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Bertha Alicia Hernandez-Leos

Utah State University

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WATER UPTAKE, WATER RELATIONS, TREE GROWTH, AND ROOT DISTRIBUTION UNDER HERBACEOUS COMPETITION

by

Bertha Alicia Hernández Leos

A dissertation submitted in partial fulfillment
of the requirements for the degree

of

DOCTOR OF PHILOSOPHY

in

Plant Science

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ABSTRACT

Water Uptake, Water Relations, Tree Growth, and Root Distribution under Herbaceous Competition

by

Bertha A. Hernández-Leos, Doctor of Philosophy

Utah State University, 1998

Major Professor: Dr Roger Kjelgren
Department: Plants, Soils, and Biometeorology

There are numerous situations where trees are grown together with herbaceous plants. In these situations there will be some degree of competition between their root zones, depending on the water content of the soils and crop and tree root distribution. Two studies were conducted: the first with maple (*Acer platanoides*) grown in turf grass, and the second with willow (*Salix matsudana*) grown in more deeply rooted barley. The objectives of this study were to quantify the effect of herbaceous competition of potential tree water stress under irrigation and when the soil is allowed to dry-down. Soil water uptake was measured in both studies to 1.2 m depth and outwards to 1.2-2.10 m away from the tree. In the maple-turf grass study, water content was measured in a single line away from the tree, while four lines covering a quadrant of the surface area were measured in willow. Water relations stomatal conductance and water potential, and tree growth were also monitored in both studies. Water uptake in turf plots was statistically different from mulch plots by depth and distance during three seasons. Water uptake was greatest at 0-60 cm depth in the turf treatments compared with mulch treatments. Soil water in mulched plots decreased slowly during the growing season. There were no statistical differences between bare soil and barley competition water uptake after soil surface water was depleted.

There were marked differences in tree root characteristics as a result of competition from turf or barley roots. The root systems of maples in the mulch and willow in bare soil extended laterally and fine roots were evident. Tree roots extended deeper and fine root were reduced under competition from turf and barley. Trees growing with turf and barley had fewer roots in the top 0.3 m soil surface while trees in mulch and bare soil had more and greater diameter roots at the same depth. Early in the season, when water content is high, root competition for water was not evident, and late in the season after turf roots and barley had depleted the soil water, trees exhibited more negative predawn leaf water potential and less stomatal conductance in response to water stress during a soil dry-down period. Tree growth was measured periodically during 1994, 1995, and 1996. Leaf area and stem growth comparisons showed a significant increase in size as a result of the absence of competition in both species, with mulch and bare soil treatments. Leaf area in mulched trees was twice that in turf treatments. In summary, we found that competition resulted in deeper tree root growth and less top growth in the presence of herbaceous competitors.

(117 pages)

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Bertha Alicia Hernández Leos

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CHAPTER 1

INTRODUCTION AND LITERATURE REVIEW

Introduction

Woody plants are the major component of several different systems of plant culture, such as pomology, forestry, and landscape horticulture. There are several situations where woody plants are grown in competition with herbaceous crops such as ground covers in orchard crops, intercropping woody and herbaceous crops, landscape trees, and turf. Woody plants are generally of higher value than herbaceous plants due to greater investment in time and management to get them to where they are producing or meeting expectations. In these situations, maximum performance is expected of both woody and herbaceous vegetation. Growing woody and herbaceous plants together means intermingling root systems and increasing competition for soil resources. Nutrients, especially nitrogen and water (Harris 1983; Kramer 1987), can be more rapidly depleted when extracted by competing root systems. In particular, understanding how competition affects water uptake is critical because soil water can be depleted rapidly and water deficiency occurs quickly and severely in both herbaceous and woody plants. Any woody and herbaceous culture system has trees or shrubs spaced enough apart that herbaceous plants receive enough light. Such spacing allows vigorous herbaceous growth and high demand for nutrients and water (Van Noordwijk and Purnomosidhi 1995). For example, grasses, with their numerous roots, are competitively superior to trees in acquiring water from the upper soil horizons (Belsky 1994).

The effects of competition below ground are known more by manifestations than mechanisms (Caldwell 1987). Trees stressed for resources due to competition produce less leaf area and therefore intercept less radiation and produce less stem wood (Nambiar and Sands 1993). Leaf area by itself is strongly determined by water and nutrient uptake (Allen et al. 1990).

With increased emphasis on landscape water conservation, irrigation of turf is being scheduled more closely. This results in more uniform application and fewer wet spots from which trees can increase water uptake. We do not know if trees are under greater water stress under more closely scheduled irrigation, and are more susceptible to water stress when turf irrigation is halted, for example during a drought.

The overall goal of this research was to determine if trees competing with herbaceous groundcover for rooting space and water are more susceptible to soil water deficits than those without competition. The supporting specific objectives are to:

1. Determine spatial patterns of soil water depletion of tree root systems under herbaceous competition under irrigation and during dry-down period;
2. Define the spatial distribution of tree roots in the soil with and without herbaceous competition;
3. Evaluate tree water relations with and without competition;
4. Determine the effect of herbaceous competition on overall tree growth.

