adaptive value of these changes.

Smaller clone-site trials, ranging in size from 0.5 to 1.0 ha, were established in ten states in southern Quebec. At each site, six and thirty-two different clones of willow were planted on ten sites to study their suitability to different soils and climate conditions. These trials indicated that shrub willow could be developed across a wide geographical area. Results showed that several of the clones tested were plastic in nature, and they grow well across a range of sites, while other clones were more site-specific (Kiernan *et al* 2003). Growth and nutrition of twenty clones representing different species and interspecific hybrids of willows growing on an abandoned field were studied by vihera-Aarnio and Saarsalimi (1994). Difference among the

clones was highly significant for the survival, number of sprouts/stool, sprout mean height and diameter and stem biomass production/stool.

The relationship between important seven characters for biomass production like basal area diameter, stem numbers, number of branches, height, wood moisture content, heritability and specific gravity was examined using twenty clones at two sites in eastern Ontario, Canada . Significant clonal variation was observed for all traits except stem height and biomass. Clone-site interaction was also non-significant for all the characters. Results showed that large genetic gain is possible in selection based on the clonal mean and individual ramets. No indirect selection, however, was found to be more efficient than direct selection for number of stems, wood moisture content and wood specific gravity (Lin and Zsuffa 1993). Forty families of *Salix viminalis* were planted in contrasting environments to estimate genetic additive, dominance, and epistatic variances and to estimate the impact of genotype-environment interaction. Height, diameter, weight, and number of shoots were measured. Results showed additive genetic variance for number of traits and standard deviation was large from expected data. Selection on the basis of soil and nutrient was recommended due to high genotype-environment interaction (Ronnberg-Wastljung *et al* 1994).

In a test of 32 clones of cottonwood at three locations affect of clone x environment interactions on height and diameter growth was quite significant, no such affect was found on specific gravity (Randall and Cooper 1973). Barnes *et al.* (1984) reported that in tropical pines examples of genotype-environment interaction are present at each level i.e. species, provenance, family and clone level. He also reported that genotype-environment interactions reduce heritability and hence genetic gains. Studies on genotype-site interactions with thirty-five clones of *Populus deltoides* and exotic poplars conducted at four different climatic sites of Himachal Pradesh revealed that the old clones of *P. deltoides* D 181, D 121, 3201, G 3 and *P. euramericana* 72/58 performed better in the outer shiwalik foot hills as well as in the mid-mountainous zone of outer Himalaya, with overall superior growth rate in height and diameter. Amongst the new clones, *P. deltoides* 3297, A 424 (1021) and A 74 (1016) showed better performance. Genotype-environment interaction component was found to be significant for height, diameter, internodal length, survival per cent and leaf area (Khurana *et al* 1992).

Gomes and Correia (1995) evaluated twenty *Eucalyptus globules* clones at different sites in Portugal. There were significant differences in growth traits like total height, clear bole height and diameter increment due to significant genotype-environment interactions. Provenance trial was conducted by Raymond *et al* (1997) on *Eucalyptus regnans* F. muell throughout its natural range at twelve sites by material collected from forty-nine provenances. Data was recorded for

diameter at breast height, stem straightness and branching quality at ages between 9 and 13 years on the nine surviving sites. Provenance variations were found at each site and genotype-environment interactions were also significant. Change in rank of provenances was observed for performance between sites and no single provenance or group of provenances were found to be among the best for all traits at all sites. Based on mean performance across all sites, the best provenances for diameter growth were Mirboo East and Gunyah from Gippsland, Victoria and Forester and Gould's Country from Tasmania.

To examine the genotype-environment interactions during the first two years of growth two interspecific hybrid pedigrees of *Populus trichocarpa* and *P. deltoides*, each containing parental, F1 and F2 generations, were planted in two completely different environments in Northern Oregon (Wu and Stettler 1997). Results showed that genotype-environment interactions were highly significant for all stem traits, which was equal to approximately 10 per cent of the total phenotypic variance. But, genotype-environment interactions were more for stem height and proportion as compared to basal area and volume growth. The whole leaf area response of cloned interspecific hybrid pedigree of *Populus trichocarpa* and *P. deltoides* was examined by Wu and Stettler (1998) at two completely contrasting environments. Strong variation in size and number of leaves as well as branches between sites indicated the significant genotype-environment interactions for these traits.

Eighteen promising clones after nursery screening of two-hundred clones were planted in March, 2006 at university main campus Nauni, Solan, Himachal Pradesh (Sharma *et al* 2011). The five years growth performance was evaluated and clone J-799 registered first rank for plant height, diameter at breast height and volume index. Bole straightness was recorded maximum in clone J-795. Heritability in broad sense was highest for bole straightness and genetic gain was highest of the volume index. Genotypic, phenotypic and environment coefficients of variations were recorded maximum for volume index character. Genetic correlation coefficient was highest between plant height and volume, while phenotypic correlation coefficient was highest between diameter at breast height and volume index. On the basis of five year growth performance, five clones namely J- 799, NZ-1140, 131/25, SI-63-007 and PN-731 are found suitable for lower and mid-hills of Himachal Pradesh. An experiment conducted by Khalil (1984) on poplar at two different locations showed little difference in the rank of classes of clones but large difference in the rank of individual clones for survival, it indicated the need for selection of individual clones rather than classes for best survival. Perennial plants often show a strong genetic variation in important phenological traits, representing regional adaptation to latitudinal changes in the growing-season length (Luquez *et al* 2008).

It has been suggested that the differences observed between sites and among the clones tested at a given site, may be related to the length of the vegetative period for each clone and at each site (Stanton 2001, Yu *et al* 2001). When genotype-environment interactions are strong, tree breeders must decide whether to select for stability of performance and accept a slower rate of improvement, or to develop populations specifically adapted to each environment in view to maximize gain (Namkoong *et al* 1988). Thirty-six plus tree progenies of neem were analysed by Dhillon *et al* (2003) for genetic variability, heritability, genetic advance and correlation coefficient for growth characters. Substantial variability was observed for all the traits under study. Heritability and genetic advance were moderately high for clear stem height, correlation of basal diameter with seedling height, clear stem height and number of branches were positive and highly significant. Similar results for high heritability accompanied by high genetic advance for several growth parameters have also been reported by Dhillon *et al* (1995) in *Dalbergia sissoo*, and Gera *et al* (2001) in *Tectona grandis*. Fifty-eight half-sib families of chirpine (*Pinus roxburghii*) were evaluated at the age of five years, with respect to some indirect traits (Sehgal and Chauhan, 1995). The heritability values were quite high for all the characters studied, indicting the early selection for greater improvement. Result also showed that genetic gain within family selection was higher than within progenies selection.

Fifty three clones were selected from natural willow populations occurring in the Black Sea, Marmara, Trace, Central Anatolia and South-east Anatolia regions to study growth performances and wood properties. Genetic characteristics of the willow clones and poplar clone (I-214) for different growth and wood characteristics were determined. The data obtained from the experiment for height and diameter showed significant differences at 0.001 confidence level. Some of the willow clones showed better growth performances than poplar clone, I-214. Selection of the willow clones to be used for further research studies was made (Tunctaner 2002). Stolarski *et al* (2008) observed huge variation in the performance of seven willow clones within and between the locations. Twenty one clones of seven *Salix* species along with two check clones (*S. tetrasperma* and *S. alba* cv. *Coerulea*) was evaluated for growth, wood and physiological characteristics in Solan, Himachal Pradesh. Variations between clones were very high for different traits and performance of seven clones was better than check clones.

Nine poplar clones were tested by Sixto *et al* (2011) for growth and production in the first year to be used as short rotation woody crops in the production of biomass for energy purposes. Multilocation trials were established to identify the most promising clones in terms of growth and yield and also to assess their stability. In any case, determining clonal stability in terms of growth is of great use not only when deciding on the clones to be used in plantations but also when

developing breeding programs. Differences were detected between clones as well as between the different environments tested. 'Monviso', 'Guardi', 'AF2' and '2000 verde' were the most productive clones, whereas 'Unal', 'Pegaso' and 'USA 49-177' were the least productive. The stability analysis identified 'AF2', 'Guardi', 'I-214' and 'MC' as more stable clones while 'Monviso', '2000 verde', 'Unal', 'Pegaso' and 'USA 49-177' were found to be specifically adapted to certain environments.

Genotype–environment interaction and phenotypic stability in *Gliricidia sepium* clones of fourteen provenances were investigated for dry matter leaf biomass yield across five diverse sites in the tropics (Indonesia and Nigeria) and subtropics (Australia, Malawi and Zambia). After analysis of data results showed that genotype–environment interaction is present and that some provenances were unstable across these diverse environments (Nyokaa *et al* 2012). Twenty-four aspen hybrid clones and one *Populus tremula* clone of three to four year age were investigated in four field trials for clonal repeatability, stability parameters and clone-site interactions for height and basal diameter. The ranking of clones changed across the sites, indicating significant site-clone interactions in height and diameter. Clone-site interactions were highly significant ($P < 0.001$) in the overall basal diameter in the overall analysis of variance (Yu and Pulkkinen, 2003).

Chapter III

MATERIALS AND METHODS

The present study entitled “Genotypes and site interaction studies on *Salix* clones in Punjab” was conducted in 2012-13 on clones established on three locations. Details about the collection of material, experimental sites, experimental procedures and methodology adopted are described in this chapter as follows:

3.1 Collection of clonal material

Twenty two clones were obtained from the University of Horticulture and Forestry Science, Solan. One year old nursery raised clones were planted at three locations, Environment 1 (University Seed Farm, Ladhawal, Ludhiana), Environment 2 (Badhian Forest, Range & Division Dasuya) and Environment 3 (Alamwala, Range - Malout, Division - Faridkot). These sites are located in the different agro-climatic zones of Punjab (lower shivaliks, central Punjab and south-western Punjab). Plantation was done at a spacing of 4m × 4m during the month of February, 2012.

3.2 Experimental sites

Detail about the location, edaphic and meteorological conditions of the three locations is given below:

3.2.1 Geographical information:

Environment 1 (University Seed Farm, Ladhawal, Ludhiana) is located in the central plane zone of Punjab. It lies at 30° 58' N latitude and 75° 45' E longitude, and 776 feet above sea level. Environment 2 (Badhian Forest, Range & Division Dasuya) is on the periphery of river Beas in the sub-mountain undulating zone of lower shivaliks of Punjab. It lies at 31° 52' N latitude and 75° 34' E longitude, and 787 feet above sea level. Environment 3 (Alamwala, Range-Malout, Division-Faridkot) is located in the south-western zone of Punjab. It lies at 30° 15' N latitude and 74° 25' E longitude, its elevation from sea level is 639 feet.

3.2.2 Climate:

Punjab state comes under subtropical climate. It experience severe summer during May-June and severe winter during Dec.-Jan.. The average annual rainfall ranges from 400-600mm, 600-800mm and 300-500mm in central plane zone, sub-mountain undulating zone and western zone of Punjab, respectively. Major portion of rainfall is received during monsoon (July-Sept.). Winter showers are mild. Meteorological data of Environment 1, Environment 2 and Environment 3 is given in Fig 1, Fig 2 and Fig 3, respectively.

3.2.3 Soil analysis:

In order to assess the edaphic status of experimental sites, samples were drawn and analysed from different depths (0-15, 15-30, 30-60 and 60-90cm) in all three locations. The details about the texture, pH and nutrient status of soil of Environment 1, Environment 2 and Environment 3 are given in the Table 1, Table 2 and Table 3, respectively.

3.3 Experimental design

The experiment was laid out in Randomized Block Design. The other details of the trial are as under:

Number of locations/environments	: 3
Total no. of clones	: 22
Experimental design	: Randomized Block Design
Spacing	: 4m × 4m
No. of replications	: 3
Plot size	: 1 plant

3.4 Observations recorded

Observations for plant height and collar diameter were recorded on all three locations, whereas other observations were recorded only at USF, Ladhawal (Environment 1).

3.4.1 Plant height (m)

The height of the main shoot was recorded from the ground level to the apex of the leading shoot by using measuring scale.

3.4.2 Collar diameter (cm)

Collar diameter of the plant was measured with the help of calliper at the collar region i.e. 5cm above the soil surface.

3.4.3 Number of branches per plant

For these primary branches of plants having diameter above 5 mm were recorded from each plant.

3.4.4 Days to complete leaf fall

The data was recorded from the date of leaf fall initiation to the date of complete leaf fall.

3.4.5 Days for complete leaf sprouting

The data was recorded from the date when buds started transforming into leaves to the date of full growth of leaves.

3.4.6 Leaf less days

Days were calculated from the date of completion of leaf fall to the date of leaf sprouting initiation.

Table 1: Physico-chemical properties of soil at USF, Ladowal (environment 1)

Depth (cm)	Texture	N (Kg/ha)	P (Kg/ha)	K (Kg/ha)	OC (%)	EC (mmhos/cm)	pH
0-15	Loamy sand	150.4	7.25	216.5	0.36	0.22	8.4
15-30	Loamy sand	145.6	7.50	214.0	0.35	0.22	8.3
30-60	Loamy sand	150.4	6.50	190.5	0.28	0.19	8.4
60-90	Loamy sand	148.5	7.00	210.0	0.28	0.20	8.4

Table 2: Physico-chemical properties of soil at Badhian forest (environment 2)

Depth (cm)	Texture	N (Kg/ha)	P (Kg/ha)	K (Kg/ha)	OC (%)	EC (mmhos/cm)	pH
0-15	Sandy loam	184.6	5.00	173.0	0.82	0.39	7.3
15-30	Loamy sand	190.3	5.00	170.3	0.15	0.40	7.5
30-60	Sandy	176.5	4.75	166.4	0.12	0.16	7.4
60-90	Sandy	165.6	5.25	160.4	0.12	0.32	7.4

Table 3: Physico-chemical properties of soil at Alamwala forest nursery (environment 3)

Depth (cm)	Texture	N (Kg/ha)	P (Kg/ha)	K (Kg/ha)	OC (%)	EC (mmhos/cm)	pH
0-15	Sandy loam	255.3	9.2	321.2	0.55	0.36	8.4
15-30	Sandy loam	249.4	9.0	320.0	0.54	0.28	8.2
30-60	Sandy loam	244.6	8.3	305.6	0.54	0.31	8.3
60-90	Sandy loam	232.0	8.8	305.8	0.33	0.25	8.5

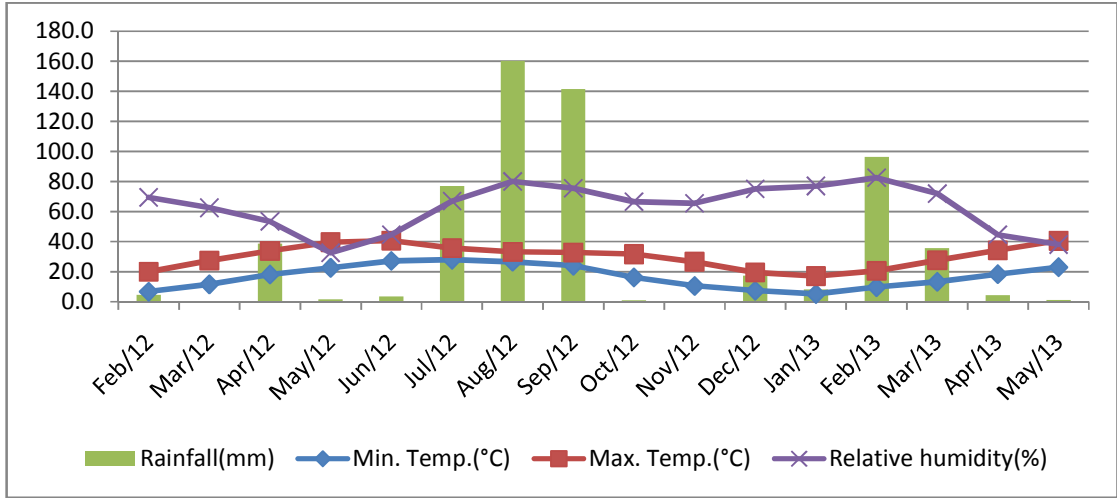


Fig 1: Meteorological data of USF, Ladhawal (Environment 1)

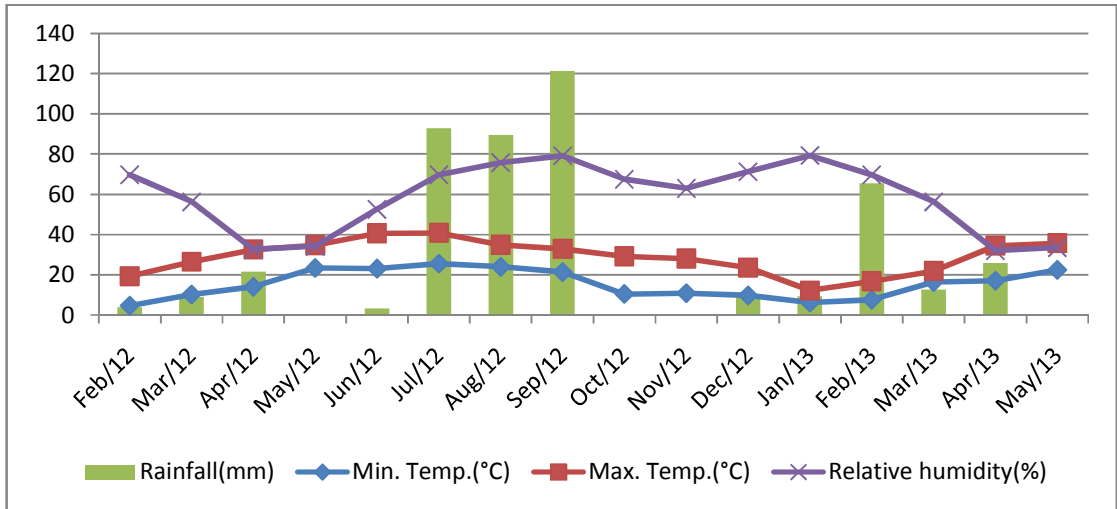


Fig 2: Meteorological data of Badhian forest (Environment 2)

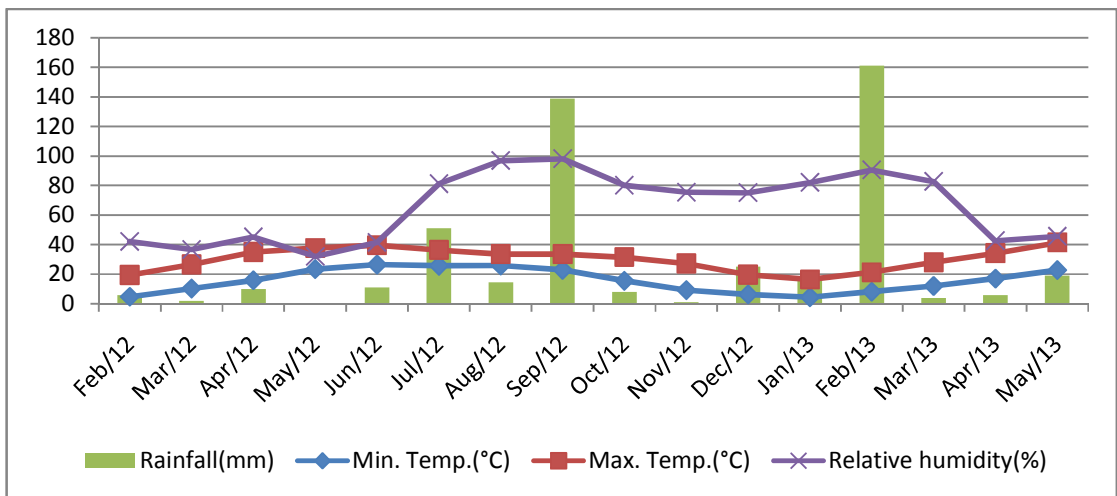


Fig 3: Meteorological data of Alamwala forest nursery (Environment 3)

3.4.7 Leaf area (cm²)

Leaf area was calculated by multiplying the length of leaves to the mean width of leaves. Five leaves were selected from the central portion of branch at 1.3 m height of plant.

3.4.8 Insect-pest/disease attack

Only visual observations for the symptoms of disease or insect-pest attack were recorded on different parts of plant in all three environments.

3.5 Genotype and site interaction: It was studied on the basis of the final and incremental ranking for plant height and collar diameter in all the three environments. In final ranking First rank was given to clone having highest plant height or collar diameter and lowest rank was given to clone having lowest plant height or collar diameter. In incremental ranking, first rank was given to clone, which showed highest growth and last rank was given to clone, which showed lowest growth. Larger the difference, larger is the genotype and site interaction and *vice-versa*.

3.6 Statistical analysis

3.6.1 Parameters of variability

3.6.1.1 Mean: The mean value of each character was worked out by dividing the sum by corresponding number of observations:

$$\bar{X} = \frac{\sum X_{ij}}{N}$$

Where, X_{ij} = Any observation in i^{th} genotype and j^{th} replication

\bar{X} = Mean of character X

N = Total number of observations

3.6.1.2 Range: The lowest and the highest values for each character was recorded for determining range of that character.

The data obtained for different parameters was subjected to statistical analysis using randomized block design in CPCS1 and MVM computer package.

3.6.2 Analysis of variance table for single environment

The analysis of variance over different environments was based on the statistical model:

$$Y_{ik} = \mu + g_i + r_k + (g)_{ik} + e_{ik}$$

Here,

Y_{ik} = mean performance of genotype i in replicate k

μ = overall mean

g_i = contribution of genotype i

r_k = contribution of the replicate k

e_{ik} = residual variation of genotype i in replicate k.

Randomized block design

Source of variation	Degree of freedom	Sum of squares	Mean sum of squares	F _{cal}
Replications	(r-1)	$\frac{1}{g} \sum_k Y^2_{.k} - \frac{Y2_{..}}{gr}$	M ₁	$(\sigma_e^2 + g \sigma_r^2)$ or (M ₁ /M ₃)
Genotype	(g-1)	$\frac{1}{r} \sum_i Y^2_{i.} - \frac{Y2_{..}}{gr}$	M ₂	$(\sigma_e^2 + r \sigma_g^2)$ or (M ₂ /M ₃)
Error	(g-1)(r-1)	$\sum_i \sum_j Y^2_{ik} - \frac{Y2_{..}}{gr}$ - Replications SS - Genotypes SS	M ₃	σ_e^2
Total	rg - 1	$\sum_i \sum_j Y^2_{ik} - \frac{Y2_{..}}{gr}$		

g = number of genotypes

r = number of replications

3.6.3 Analysis of variance table over different environments

The analysis of variance over different environments was based on the statistical model:

$$Y_{ijk} = \mu + g_i + e_j + r_{jk} + (ge)_{ij} + e_{ijk}$$

Here,

Y_{ijk} = mean performance of genotype i in replicate k of environment j

μ = overall mean

g_i = contribution of genotype i

e_j = contribution of environment j

r_{jk} = contribution of the replicate k in environment j

e_{ijk} = residual variation of genotype i in replicate k of environment j.

Randomized block design

Source of variation	Degree of freedom	Sum of squares	Mean sum of squares	F _{cal}
Replications within environment	n(r-1)	$\sum_j (\frac{1}{g} \sum_k Y^2_{.jk} - \frac{Y2_{.j}}{gr})$	M ₁	$(\sigma_e^2 + g \sigma_r^2)$ or (M ₁ /M ₅)
Environment	(n-1)	$\frac{1}{gr} \sum_i Y^2_{.j.} - \frac{Y2_{..}}{grn}$	M ₂	$(\sigma_e^2 + rg \sigma_e^2)$ or (M ₂ /M ₅)
Genotype	(g-1)	$\frac{1}{nr} \sum_i Y^2_{i.} - \frac{Y2_{..}}{grn}$	M ₃	$(\sigma_e^2 + re \sigma_g^2)$ or (M ₃ /M ₅)
Genotype x environment	(g-1)(n-1)	$\frac{1}{r} \sum_i \sum_j Y^2_{ijk} - \frac{Y2_{..}}{grn}$	M ₄	$(\sigma_e^2 + r \sigma_{ge}^2)$ or (M ₄ /M ₅)
Error	n(g-1)(r-1)	Pooled over environments	M ₅	σ_e^2
Total	gnr-1			

g = number of genotypes

n = number of environments

r = number of replications

3.6.4 Critical difference (CD)

In order to compare the mean of various parameters, the critical difference (CD) was calculated (at 5 per cent level of significance) by formula:

$$CD = S.E.d \times t_{0.05}$$

Here S.E. is the standard error of the difference of the treatment means to be compared and is equal to:

$$SE_d = \sqrt{2MSe/R}$$

With MSe as error means sum of square and R as number of replications and 't' is the tabulated value of 't' at 5 per cent or 1 per cent level of significance for the degree of freedom of error mean square.

3.6.5 Variance components

3.6.5.1 Genotypic variance

$$\sigma^2_g X = \frac{MSg - MSe}{r}$$

$$\sigma^2_g X = \text{Genotypic variance of character X}$$

3.6.5.2 Error (environmental) Variance

$$\sigma^2_e X = MSe$$

$$\sigma^2_e X = \text{error (environmental) variance for character X}$$

3.6.5.3 Phenotypic variance

$$\sigma^2_p X = \sigma^2_g X + \sigma^2_e X$$

$$\sigma^2_p X = \text{Phenotypic variance of character X}$$

3.6.5.4 Coefficient of variation:

Genotypic and phenotypic coefficient of variation was estimated by the formula suggested by Singh (2006) for each character as:

3.6.5.5 Genotypic coefficient of variance (GCV)

$$G. C. V. (\%) = \frac{\sigma_g}{\bar{X}} * 100$$

$$\sigma_g = \text{Genotypic standard deviation}$$

$$\bar{X} = \text{mean of that particular character}$$

3.6.5.6 Phenotypic coefficient of variance (PCV)

$$P. C. V. (\%) = \frac{\sigma_p}{\bar{X}} * 100$$

$$\sigma_p = \text{Phenotypic standard deviation}$$

$$\bar{X} = \text{mean of that particular character}$$

3.6.6 Heritability (broad sense)

Heritability in broad sense was calculated by the formula suggested by Jhonson *et al* (1955) for each character.

$$h^2_{b.s} = \frac{\sigma^2_g}{\sigma^2_p}$$

Where,

$h^2_{b.s}$ = Heritability (broad sense)

σ^2_g = Genotypic Variance and

σ_p = Phenotypic variance

3.6.7 Genetic advance

The expected genetic improvement at five per cent selection intensity was calculated by the formula suggested by Jhonson *et al* (1955). It is expressed as percentage of mean.

$$\text{Genetic advance (\%)} = \frac{K \sigma_p H}{\bar{X}} * 100$$

Where,

K = selection intensity

Using 5 per cent selection in sample from a normally and independently distributed population, the value of selection intensity (K) is equal to 2.06.

σ_p = phenotypic standard deviation

H = Heritability in broad sense

\bar{X} = Mean value for that character over all the genotypes.

3.6.8 Correlation studies

Genotypic and phenotypic correlation coefficients were worked out by the formulae suggested by Gupta (1981).

3.6.8.1 Genotypic correlation coefficient (r_g):

$$r_g = \frac{\sigma_{gxy}}{(\sigma^2_{gx} \times \sigma^2_{gy})^{1/2}}$$

Where,

Σ_{gxy} = genotypic covariance between two characters

σ^2_{gx} = genotypic variance of the x character

σ^2_{gy} = genotypic variance of the y character

3.6.8.2 Phenotypic correlation coefficient (r_p):

$$r_p = \frac{\sigma_{pxy}}{(\sigma_{px}^2 \times \sigma_{py}^2)^{1/2}}$$

Where,

σ_{pxy} = phenotypic covariance between two characters

σ_{px}^2 = phenotypic variance of the x character

σ_{py}^2 = phenotypic variance of the y character

CHAPTER IV

RESULTS AND DISCUSSION

The results of data collected for different parameters of the research trials on genotype and site interaction in different *Salix* clones carried out during 2012-13 are presented and discussed in this chapter. In the present study, data were analysed in randomized block design raised at three locations, Environment 1 (University Seed Farm, Ladhawal, Ludhiana), Environment 2 (Badhian Forest, Range & Division Dasuya) and Environment 3 (Alamwala forest nursery, Range- Malout, Division - Faridkot). The data for plant height and collar diameter was recorded at all three locations and for rest of the traits (number of branches, leaf length, leaf width, leaf area, days to complete leaf fall, days to complete sprouting, leaf less days and insect/pest attack) data was collected only at USF, Ladhawal (environment 1). Results obtained in the study are discussed in four principal headings.

4.1 Growth Performance

4.2 Genotype and Site Interactions- Ranking of clones

4.3 Variation, Heritability and Genetic Gain

4.4 Correlation Studies

4.1 Growth Performance

The performance of any plant is a function of both hereditary potential of the individual of a population and the extent to which such potentialities are permitted to be realized by the environment in which plant is growing. The basic aim of this study was to determine inherent differences among the individual clones and their response to different environmental conditions.

4.1.1 Plant Height

The data recorded for plant height under all three environments is provided in Table 4.

4.1.1.1 Clonal performance within the same environment

4.1.1.1.1 Environment 1 (USF Ladhawal)

The perusal of the data in Table 4 showed that the plant height of different clones ranged between 2.24 and 4.00 m, with overall mean of 3.23m. Clone UHFS-13 registered the maximum plant height (4.00m) followed by the UHFS-14 (3.97 m) and UHFS-18 (3.59 m), whereas, the clone UHFS-21 registered the minimum plant height (2.24 m). The differences for plant height between different clones are significant (Fig 4). But clone UHFS-13, which had maximum plant height (4.00m) was statistically at par with clone UHFS-2, UHFS-3, UHFS-5, UHFS-12, UHFS-13, UHFS-14, UHFS-17, UHFS-18 and UHFS-20. All these clones had plant height more than the mean value (3.23m). Clone UHFS-21, which had minimum plant height (2.24m) was also statistically at par with clone UHFS-6, UHFS-7, UHFS-8, UHFS-10 and UHFS-22.

4.1.1.1.2 Environment 2 (Badhian forest)

The perusal of Table 4 depicted that the plant height ranged between 1.86 and 3.62 m, with overall mean of 2.83m. Maximum plant height (3.62m) was observed in clone UHFS-1, followed by UHFS-11 (3.45 m) and UHFS-2 (3.41 m) and minimum (1.86m) was observed in clone UHFS-21. Differences between the different clones for plant height are significant (Fig 5). But clone UHFS-1, which had maximum plant height (3.62m) was statistically at par with clone UHFS-2, UHFS-4 and UHFS-11. Similarly clone UHFS-21, which had minimum plant height (1.86m) was statistically at par with clone UHFS-17 and UHFS-22.

4.1.1.1.3 Environment 3 (Alamwala forest nursery)

Data from Table 4 depicted that plant height of different clones ranged between 1.78 and 5.39 m with overall mean of 3.01m. Height of clone UHFS-19 was maximum (5.39 m), followed by UHFS-7 (3.70 m) and UHFS-6 (3.57m) and height of clone UHFS-21 was minimum (1.78 m). Plant height differences were significant between different clones (Fig 6). Clone UHFS-21, which had minimum plant height (1.78m) from all clones was at par only with clone UHFS-22 and differed significantly from all other clones. But clone UHFS-19, which had maximum plant height (5.39m) was significantly different from all other clones.

4.1.1.2 Clonal response in different environments

Differences in the overall performance of clone under different environments were also found significant when compared with critical value (5%) of 0.12 (Table 4). Overall height of all clones was maximum in environment 1 (3.23m) followed by environment 3 (3.01m) and environment 2 (2.84m). After pooled analysis, individual plant height of different clones ranged between 1.96 m and 3.65m, with overall mean of 3.03m. Clone UHFS-19 registered maximum plant height (3.65 m), followed by the clone UHFS-1(3.45m) and UHFS-11 (3.41m), whereas, clone UHFS-21 registered the minimum plant height (1.96 m). Pooled analysis showed that differences between the different clones were significant for plant height. But clone UHFS-19, which had maximum plant height (3.65m) was statistically at par with clone UHFS-1, UHFS-2, UHFS-11 and UHFS-13. The clone UHFS-21 had significantly lowest plant height (1.96m) than all other clones. Differences among the clones for plant height under different environments are shown in Fig 7.

The genotype and site interactions were also significant among the clones when compared with critical value (5%) of 0.58 (Table 4). Perusal of the data in Table 4 showed that the performance of clone UHFS-13 for plant height was in decreasing order from environment 1 to environment 3 (4.00m, 3.17m and 2.77m in environment 1, environment 2 and environment 3, respectively). Similarly clone UHFS-2, UHFS-4, UHFS-9, UHFS-13, UHFS-16, UHFS-18,

UHFS-20, UHFS-21 and UHFS-22 also showed plant height in decreasing order from environment 1 to environment 3. But clone UHFS-7 and UHFS-11 showed increasing trend in the plant height from environment 1 to environment 3. Plant height of clone UHFS-5, UHFS-12 and UHFS-17 was at first position in environment 1, at second position in environment 3 and at third position in environment 2, whereas, position of clone UHFS-3, UHFS-6, UHFS-10 and UHFS-19 was first in environment 3, second in environment 1 and third in environment 2. The change in the performance of clones among the environments reveals that the clones showed genotype and site interactions in different environments, which resulted in variable response.

The results of study indicated significantly large variation in plant height between the clones in same environment and between different environments. Sharma *et al* (2011) reported significant differences in the plant height of eighteen clones after five years of evaluation in Himachal Pradesh. Tunctaner (2002) also observed large variations (2.3m to 6.7m) in plant height of fifty-three willow clones after two years at Izmit nursery (Turkey), these clones were selected from different locations in Turkey. Large variations in plant height were also observed by Labrecque and Teodorescu (2005) in second, third and fourth growing season of willow clones. These clones were collected from different locations in Canada and were grown over an abandoned agriculture land in southern Quebec without fertilization and irrigation. Similarly, significant variations in plant height of willow (Poland cultivars) were recorded by Stolarski *et al* (2011) at the end of fourth growing season when tested on two different soil conditions. Differences were significant between the locations and between the clones on same location. Significant differences in plant height of two year old sprouting of different species and hybrids of willow were observed by Vihera-Aarnio and Saarsalmi (1994) on abandoned field in southern Finland. Arun (2009) also reported large variation (66cm to 259.87cm) in height of willow clones collected from different parts of the north India in his study in Punjab at nursery stage.

4.1.2 Collar diameter

Data recorded for collar diameter of different clones under different environments is provided in Table 5.

4.1.2.1 Clonal performance within the same environment

4.1.2.1.1 Environment 1 (USF Ladhawal)

The perusal of data in Table 5 showed that the collar diameter of clones ranged between 2.27 cm and 3.57 cm with a mean of 2.75 cm. Maximum collar diameter (3.57 cm) was in clone UHFS-13, followed by clone UHFS-19 (3.30 cm) and UHFS-3 (3.27 cm) and minimum (2.27 cm) was in clone UHFS-10. Differences between the clones for collar diameter were significant (Fig 4). But clone UHFS-13, which had maximum collar diameter (3.57cm) was statistically at

Table 4: Mean values of plant height (m) recorded in different clones under different environments

Clone	Environment 1	Environment 2	Environment 3	Pooled
UHFS-1	3.24	3.62	3.48	3.45
UHFS-2	3.47	3.41	3.13	3.34
UHFS-3	3.48	2.69	3.56	3.24
UHFS-4	3.25	3.20	3.02	3.15
UHFS-5	3.30	2.70	2.74	2.91
UHFS-6	2.86	2.79	3.57	3.08
UHFS-7	2.82	3.15	3.70	3.22
UHFS-8	2.91	2.97	2.53	2.80
UHFS-9	3.21	2.92	2.55	2.89
UHFS-10	2.62	2.57	2.89	2.69
UHFS-11	3.22	3.46	3.54	3.41
UHFS-12	3.59	2.68	2.89	3.06
UHFS-13	4.00	3.17	2.77	3.31
UHFS-14	3.97	3.03	2.78	3.26
UHFS-15	3.21	2.55	2.55	2.77
UHFS-16	3.27	3.10	2.95	3.10
UHFS-17	3.48	1.95	3.36	2.93
UHFS-18	3.59	2.97	2.63	3.06
UHFS-19	3.10	2.46	5.39	3.65
UHFS-20	3.32	3.00	2.48	2.94
UHFS-21	2.24	1.86	1.78	1.96
UHFS-22	2.96	2.28	2.03	2.42
Mean	3.23	2.84	3.01	3.03
Range	2.24–4.00	1.86–3.62	1.78–5.39	1.96–3.65
CD (5%) clones (C)	0.72	0.41	0.59	0.34
CD (5%) Environments (E)	0.12			
CD (5%) Interaction (C×E)	0.58			

Environment 1 = University Seed Farm, Ladhowal, Ludhiana

Environment 2 = Badhian forest, Range and Division Dasuya

Environment 3 = Alamwala forest nursery, Range - Malout, Division - Faridkot.

par with clone UHFS-1, UHFS-3, UHFS-5, UHFS-9, UHFS-14, UHFS-16 and UHFS-19. Similarly clone UHFS-10, which had minimum collar diameter (2.27cm) was statistically at par with all clones except clone UHFS-3, UHFS-13, UHFS-14 and UHFS-19.

4.1.2.1.2 Environment 2 (Badhian forest)

The perusal of data in Table 5 showed that the range of collar diameter was present between 1.53 cm and 2.52 cm with a mean of 1.91 cm. Maximum collar diameter was recorded in clone UHFS-1 (2.52 cm), followed by UHFS-11 (2.40 cm) and UHFS-2 (2.23 cm). Clone UHFS-17 registered the minimum collar diameter (1.53 cm). Here also, the differences between clones for collar diameter were significant (Fig 5). But clone UHFS-17, which had minimum collar diameter (1.53cm) was statistically at par with clone UHFS-4, UHFS-5, UHFS-9, UHFS-10, UHFS-12, UHFS-15, UHFS-18, UHFS-20, UHFS-21 and UHFS-22, and all these clones had diameter below the mean value. The clone UHFS-1, which had maximum collar diameter (2.52cm) was at par only with clone UHFS-11 and UHFS-2 and differed significantly from all others clones.

4.1.2.1.3 Environment 3 (Alamwala forest nursery)

The perusal of data in Table 5 showed that collar diameter ranged between 1.67 cm and 4.82 cm, with an average collar diameter of 2.29cm. Significant differences were observed between clones for collar diameter (Fig 6). Collar diameter of clone UHFS-19 was maximum (4.82 cm), followed by statistically lower diameter in UHFS-3 (3.27cm) and UHFS-7 (3.03cm), and minimum collar diameter (1.67 cm) was recorded in UHFS-18 and UHFS-21. Clone UHFS-18 and UHFS-21, which had minimum collar diameter (1.67cm) were statistically at par with clone UHFS-2, UHFS-4, UHFS-5, UHFS-8, UHFS-9, UHFS-10, UHFS-12, UHFS-13, UHFS-14, UHFS-15, UHFS-16, UHFS-17, UHFS-20 and UHFS-22. But clone UHFS-19, which had maximum collar diameter (4.82cm) was significantly different from all other clones.

4.1.2.2 Clonal response in differernt environments

Pooled analysis of data from three sites showed that the differences in the performance of clones for collar diameter on different environments were significant when compared with critical value of 0.12 at 5% level of significance. The perusal of data in Table 5 showed that overall performance of clones for collar diameter was highest in environment 1 (2.75cm), followed by environment 3 (2.29cm) and then environment 2 (1.91cm). After pooled analysis, range of individual clones for collar diameter was found between 1.91cm and 3.38cm with a mean value of 2.32cm. Collar diameter of clone UHFS-19 was maximum (3.38cm), followed by UHFS-3 (2.80cm) and UHFS-1 (2.78cm), while the clone UHFS-22 recorded the minimum diameter (1.91cm) which was statistically at par with clone UHFS-4, UHFS-5, UHFS-8, UHFS-9, UHFS-

10, UHFS-12, UHFS-15, UHFS-16, UHFS-17, UHFS-18, UHFS-20 and UHFS-21. Clone UHFS-19, which had maximum collar diameter was significantly superior than all other clones. Differences among the clones for collar diameter under different environments are shown in Fig 8.

The genotype and site interaction differences were also found significant among the clones when compared with critical value (5%) of 0.57 (Table 5). The perusal of the data in Table 5 showed that the performance of clone UHFS-2, UHFS-8, UHFS-13, UHFS-14, UHFS-16, UHFS-18 and UHFS-21 for collar diameter was in decreasing order from environment 1 to environment 3. Position of clones UHFS-4, UHFS-5, UHFS-9, UHFS-10, UHFS-12, UHFS-15, UHFS-17, UHFS-20, UHFS-22 for collar diameter was first in environment 1, second in environment 2 and third in environment 3, Whereas position of clone UHFS-1, UHFS-6, UHFS-7, UHFS-11 and UHFS-19 was in reverse order, i.e. first in environment 3, second in environment 1 and third in environment 2. Changes in the performance of clones for collar diameter between the environments reveal that they showed significant genotype and site interaction. Performance of willow clones during different phases of life is shown in Plate 1 and Plate 2.

Lower growth in collar diameter and plant height in environment 2 as compared to other environments may be due to water logging, which coincides with the active vegetative growth phase and lead to early fall of leaves. However, these results should not be regarded as exceptional since due to high rainfall in this area these conditions may happen again in the future also. The results of study indicated large variations in collar diameter, its value ranged from 1.53cm to 4.82cm. Like plant height, Sharma *et al* (2011) also reported significant differences in the plant height of eighteen clones after five years of evaluation in Himachal Pradesh. Tunctaner (2002) also observed large variations (4.7cm to 1.9cm) in diameter of fifty-three willow clones after a period of two years. Labrecque and Teodorescu (2005) in their trial on willow clones, which was collected from different locations in Canada observed that differences between the diameter was less after second growing season but differences increased after third and fourth growing season. As in case of plant height, Vihera-Aarnio and Saarsalmi (1994) also reported significant differences in the diameter of different willow species and hybrids. Arun (2009) also observed significant variations (5.72mm to 14.02mm) in the collar diameter of clones at nursery stage in Punjab. But present study contradict with Stolarski *et al* (2011), they reported non-significant differences in diameter of willow clones after four growing season both within the location and between the locations, when grown over different soil conditions.



Plate 1: Performance of willow clones in field



Plate 2: Performance of willow clones in field

Table 5: Mean values of collar diameter (cm) recorded in different clones under different environments

Clone	Environment 1	Environment 2	Environment 3	Pooled
UHFS-1	2.87	2.52	2.97	2.78
UHFS-2	2.73	2.23	2.20	2.39
UHFS-3	3.27	1.88	3.27	2.80
UHFS-4	2.47	1.77	2.17	2.13
UHFS-5	2.90	1.77	1.87	2.18
UHFS-6	2.47	1.93	2.80	2.40
UHFS-7	2.57	2.17	3.03	2.59
UHFS-8	2.57	1.90	1.87	2.11
UHFS-9	2.97	1.85	1.90	2.24
UHFS-10	2.27	1.82	2.13	2.07
UHFS-11	2.47	2.39	2.77	2.54
UHFS-12	2.83	1.67	1.93	2.14
UHFS-13	3.57	1.93	1.90	2.47
UHFS-14	3.20	1.97	1.86	2.34
UHFS-15	2.63	1.72	2.03	2.13
UHFS-16	2.93	2.10	1.77	2.27
UHFS-17	2.73	1.53	2.27	2.18
UHFS-18	2.33	1.82	1.67	1.94
UHFS-19	3.30	2.03	4.82	3.38
UHFS-20	2.50	1.69	1.70	1.96
UHFS-21	2.63	1.70	1.67	2.00
UHFS-22	2.37	1.61	1.75	1.91
Mean	2.75	1.91	2.29	2.32
Range	2.27–3.57	1.53–2.52	1.67–4.82	1.91–3.38
CD (5%) clones (C)	0.72	0.33	0.61	0.33
CD (5%) Environments (E)	0.12			
CD (5%) Interaction (C×E)	0.57			

Environment 1 = University Seed Farm, Ladhawal, Ludhiana

Environment 2 = Badhian forest, Range and Division Dasuya

Environment 3 = Alamwala forest nursery, Range - Malout, Division - Faridkot

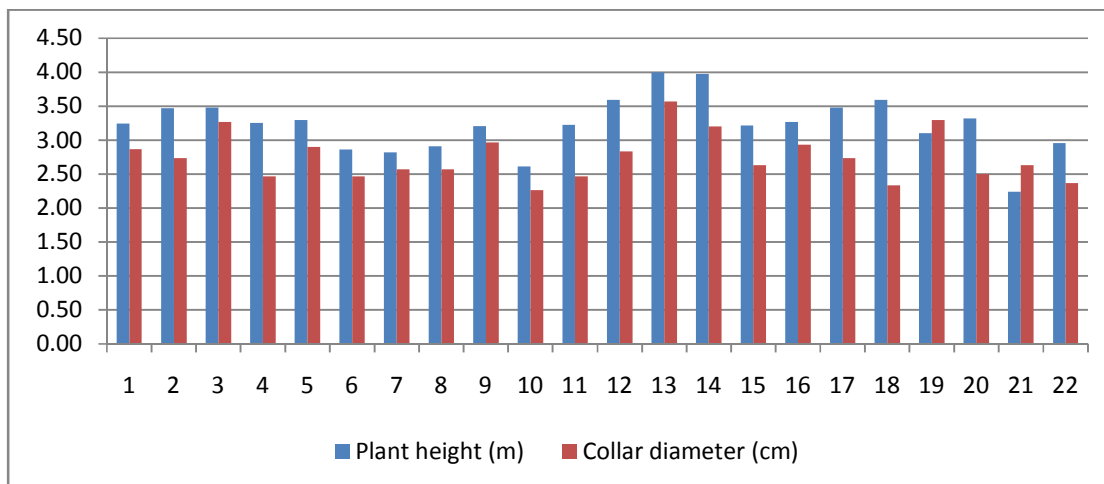


Fig 4: Variation in height and collar diameter among clones at USF, Ladhawal (Environment 1)

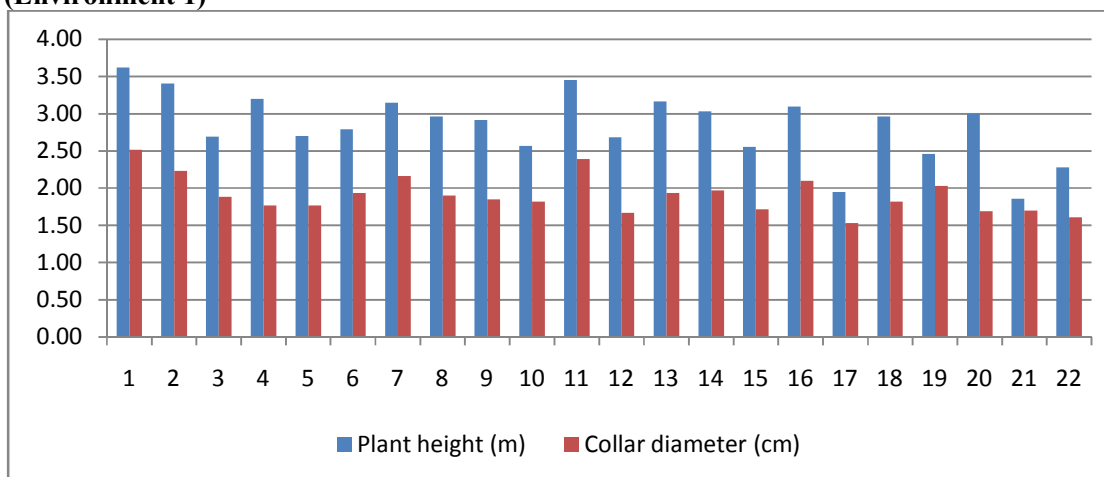


Fig 5: Variation in height and collar diameter among clones at Badhian forest (Environment 2)

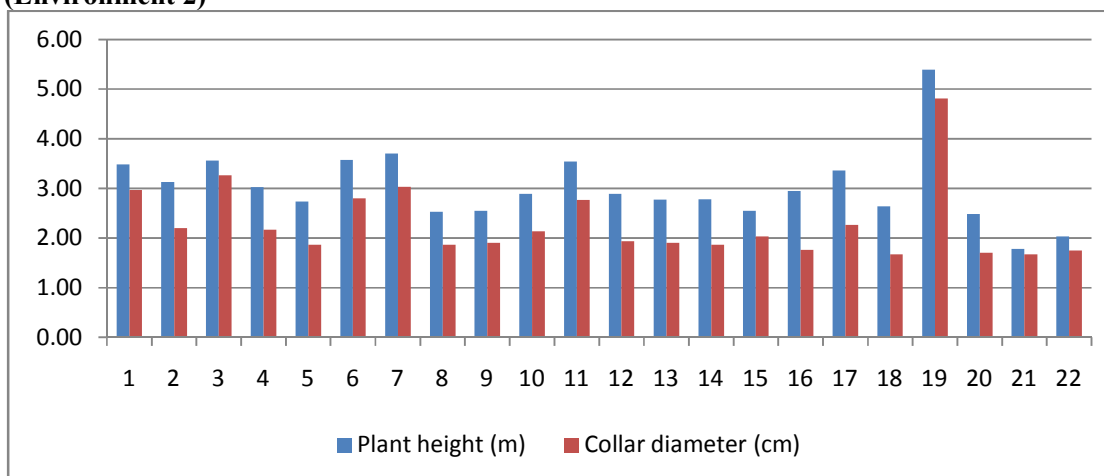


Fig 6: Variation in height and collar diameter among clones at Alamwala forest nursery (Environment 3)

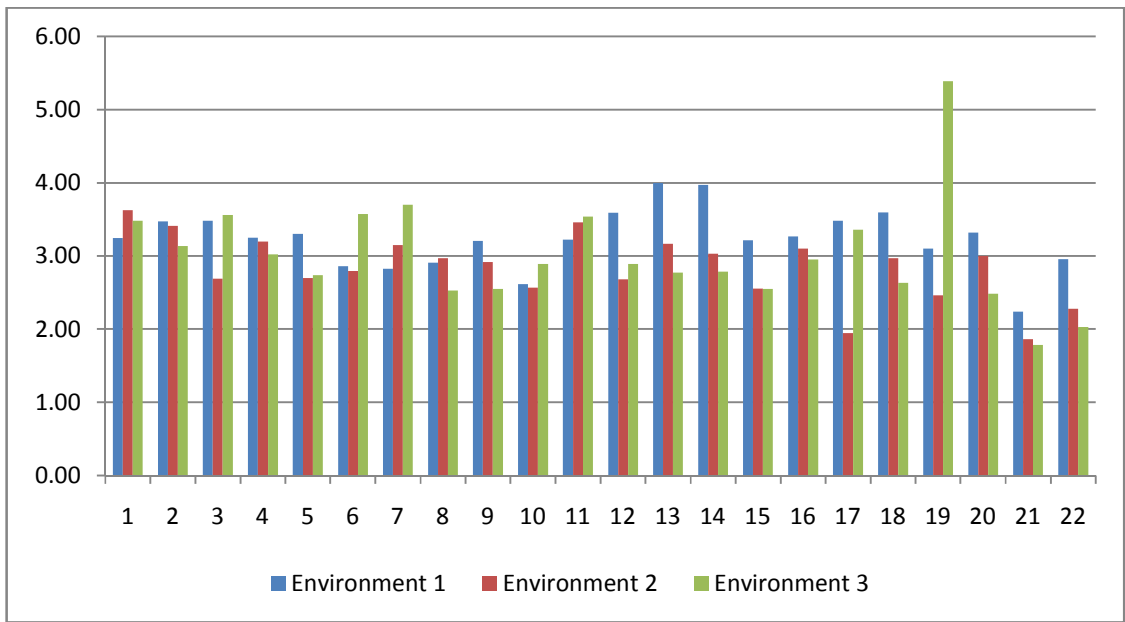


Fig 7: Variation in plant height among clones under different environments

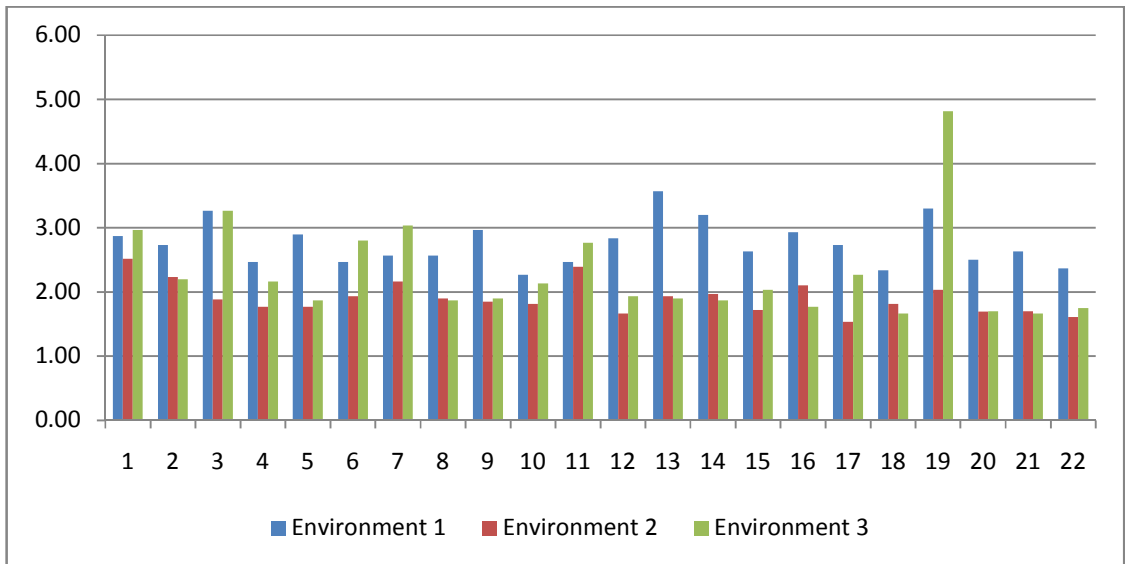


Fig 8: Variation in collar diameter among clones under different environments

4.1.3 Number of Branches

Data for the number of branches, which was recorded at USF, Ladhowal (environment 1) only is presented in Table 6. The perusal of data showed that the total number of branches per plant ranged between 5.33 and 22.33 with overall mean of 12.15. Highest number of branches were found in clone UHFS-3 (22.33), followed by clone UHFS-13 (20.33) and UHFS-6 (17.33) and lowest number of branches were found in clone UHFS-18 (5.33). Apart from clone UHFS-18, the clones UHFS-4 (8.69), UHFS-5 (9.67), UHFS-12 (8.33) and UHFS-19 (6.67) had also less number of branches. Variation in the number of branches among clones at USF Ladhowal (environment 1) is shown in Plate 3. Differences between the clones for total number of branches were found significant when compared with critical value (5% level of significance) of 4.75. But clone UHFS-18, which had lowest number of branches was statistically at par with clones UHFS-2, UHFS-4, UHFS-5, UHFS-10, UHFS-12 and UHFS-19 and all these clones had less number of branches than mean value. Clone UHFS-3, which had highest number of branches was at par with UHFS-13 only and differed significantly from all other clones.

Range for number of branches in present study was observed from 5.33 to 20.33. Similarly large variation (1 to 12.31) in number of branches/ plant was recorded by Arun (2009). Results of present study are also in line with those reported by Stolarski *et al* (2011), who reported significant differences between the clones for number of primary branches between six genotypes of willow in northern Poland. For agroforestry system, trees with less number of branches are desirable as such plants will have less shade effects on the intercultivated agricultural crops in the understory. For round wood production also trees with fewer branches are preferred. But for biomass production and phytoremediation, trees with large number of branches are preferred. Therefore, this variation would help in making selection for different purposes. Even the drooping nature of branches revealed in clone UHFS-10 is suitable to add landscape value (Plate 4).

4.1.4 Leaf parameters

Data for leaf parameters (leaf length, width and area), which was recorded at USF, Ladhowal (environment 1) only is presented in table 6.

4.1.4.1 Leaf Length

The perusal of data in table 6 showed that the range for leaf length was between 7.87cm and 16.04cm, with overall mean of 11.27cm. Differences between the clones for leaf length were found significant when compared with critical value (5%) of 1.51. Clone UHFS-21 recorded the maximum leaf length (16.04cm), followed by UHFS-19 (15.03cm) and UHFS-6 (14.05cm). Clone UHFS-8 had the lowest leaf length (7.87cm). Other clone like UHFS-7, UHFS-20, UHFS-



Plate 3: Variation in the number of branches among clones at USF, Ldhowal (Environment 1)



Plate 4: Variation in the branching nature among clones (drooping and straight) at USE, Ldhowal (Environment 1)

2 and UHFS-4 also registered lower leaf length, having leaf length (8.89cm, 8.94cm, 9.29cm and 9.47cm, respectively). But clone UHFS-8 had lowest leaf length was statistically at par with clone UHFS-2, UHFS-7 and UHFS-20. Similarly clone UHFS-21, which had highest leaf length was statistically at par only with clone UHFS-19 and significantly different from all other clones.

4.1.4.2 Leaf Width

The perusal of data in table 6 revealed that the leaf width of different clones ranged between 0.86cm and 1.99cm. Differences between clones for leaf width were significant. Overall mean of leaf width for different clones was 1.21 cm. Significantly highest width was revealed in clone UHFS-19 (1.99 cm), followed by UHFS-13 (1.56 cm) and UHFS-3 (1.45 cm). Clone UHFS-2, which had lowest leaf width (0.86cm) was statistically at par with clone UHFS-4 (0.96cm), UHFS-7 (0.90cm), UHFS-9 (0.96cm), UHFS-10 (0.95cm), UHFS-16 (1.03cm) and UHFS-20 (0.98cm). But clone UHFS-19, which had highest leaf width was significantly different from all other clones.

4.1.4.3 Leaf Area

The perusal of data in table 6 revealed that the leaf area of different clones ranged from 8.04 cm² to 29.91 cm² with overall mean of 14.08 cm². Differences between clones for leaf area are significant. Clone UHFS-19 recorded the highest (29.91 cm²) leaf area, followed by UHFS-21 (21.51 cm²) and UHFS-13 (19.87 cm²), whereas, lowest area was registered by clone UHFS-2 (8.04 cm²), other clones which had less leaf area included UHFS-7 (8.09 cm²), UHFS-20 (8.78 cm²), UHFS-4 (9.26 cm²) and UHFS-8 (9.65 cm²). But clone UHFS-2, which had lowest leaf area was statistically at par with clone UHFS-4, UHFS-7, UHFS-8, UHFS-9, UHFS-10, UHFS-12, UHFS-16 and UHFS-20. However clone UHFS-19, which had highest leaf area differed significantly from all other clones.

The results of present study revealed large variations among the clones for leaf area. Similar results were recorded by Robinson *et al* (2004) for six willow clones in England, leaf area ranged between 140mm² and 574mm². Study conducted by Arun (2009) at nursery stage in Punjab also confirmed the results of present study, he observed the range of variation from 16.80cm² to 72.55 cm².

4.1.5 Leaf display

Data about leaf display (days to complete leaf fall, days for complete sprouting and leaf less days) at USF, Ladhawal (environment 1) is given in table 7.

4.1.5.1 Days taken to complete leaf fall

Data in the table 7 revealed that days taken by different clones for complete leaf fall ranged from 78.67 to 129.67, with a mean of 107.92 days. Highest number of days (129.67) were

Table 6: Mean values of number of branches/plant, leaf length (cm), leaf width (cm) and leaf area (cm²) of different clones at USF, Ladhawal (environment 1)

Clone	Number of branches/plant	Leaf length (cm)	Leaf width (cm)	Leaf area (cm²)/leaf
UHFS-1	12.67	11.93	1.34	16.03
UHFS-2	8.00	9.29	0.86	8.04
UHFS-3	22.33	10.07	1.45	14.69
UHFS-4	8.67	9.47	0.96	9.26
UHFS-5	9.67	11.72	1.36	15.99
UHFS-6	17.33	14.05	1.39	19.53
UHFS-7	11.00	8.89	0.90	8.09
UHFS-8	11.00	7.87	1.22	9.65
UHFS-9	13.33	10.21	0.96	9.95
UHFS-10	10.00	11.45	0.95	10.88
UHFS-11	12.33	11.23	1.32	15.00
UHFS-12	8.33	10.85	1.09	11.90
UHFS-13	20.33	12.68	1.56	19.87
UHFS-14	16.33	10.97	1.10	12.15
UHFS-15	11.33	11.67	1.13	13.19
UHFS-16	16.00	10.92	1.03	11.27
UHFS-17	11.33	11.57	1.14	13.37
UHFS-18	5.33	12.40	1.30	16.14
UHFS-19	6.67	15.03	1.99	29.91
UHFS-20	12.67	8.94	0.98	8.78
UHFS-21	11.67	16.04	1.39	22.51
UHFS-22	11.00	10.71	1.26	13.51
Mean	12.15	11.27	1.21	14.08
Range	5.33 – 22.33	7.87 – 16.04	0.86 – 1.99	8.04 – 29.91
CD (5%) clones	4.75	1.51	0.21	3.97

taken by clone UHFS-12 and UHFS-13, followed by UHFS-8 (124.33), UHFS-3 (123.33) and UHFS-11 (121.67). Variation for leaf fall among the clones at USF, Ladhawal (Environment 1) are shown in Plate 5. Clone UHFS-16 had taken lowest numbers of days (78.67) to shed its leaves. Clone UHFS-12 and 13, which took largest number of days to shed their leaves were statistically at par with clone UHFS-1, UHFS-3, UHFS-8, UHFS-11, UHFS-12, UHFS-13 and UHFS-18, whereas, clone UHFS-16, which took least number of days to shed leaves was statistically at par with clone UHFS-4 only.

4.1.5.2 Days taken for complete sprouting

The perusal of data in table 7 showed that range for days taken by clones for complete sprouting of leaves was between 12.00 and 33.33, with overall mean of 22.01 days. Highest number of days were taken by clone UHFS-12 (33.33), whereas, lowest number of days were taken by clone UHFS-14 (12.00). Other clones which had taken more number of days (at par to clone UHFS-12) included UHFS-2 (30.67), UHFS-6 (29.33) and UHFS-10 (29.00). Variation for leaf emergence among clones at USF, Ladhawal (Environment 1) are shown in Plate 6. Differences among the clones for number of days for complete sprouting were significant. Clone UHFS-14, which had taken minimum days to complete sprouting of leaf was at par only with clone UHFS-3. Leaf sprouting varied by 46 days among different clones. Clones in which leaf sprouting started later had take fewer days for complete leaf development, whereas clones in which sprouting started earlier had taken more days for leaf development. Similar growth pattern was observed by Weih (2009) in six willow varieties under different irrigation and fertilizer treatments in central Sweden. But present study contradicts the observations that the sprouting initiate earlier in spring in genotypes which shed their leaves early in autumn.

4.1.5.3 Leaf less Days

The perusal of data in table 7 revealed that the number of leaf less days of different clones ranged between 18.00 and 97.67, with overall mean of 65.87 days. Differences between the clones for leaf less period were significant when compared with critical value of 12.85 at 5% level of significance. Clones UHFS-16 registered highest number of days for leaf less period (97.67). Opposite to this, clone UHFS-12 registered lowest number of days for leaf less period (18.00). But clone UHFS-16, which remained leaf less for highest number of days was statistically at par with clone UHFS-4, UHFS-7, UHFS-9, UHFS-14, UHFS-15, UHFS-17, UHFS-20 and UHFS-22. Whereas, clone UHFS-12, which remained leaf less for lowest number of days (18 days) differed significantly from all other clones.

The number of days for which different clones remained leaf less showed large variations, it varied between 18.00 and 97.67 days. Arun (2009) also observed large variations in leaf less days among different clones.

4.1.6 Insect/Pest Attack

Any kind of insect/pest incidence was not observed on the clones in all three locations except leaf eating caterpillars (semi-loopers), but its attack was not severe and was only for a small period of time.

4.2 Genotype and Site Interaction – Ranking of clones

The concept of genotype and site interaction has been defined as the varying relative performance of genotypes with changing environments. Present study helps us to predict how the specific clones will perform for growth parameters when grown in different environments.

4.2.1 Plant Height

The ranking of different clones on the basis of final plant height (after one year old of planting) and increment in plant height recorded under different environments is given in table 8.

4.2.1.1 Final ranking

The perusal of data in table 8 revealed strong genotype and site interaction among clones, exhibiting large changes in ranks at three sites. Clone UHFS-13, which was at first position in environment 1, was at fourth and fourteenth position in environment 2 and 3, respectively. Similarly, clone UHFS-14, which was at second position in environment 1, was at seventh and thirteenth position in environment 2 and 3, respectively. Clone UHFS-18, which registered third rank in environment 1, registered ninth and sixteenth rank in environment 2 and 3, respectively. Similarly, clone UHFS-12, which registered third rank in environment 1, registered sixteenth and eleventh rank in environment 2 and 3, respectively. Similarly, clones which performed well in environment 2 were ranked lower under other two environments. Clone UHFS-1, which was at first rank in environment 2, registered twelfth and sixth rank in environment 1 and 3, respectively. Clone UHFS-11, which was at second rank in environment 2, registered thirteenth and fifth rank in environment 1 and 3, respectively. Clone UHFS-19, which performed very well in environment 3 (rank first), was found at sixteenth and nineteenth position in environment 1 and 2, respectively. Similar pattern were found in clone UHFS-3, UHFS-6, UHFS-7, UHFS-8, UHFS-10, UHFS-17 and UHFS-20, where performance changed considerably between the environments. However, some clones showed only small changes in ranking like clone UHFS-2, which ranked at seventh, third and eighth in environment 1, 2 and 3, respectively. Similarly, clone UHFS-4 registered eleventh, twelfth and ninth rank in environment 1, 2 and 3, respectively. Similar patterns were found in clone UHFS-5, UHFS-9, UHFS-15, UHFS-16 and UHFS-22,



Plate 5: Variation for leaf fall among clones at USF, Ldhawal (Environment 1)



Plate 6: Variation for leaf emergence among clones at USF, Ldhowal (Environment 1)

Table 7: Mean values of days taken to complete leaf fall, days taken for complete sprouting and leaf less days of different clones at USF, Ladhowal (environment 1)

Clone no.	Days taken to complete leaf fall	Days taken for complete sprouting	Leaf less days
UHFS-1	118.67	19.33	46.67
UHFS-2	115.00	30.67	44.00
UHFS-3	123.33	13.33	49.00
UHFS-4	89.33	21.00	94.67
UHFS-5	113.67	21.00	50.33
UHFS-6	112.33	29.33	48.00
UHFS-7	94.00	20.67	92.67
UHFS-8	124.33	22.67	43.67
UHFS-9	100.00	20.67	85.67
UHFS-10	100.00	29.00	54.00
UHFS-11	121.67	21.00	47.67
UHFS-12	129.67	33.33	18.00
UHFS-13	129.67	20.67	52.00
UHFS-14	91.67	12.00	86.33
UHFS-15	97.33	20.67	85.00
UHFS-16	78.67	22.67	97.67
UHFS-17	96.67	21.00	94.67
UHFS-18	118.33	26.67	49.00
UHFS-19	107.67	19.33	67.33
UHFS-20	103.67	20.67	87.33
UHFS-21	115.67	19.33	68.00
UHFS-22	93.00	19.33	87.67
Mean	107.92	22.02	65.88
Range	78.67 – 129.67	12.00 – 33.33	18.00 – 97.67
CD (5%) clones	11.57	4.46	12.86

which showed small changes in ranking, due to stability of genotypes at different sites. Only position of clone UHFS-21 did remained unchanged on all three environments, but its growth performance was very poor (rank twenty-two).

4.2.1.2 Incremental ranking

Ranking on the basis of plant height increment also showed large changes among three environments as it was observed in final ranking. Clones which performed well under one environment, performed poorly under other environments and *vice versa*, due to differential response of clones in different environments. Clone UHFS-13, which was at first rank in environment 1 due to high increase in height, showed moderate growth in environment 2 (rank six) and remained very small in environment 3 (rank nineteen). Increment was high in clone UHFS-14 under environment 1 (rank second) and environment 3 (rank four), but its performance was poor under environment 2 (rank fifteen). Similarly, clone UHFS-22 showed good increment in height in environment 1 (rank three) and environment 2 (rank eight), but increment was very small in environment 3 (rank sixteen). Similarly, clone UHFS-15 and UHFS-20 showed large increase in height in environment 1 (rank seven and five, respectively), but increment was very small in environment 2 (rank twenty-two and nineteen, respectively) and environment 3 (rank twenty and eleven, respectively). Clone UHFS-10 and UHFS-11, which showed high increment in environment 2 (rank three and first, respectively), showed poor growth in environment 1 (rank nineteen and thirteen, respectively) and moderate growth in environment 3 (rank seven and four, respectively). Clone UHFS-16, which registered high increment in environment 2 (rank second) showed poor growth performance in environment 1 (rank fourteen) and environment 3 (rank twenty-one). Similar results were found for clones which performed well under environment 3, like clone UHFS-3 and UHFS-6 in environment 3 (rank two and three, respectively), registered only small growth in environment 1 (rank eleven and twenty-two respectively) and in environment 2 (rank fifteen each). Only clone UHFS-18 showed high growth under all three environments, ranked fourth, seventh and sixth in environment 1, environment 2 and environment 3, respectively. Clone UHFS-5 and UHFS-21 also showed only small change in ranking between environments but their performance was poor under all three environments.

4.2.2 Collar Diameter

The ranking of different clones on the basis of final collar diameter (after one year old of planting) and increment in collar diameter under different environments is given in table 9.

4.2.2.1 Final ranking

The perusal of data in table 9 shows that performance of the clones varied significantly at different environments. Genotype and site interactions response was significant for collar

diameter among three environments. Clone UHFS-13 whose performance was very good in environment 1 (rank first), performed moderately in environment 2 (rank eighth) and poor in environment 3 (rank thirteenth). Similarly clone UHFS-9, which performed well under environment 1 (rank fifth), performed poor under environment 2 (rank twelfth) and environment 3 (rank thirteenth). Similarly clone UHFS-2, which performed well under environment 2 (rank second), performed moderately under environment 1 (rank tenth) and environment 3 (rank eighth). Clone UHFS-1 and UHFS-19 performed well under all the three environments. Clone UHFS-1 was present at position eighth, first and fourth in environment 1, environment 2 and environment 3, respectively. Similarly, clone UHFS-19 registered second, sixth and first rank in environment 1, environment 2 and environment 3, respectively. Performance of clones UHFS-8, UHFS-10, UHFS-15, UHFS-18, UHFS-20, UHFS-21 and UHFS-22 was poor under all the three environments as shown in table 6. Clone UHFS-20 was at position sixteenth, nineteenth and twentieth and clone UHFS-22 was at twentieth, twenty-first and nineteenth position under environment 1, environment 2 and environment 3, respectively, which exhibits poor performance of these clones irrespective of site conditions in Punjab.

4.2.2.2 Incremental ranking

Growth of collar diameter of different clones also showed large variation between different environments. Clones which showed high increment in diameter under one environment showed less increment under other environments and *vice versa*. Clone UHFS-13, which showed highest increment in environment 1 (rank first), registered only small increase in collar diameter under environment 2 (rank fifteen) and environment 3 (rank twenty). Clone UHFS-14, which also showed large increment in environment 1 (rank second) and environment 2 (rank three), registered poor growth in environment 3 (rank sixteen). Clone UHFS-3 and UHFS-9 showed high increment in environment 1 (rank four and six, respectively) and environment 3 (rank second and seven, respectively), but increment was small in environment 2 (rank twelve and eighteen, respectively). Similarly, clone UHFS-12, which had high increment in collar diameter in environment 1 (rank eight), showed small increase in collar diameter in environment 2 (rank twenty) and environment 3 (rank fifteen). Similarly clone UHFS-7 and UHFS-11, which showed high increase in collar diameter in environment 2 (rank second and first, respectively) and environment 3 (rank third and five, respectively), registered only small increase in collar diameter in environment 1 (rank fourteen and nineteen, respectively). Clone UHFS-2, which showed good growth in environment 2 (rank six), performed poorly in environment 1 (rank twenty) and in environment 3 (rank thirteen). Similarly, clone UHFS-6 and UHFS-10, which showed good growth under environment 3 (rank four and seven, respectively), showed only small increase in environment 1 (rank twenty

and twenty-two, respectively) and moderate increase in environment 2 (rank twelve and ten, respectively). Clone UHFS-19 showed high increment in collar diameter under all three environments, it was at second, fifth and first position in environment 1, environment 2 and environment 3, respectively, reflecting strong genetic control of the clone, which performed well in all the three environments. Performance of clone UHFS-8, UHFS-15, UHFS-17, UHFS-18 and UHFS-22 was poor under all three environments as shown in table 9.

4.3 Variation, Heritability and Genetic Gain

Data about the, PCV, GCV, heritability and genetic gain for different traits under all three environments is presented in table 10.

4.3.1 Variability

4.3.1.1 Phenotypic Variability

The perusal of figures in table 10 revealed that the values of phenotypic coefficient of variation (PCV) for all traits taken in only environment 1 ranged between moderate to high. Highest variation was present in leaf area (40.14) among different clones, followed by number of branches (39.55), leaf less days (35.96), days taken for complete sprouting (25.23), leaf width (23.25) and leaf length (18.74). Days taken to complete leaf fall recorded the lowest variation (14.27). Phenotypic variations for plant height and collar diameter ranged between moderate to high under all three environments. Maximum phenotypic variations for plant height was 26.34 in environment 3, followed by environment 2 (17.46) and environment 1 (16.78). Maximum variations for collar diameter was found in environment 3 (40.84), followed by environment 1 (18.08) and environment 2 (15.67). In environment 1, values of PCV were high for leaf area and number of branches and leaf less days, this indicated that the clones had high heterogeneity for loci affecting these traits and these loci also interact with micro and macro-environmental parameters to create high amount of phenotypic variations. On the other hand, characters like plant height, collar diameter, leaf length and days taken to complete leaf fall had moderate heterogeneity and showed small interactions with climatic factors. But in environment 3, high value of PCV for collar diameter and plant height indicated that the interactions of both the parameters with climatic factors were high.

4.3.1.2 Genotypic Variability

The perusal of the figures in table 10 revealed that the genotypic coefficient of variation (GCV) values were recorded between moderate to high for all characters recorded only under environment 1. Leaf area registered the highest GCV (36.33), followed by leaf less days (33.95) and number of branches (31.64). Lowest value of GCV was recorded for days taken to complete leaf fall (12.70). Values of GCV were observed between low to high for plant height and collar

Table 8: Final and incremental ranking of different clones for plant height under different environments

Clone	Environment 1		Environment 2		Environment 3	
	Final ranking	Incremental ranking	Final ranking	Incremental ranking	Final ranking	Incremental ranking
UHFS-1	12	18	1	11	6	8
UHFS-2	7	21	3	10	8	16
UHFS-3	5	11	15	15	4	2
UHFS-4	11	12	12	9	9	10
UHFS-5	9	14	14	13	15	16
UHFS-6	19	22	13	15	3	3
UHFS-7	20	20	5	5	2	4
UHFS-8	18	8	9	17	19	22
UHFS-9	15	17	11	17	17	9
UHFS-10	21	19	17	3	11	7
UHFS-11	13	13	2	1	5	4
UHFS-12	3	6	16	20	11	12
UHFS-13	1	1	4	6	14	19
UHFS-14	2	2	7	4	13	15
UHFS-15	14	7	18	22	17	20
UHFS-16	10	14	6	2	10	21
UHFS-17	5	10	21	21	7	13
UHFS-18	3	4	9	7	16	6
UHFS-19	16	9	19	13	1	1
UHFS-20	8	5	8	19	20	11
UHFS-21	22	14	22	12	22	14
UHFS-22	17	3	20	8	21	16

Environment 1 = University Seed Farm Ladhawal, Ludhiana.

Environment 2 = Badhian forest, Range and Division Dasuya

Environment 3 = Alamwala forest nursery, Range Malout, Division Faridkot.

Table 9: Final and incremental ranking of different clones for collar diameter under different environments

Clone	Environment 1		Environment 2		Environment 3	
	Final ranking	Incremental ranking	Final ranking	Incremental ranking	Final ranking	Incremental ranking
UHFS-1	8	10	1	4	4	6
UHFS-2	10	20	3	6	8	13
UHFS-3	3	4	11	12	2	2
UHFS-4	17	17	15	19	9	9
UHFS-5	7	8	15	17	15	20
UHFS-6	17	20	8	12	5	4
UHFS-7	14	14	4	2	3	3
UHFS-8	14	10	10	15	15	16
UHFS-9	5	6	12	18	13	7
UHFS-10	22	22	13	10	10	7
UHFS-11	17	19	2	1	6	5
UHFS-12	9	8	20	20	12	16
UHFS-13	1	1	8	15	13	20
UHFS-14	4	2	7	3	15	16
UHFS-15	12	10	18	22	11	12
UHFS-16	6	5	5	8	18	22
UHFS-17	10	15	22	20	7	15
UHFS-18	21	17	13	10	21	19
UHFS-19	2	2	6	5	1	1
UHFS-20	16	10	19	9	20	13
UHFS-21	12	7	17	6	22	10
UHFS-22	20	15	21	14	19	11

Environment 1 = University Seed Farm Ladhawal, Ludhiana.

Environment 2 = Badhian forest, Range and Division Dasuya

Environment 3 = Alamwala forest nursery, Range Malout, Division Faridkot.

diameter under all three environments. For plant height values of GCV was 9.79, 14.98, and 18.34 under environment 1, environment 2 and environment 3, respectively. Similarly, values of GCV for collar diameter were 8.57, 11.59 and 25.50 under environment 1, environment 2 and environment 3, respectively.

High value of GCV for leaf area, leaf less days and number of branches indicated that the amounts of genetic variations for these traits were high. Genetic variability is controlled by the number of loci affecting that trait and the intensity of their heterogeneity. Large the number of loci's and high the intensity of heterogeneity resulted in large genetic variation. It revealed that leaf area, leaf less days and number of branches were controlled by large number of loci's and the intensity of their heterogeneity was high. Lower value of GCV for plant height and collar diameter indicated that these were controlled by less number of loci's and intensity of their heterogeneity was low.

The higher values of PCV than GCV for all parameters under study was in consonance with the results observed by Sharma *et al* (2011), The existence of genotypic and phenotypic differences among white willow populations for rate of growth, length of growing season, leaf characteristics and branching was also reported by Kristinic (1979). Variations in plant height, leaf area and branching pattern was also reported by Tu and Pan (1984) in twenty clones of ten willow species.

4.3.2 Heritability (Broad sense)

Heritability values express the proportion of variation in the population that is attributed to genetic differences among individuals. It is therefore the degree to which the parents pass on their characteristics to their offspring. It also gives a measure of the accuracy with which the selection for a genotype can be made from a phenotype of the individual or group of individuals. The perusal of table 10 revealed that all the characters under study exhibited moderate to high heritability value. From the characters about which data was recorded only in environment 1, leaf less days showed the highest heritability (89.15%), whereas, number of branches recorded lowest (64.01%) heritability. But all these characters showed high heritability value ranging between 64.01% and 89.15%. This reveals that high genetic improvement is possible for these traits by selection on phenotypic traits. Branching traits are important to decide the selection of willow for different purposes i.e., phytoremediation, agroforestry, energy, etc. For plant height maximum heritability was recorded in environment 2 (73.61), followed by environment 3 (48.50) and environment 1 (34.05). Like plant height, collar diameter also followed the similar patten, maximum heritability for collar diameter was recorded in environment 2 (54.72), followed by environment 3 (38.97) and environment 1 (22.46).

The heritability values for different characters in the present study were high which revealed that moderate to high genetic improvement can be expected by selection on phenotypic basis. Results of the present study are in line with the observations of Arun (2009) for heritability of growth and biomass characters. High heritability of plant height as compared to diameter was also reported by Sharma *et al* (2011) in different tree willow species and hybrids and Ronnbey-Wastljung and Gullberb (1999) in *Salix viminalis*.

4.3.3 Genetic gain

The perusal of figures in table 10 revealed that all traits in environment 1 showed low to high genetic gain. Highest genetic gain of 67.73 (%) was registered by the leaf area, followed by leaf less days (66.04%) and number of branches (52.15%). Days taken to complete leaf fall exhibited the lowest (23.29%) genetic gain. Genetic gain for plant height and collar diameter was low under all three environments. Maximum genetic gain for plant height was found in environment 2 (26.48%), followed by environment 3 (26.32%) and environment 1 (11.77%). Similarly, maximum genetic gain for collar diameter was found in environment 3 (32.79%), followed by environment 2 (17.67%) and environment 1 (8.37%).

Table 10: Variability, heritability and genetic gain magnitude of different parameters under different environments

Sr. No.	Parameters	Environment	PCV(%)	GCV(%)	Heritability (%)	Genetic gain (%)
1	Leaf length	Environment 1	18.74	16.88	81.10	31.32
2	Leaf width		23.25	20.82	80.19	38.41
3	Leaf area		40.14	36.33	81.92	67.73
4	Days taken to complete leaf fall		14.27	12.70	79.20	23.29
5	Days taken for complete sprouting		25.23	22.03	76.27	39.64
6	Leaf less days		35.96	33.95	89.15	66.04
7	Number of branches		39.55	31.64	64.01	52.15
8	Plant height	Environment 1	16.78	9.79	34.05	11.77
		Environment 2	17.46	14.98	73.61	26.48
		Environment 3	26.34	18.34	48.50	26.32
9	Collar diameter	Environment 1	18.08	8.57	22.46	8.37
		Environment 2	15.67	11.59	54.72	17.67
		Environment 3	40.84	25.50	38.97	32.79

Environment 1 = University Seed Farm Lathowal, Ludhiana.

Environment 2 = Badhian forest, Range and Division Dasuya

Environment 3 = Alamwala forest nursery, Range Malout, Division Faridkot.

4.4 Correlation studies

Correlation studies help to reveal the degree of inter-relationship between different parameters. Some traits are strongly interlinked with each others as compared to others and it helps us to select clones for a particular trait on the basis of some other related traits. Even indirect selection can be facilitated through correlation coefficients, where easily measurable parameters can be used to select the plants for particular related parameter.

4.4.1 Environment 1

4.4.1.1 Genotypic Correlation

Genetic correlation values between different traits at USF Ladhawal (environment 1) are depicted in table 11. Plant height exhibited positive correlation with collar diameter, leaf width, days taken to complete leaf fall and days taken for complete sprouting and negative correlation with leaf length, leaf area, leaf less days and number of branches. But only collar diameter (0.3518) showed significant and positive correlation. Significant and negative correlation was recorded in leaf length (-0.3041) and leaf less days (-0.2481) with plant height. Collar diameter exhibited significant positive correlation with height, leaf length, leaf width, leaf area, days taken to complete leaf fall and days taken for complete sprouting. It also had significantly negative correlation with leaf less days. Leaf length had positive and significant correlation with collar diameter (0.2931), leaf width (0.7264) and leaf area (0.5754). Leaf width had positive and significant correlations with collar diameter, leaf length, leaf area and days taken for complete sprouting but significantly negative with leaf less days and number of branches. Leaf area had positive and significant correlations with collar diameter, leaf length, leaf width and days taken for complete sprouting. Days taken to complete leaf fall exhibited positive correlations with all traits except leaf length and leaf less days for which correlation is negative. But correlation was significant and positive only with collar diameter and negative only with leaf less days. Days taken for complete sprouting had positive and significant correlations with collar diameter, leaf width, leaf area, and leaf less days, whereas it had negative correlation with only number of branches. The only trait for which correlation with all other traits was positive and significant was days taken for complete sprouting.

4.4.1.2 Phenotypic Correlation

Phenotypic correlation between different traits at USF Ladhawal (environment 1) is given in table 11. The perusal of data of table 11 showed that plant height exhibited strong positive and significant phenotypic correlation with collar diameter and days taken to complete leaf fall. Collar diameter had significantly positive correlation with leaf width, leaf area and days taken to complete leaf fall. Correlation coefficient values were positive and significant between

Table 11: Genotypic and phenotypic correlation coefficient among different parameters at USF, Ladhawal (environment 1).

Parameters		Plant height	Collar diameter	Leaf length	Leaf width	Leaf area	Days to complete leaf fall	Days for complete sprouting	Leaf less days
Collar diameter	GC	0.3518**							
	PC	0.6706**							
Leaf length	GC	-0.3041*	0.2931*						
	PC	-0.1692	0.1214						
Leaf width	GC	0.0523	0.7264**	0.6831**					
	PC	-0.0122	0.2978*	0.6763**					
Leaf area	GC	-0.1482	0.5753**	0.8933**	0.9305**				
	PC	-0.0962	0.2551*	0.8869**	0.9294**				
Days to complete leaf fall	GC	0.1610	0.4964**	-0.0017	0.1685	0.0473			
	PC	0.3222**	0.5464**	-0.0025	0.0916	0.0285			
Days for complete sprouting	GC	0.1444	0.2672*	0.1852	0.4907**	0.3566*	0.0867		
	PC	0.1588	0.1742	0.1494	0.3710**	0.2751*	0.0455		
Leaf less days	GC	-0.2481*	0.7311**	0.0037	-0.2975*	-0.1660	-0.5325**	0.2711*	
	PC	-0.0378	-0.2336	-0.0149	-0.2438	-0.1538	-0.3408**	0.2049	
Number of branches	GC	-0.0904	-0.0601	-0.1369	-0.3239**	-0.2315	0.0614	-0.9105**	-0.5269**
	PC	-0.0953	-0.077	-0.1455	-0.2795*	-0.2118	0.0641	-0.8511**	-0.4501**

GC = Genotypic correlation, PC = Phenotypic correlation.

*- Significant at 5% level of significance

** - Significant at 1% level of significance

leaf length, leaf width and leaf area. Leaf width and leaf area also exhibited significantly positive correlations with days taken for complete sprouting. Correlation was negative but significant between leaf width and number of branches. Days taken for complete sprouting were in positive and significant correlation with leaf width and leaf area but significantly negative correlated with number of branches. Leaf less days was in negative and significant correlation with days taken to complete leaf fall and number of branches. Similarly number of branches exhibited negative but significant correlation with leaf width, days taken for complete sprouting and leaf less days.

Tunctaner (2002) and Sharma *et al* (2011) also observed highly significant correlation between plant height and collar diameter in their study on willow clones. Positive correlation between growth traits and late leaf abscission if present study was in line with the results of Weih (2009) on six willow varieties in central Sweden. Highly positive correlation between height and collar diameter of clones and negative correlation of plant height and collar diameter with leaf less days also confirmed the earlier findings of the Arun (2009) and Robinson *et al* (2004). But for correlation of plant height and collar diameter with other traits like leaf area and number of branches in present study contradicts the earlier findings of Arun (2009) and Robinson *et al* (2004).

4.4.2 Environment 2 and 3

The coefficients of genotypic and phenotypic correlation between plant height and collar diameter are given in table 12, which revealed that the strong positive correlation between both the parameters in environment 2 and 3. In environment 2 genotypic and phenotypic correlation values between plant height and collar diameter were 0.7665 and 0.7678, respectively. Similarly, values of genotypic and phenotypic correlation between plant height and collar diameter in environment 3 were 0.9068 and 0.7373, respectively.

Table 12: Correlation coefficient among plant height and collar diameter at Badhian forest (environment 2) and Alamwala forest nursery (environment 3).

		Environment 2	Environment 3
Parameters		Plant height	Plant height
Collar diameter	Genotypic correlation	0.7665**	0.9068**
	Phenotypic correlation	0.7678**	0.7373**

*- Significant at 5% level of significance

** - Significant at 1% level of significance

As both the phenotypic and genotypic correlation between collar diameter and plant height was highly positive and significant in all the three environments, so we can make selection on the basis of either collar diameter or plant height. As the correlation of height and collar diameter was negative with leaf less days, so for biomass production or phytoremediation, clones which remained leaf less for fewer days will be suitable. Similarly, positive correlation of clones with collar diameter will also help us to make selection of clones with large leaves for biomass production or phytoremediation. Negative correlation of number of branches with leaf less days was also favorable for biomass production or phytoremediation.

Data for the plant height and collar diameter of different *Salix* clones planted during Feb. 2009 and Feb. 2010 at University Seed Farm, Ladhawal, Ludhiana is given in the Appendix 1 and Appendix 2, respectively. Evaluation of data indicated the encouraging growth in some clones like PN733, PN227, PN731, V-311, UHFS-1, UHFS-3, UHFS-4, UHFS-5 and UHFS-6, which could be used for different purposes like timber, bio-energy, landscaping, etc.

Chapter V

SUMMARY

In Punjab, *Populus*, *Eucalyptus* and *Melia* are priority agroforestry trees for enhanced economics than traditional crop rotation. But, an another species i.e., willow which is multipurpose, fast growing and has lots of potential in sports industry, phytoremediation and biomass production can be introduced for agroforestry under diverse climatic and edaphic conditions of Punjab. Government of Punjab is trying to diversify rice-wheat cropping system due to continuous decrease in ground water table and pollution of soil and water due to high use of agro-chemicals. Willows belong to the genus *Salix*, family Salicaceae, are light demanding, deciduous trees and shrubs, found primarily on moist soils in cold and temperate regions of the northern hemisphere. Numbers of species of willows have adapted to a wide range of climatic and soil conditions. Being multipurpose agroforestry species, willows provide fuelwood, fodder, veneer, pulp, plywood, reconstituted wood products, artificial limbs, packing crates, agricultural implements, furniture, and sports goods. It is also helpful in protection of soil and water erosion and phytoremediation of degraded soils. They are often integrated with agriculture, horticulture, viticulture and apiculture. The objectives of this study was to identify the site specific clones based on their growth performance and to study the genotype and site interaction of introduced clones at three different locations in Punjab.

The study was conducted on twenty two clones received from Dr. Y.S.P. University of Horticulture and Forestry, Solan (HP). The trials of one year old nursery raised clones were established in randomized block design with three replications at three locations (Environment 1: University Seed Farm, Ladhawal, Ludhiana; Environment 2: Badhian Forest, Range & Division Dasuya and Environment 3: Alamwala, Range Malout, Division Faridkot). Soil samples analysis taken from different depths (0-15cm, 15-30cm, 30-60cm and 60-90cm) showed that Amount of N and P was low in all three environments and amount of K was in medium range in all three environments. Organic carbon per cent was low in environment 1 and environment 2. In environment 3 organic carbon per cent was in medium range. Range of pH and EC was within normal limits at all the three environments. Average maximum and minimum monthly temperature was almost similar in all three environments. Total rainfall was more in environment 1 as compared to other two environments but relative humidity was more in environment 3. The observations on growth parameters i.e., height and collar diameter was recorded at all three locations and for the rest of the traits (number of branches, leaf length, leaf width, leaf area, days taken to complete leaf fall, days taken to complete sprouting, leaf less days and insect/pest attack) data were collected only at USF, Ladhawal (environment 1).

Analysis of variance showed highly significant differences among the clones for all characters under study. Differences between the environments were also significant for plant height and collar diameter. The maximum height of 4.00m was attained by clone UHFS-13 in environment 1, 3.62m was attained by UHFS-1 in environment 2 and 5.39m was attained by UHFS-19 in environment 3. Performance of clone UHFS-21 was very poor in all the three environments. The environments mean was 3.23m, 2.83m and 3.01m for environment 1, environment 2 and environment 3, respectively. Like height, for collar diameter clone UHFS-13 in environment 1, clone UHFS-1 in environment 2 and clone UHFS-19 in environment 3 recorded maximum values of 3.57cm, 2.52cm and 4.82cm, respectively. Minimum collar diameter was reported in clone UHFS-10 (2.27cm) in environment 1, clone UHFS-17 (1.53cm) in environment 2 and clone UHFS-18 and UHFS-21 (1.67cm) in environment 3. The environments average values were 2.75cm, 1.91cm and 2.29cm for environment 1, environment 2 and environment 3, respectively. Maximum and minimum numbers of branches were recorded in clone UHFS-3 (22.33) and UHFS-18 (5.33), respectively. For leaf parameters, maximum values for leaf length (16.04cm), leaf width (1.99cm) and leaf area (29.91cm²) were observed in clone UHFS-21, UHFS-19 and UHFS-19, respectively. Whereas, clone UHFS-8, UHFS-2 and UHFS-2 registered minimum values for leaf length (7.87cm), leaf width (0.86cm) and leaf area (8.04cm²), respectively. Highest number of days taken to complete leaf fall were taken by clone UHFS-12 and UHFS-13, whereas, minimum days were reported in UHFS-16. Similarly maximum number of days taken for complete leaf sprouting, and maximum leaf less days were reported in clone UHFS-12 and UHFS-16, respectively, and minimum number of days taken for complete leaf sprouting, and minimum leaf less days were reported in clone UHFS-14 and UHFS-12, respectively.

Ranking of clones on the basis of performance showed large changes among three environments. Clones which performed good under one environment performed poorly under other environments and *vice versa*, due to differential response of clones in different environments. Clones UHFS-1, UHFS-3, UHFS-6, UHFS-10, UHFS-13, UHFS-14, UHFS-17 and UHFS-20 showed large differences in their performance for plant height among different environments. Performance of clone UHFS-2, UHFS-4, UHFS-5, UHFS-9, UHFS-15, UHFS-16, UHFS-21 and UHFS-22 was stable among the environments. But performance of clone UHFS-5, UHFS-9 and UHFS-15 was poor under all three environments. Likewise for collar diameter, clones UHFS-2, UHFS-3, UHFS-6, UHFS-7, UHFS-9, UHFS-11, UHFS-12 and UHFS-13 showed large variation in performance for collar diameter in different environments. Whereas, clone UHFS-1, UHFS-8, UHFS-19, UHFS-20 and UHFS-22 showed stable performance for

collar diameter among different environments. But performance of clone UHFS-20 and UHFS-22 was very poor under all three environments.

Values were found between low to high for phenotypic variations and between moderate to high for genotypic variations. Range of phenotypic coefficient of variation was found between 14.27 (days taken to complete leaf fall) and 40.84 (collar diameter). Similarly, range of genotypic coefficient of variation was found between 8.57 (collar diameter) and 36.33 (leaf area). Value of heritability was very high for characters like leaf parameters, leaf display and number of branches. For plant height and collar diameter heritability per cent ranged from low (22.46%) to high (54.72%) in different environments. Heritability per cent was higher for plant height in all three environments as compared to collar diameter. Genetic gain values were found in the range of low to high. High genetic gain reflects possibility in selection for number of branches, leaf less days and leaf area.

Highly positive genotypic and phenotypic correlation was observed between the plant height and collar diameter under all three environments. Plant height and collar diameter also showed significantly negative genotypic correlation with leaf less days. Genetic correlation of collar diameter was significantly positive with leaf area, days taken to complete leaf fall and days taken for complete sprouting. Phenotypic correlation of plant height and collar diameter was highly significant and positive with days taken to complete leaf fall. Collar diameter also showed positive correlation with leaf area of plants. Number of branches showed highly significant and negative phenotypic and genotypic correlation with days taken for complete sprouting and leaf less days.

Clone UHFS-13 showed the maximum growth for both plant height and collar diameter at USF Ladawal (environment 1). Overall performance of other clones on the basis of plant height and collar diameter was in the order of UHFS-14, UHFS-3, UHFS-12 and UHFS-19. Similarly performance of clones at Badhian forest (environment 2) was in the order of Clone UHFS-1, UHFS-11, UHFS-2, UHFS-7 and UHFS-16. On the basis of performance and increment in growth factors clone UHFS-1 and UHFS-19 had wider adaptability. In Alamwal forest nursery (environment 3), clone UHFS-19 registered the maximum growth than all other clones, and order of the performance of other clones was UHFS-3, UHFS-7, UHFS-1, UHFS-6 and UHFS-11. For agroforestry, clone UHFS-2, UHFS-5, UHFS-12 and UHFS-18 will be suitable due to less number of branches, small leaf area, large days in leaf less phase and good growth. For biofuel or phytoremediation, clone UHFS-3, UHFS-13, UHFS-14 and UHFS-16 will be suitable due to good growth, large number of branches, large leaf area, and less days in leaf less phase. Clone UHFS-10 can be used for landscape purposes due to its dropping nature of branches.

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Appendix 1: Growth performance of *Salix* clones (Planting Feb. 2009)

Clone	Plant Height	Collar Diameter
NZ1179	3.26	3.28
SI-63-007	4.35	6.38
NZ1040	5.32	6.50
SE63-616	2.85	4.92
MP368	3.92	5.60
SE75001	2.99	4.28
PN733	6.18	11.88
NZ1140	5.38	9.02
NZ1130	4.70	6.12
795	3.40	3.15
SE69002	4.35	6.18
799	5.22	7.50
V-99	4.60	7.58
PN227	6.92	9.08
PN722	4.72	6.55
131/25	6.35	9.42
SE64-017	5.05	6.50
Kashmiri	4.70	7.50
PN731	7.22	11.12
212/03	6.55	7.88
V-311	5.45	10.48
NZ1002	4.98	7.00
17-93A	2.82	2.27
PN721	3.38	2.98
Mean	4.78	6.80
CD (5%)	1.25	2.35

Appendix 2: Growth performance of *Salix* clones (planting Feb. 2010)

Clone	Plant Height	Collar Diameter
UHFS-1	6.80	11.50
UHFS-2	5.63	10.67
UHFS-3	6.03	11.23
UHFS-4	6.22	11.50
UHFS-5	8.43	10.83
UHFS-6	6.67	10.90
UHFS-7	6.17	10.23
UHFS-8	4.00	6.97
UHFS-9	4.03	7.03
UHFS-10	3.80	6.50
UHFS-11	3.33	5.30
UHFS-12	5.37	6.87
UHFS-13	4.28	4.83
UHFS-14	5.20	8.33
UHFS-15	4.23	7.27
UHFS-16	4.17	8.77
Mean	5.27	8.67
CD (5 %)	1.03	1.73

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