Literature Review

Plant root systems provide water, nutrients, and growth regulators to the shoots. Growth and production of a plant are often limited by the ability of roots to extract water and nutrients. Suboptimal resource availability due to competition, and decreasing water or nutrient availability, reduces shoot growth (Fernandez et al. 1991). Initial root system development is generally under genetic control, but environmental factors predominate later in the plant life cycle. Rooting density is greater near the soil surface because of more favorable nutrient, aeration, and temperature conditions, but decreases exponentially with depth. This pattern of rooting can be modified by changes in the soil environment (Sands and Mulligan 1990). Variations in rooting patterns follow variation in soil type, soil aeration, soil temperature, and nutrient status of the soil,

soil pH, water availability, climate cropping practice, and plant genotypes. In particular, competition below ground affects rooting patterns where root systems of neighboring plants compete for soil resources such as moisture and nutrients (Caldwell 1987).

The water status of soil has a pronounced effect on development, morphology, and growth of roots (Gregory 1987; Kozlowski 1987). Soil-water status greatly alters the density of roots in the soil and therefore adaptation of a plant community to a given site (Sainju and Good 1993). Like most plants, roots of a large tree grow primarily in the top meter of soil, where the majority of small absorbing roots are concentrated (Atkinson 1980). The small amount of roots deeper in the soil profile may obtain nutrients but, quantitatively, this is likely to be small and their functions seems to be water uptake, especially in times of stress (Nambiar 1983).

The rate of water absorption by tree roots is not an independent process, but rather is controlled largely by the rate at which water is lost by transpiration (Koslowski 1987; Roberts 1987). However, root water absorption often is impeded by low soil moisture content. Water uptake from soil depends on root density and distribution, differences between root water and soil water potential, and the transmisivity of soil to water (Stone et al. 1976). Root density by itself is useless in the analysis of water uptake (Landsberg and McMurtrie 1984). A better measure is root surface area and root distribution within the soil (Atkinson 1980). Surface area of roots rather than length or mass is a better measure because root surface area is more directly related to absorptive potential, just as leaf area is a more direct measure of photosynthetic potential.

Water stress alters the configuration of the root system (Cripps 1976). Some woody plants reduce root growth under water stress conditions, such as conifers in competition with weeds. Others develop a shallow and laterally extending root system, for example cacti and native junipers. Some species in arid areas have deep roots reaching water resources deep in the soil. However, frequent light showers of rain or frequent irrigation encourages the proliferation of a shallower root system (Gregory 1987). In general, well watered crops in uniform soil follow the rule of thumb that about 40% of the roots are in the top foot, 30% in the second foot, 20% in the third foot, and 10% in the fourth foot. However, during drought conditions and with herbaceous competition, trees will have a more complex root pattern.

Water uptake from deep roots is minor under normal soil water conditions, since trees preferentially absorb water from the upper layers of soil. Only after the upper soil is largely depleted does absorption begin from deeper in the soil (Harris 1983). Hydraulic lift is one mechanism of water movement from wet to dry zones by woody plants (Caldwell 1990; Dawson 1993; Dawson 1996). This movement increases the woody plant's ability to compete for water with the surrounding herbaceous vegetation. Dawson (1996) conducted an experiment to estimate the use of soil water and groundwater by open grown *Acer saccharum* tree canopies by measuring transpiration. Daily transpiration rates of large trees (9-14 m tall) were significantly higher than those of small trees (3-5 m tall). Also, small trees showed a greater sensitivity to environmental factors that influence transpiration, such as water deficits and increased evaporative demand. Large trees transpired only groundwater obtained by hydraulic lift, while in contrast small trees transpired exclusively soil water and exhibited no hydraulic lift.

Many studies prove that there is a detectable amount of lifted water released from the roots during the nighttime period in shallow dry soils where the greatest concentrations of roots usually occur. This creates a zone of moistened soil from which plants can supply the transpiration demand. Hydraulic lift was found in arid, semiarid, and mesic environments where water supply needed for growth is almost always limiting (Caldwell 1990). Hydraulic lift also was found in different plants species such as sugar maple, sagebrush, half-shrub *Gutierrezia sarothrae*, and in *Prosopis tamarug*, a small tree found in northern Chile. Herbaceous crop species have also shown that root systems can transfer water to drier regions of a split root container (Corak et al. 1987), similar to behavior found in woody taxa (Mooney et al. 1980).

It is commonly accepted that the soil environment can modify the root growth form within genetic constrains (Harris 1983). Soil moisture and nutrients are not uniformly distributed spatially or temporally. Thus the ability of root systems to change growth patterns and relocate zones of active absorption, even on a small scale, may be a particular advantage (Caldwell 1987). Variations in rooting pattern are produced by such factors as soil type, soil aeration, soil temperature, nutrient status of the soil, soil pH, water availability, climate cropping practice, and plant genotypes (Stone et al. 1976). An increase of root depth and density is considered a major mechanism for improved water uptake (Turner 1990).

The water uptake capacity of tree roots is proportional to their root density and distribution in the soil profile (Callaway 1990). Since this water uptake has an impact on growth and tree water relations, there is a considerable interest in studies on tree root distribution under herbaceous competition (Watson 1988). Turf grass competition can inhibit tree fine root development in the soil surface (Watson 1988). Competition between tree and grass roots may alter the periodicity and the distribution of tree root growth and hence the potential exploitation of soil water and nutrients (Atkinson et al. 1976). Once established, trees may be able to outcompete herbaceous crops for water uptake, since the tree root system is able to exploit water in deeper parts of the profile (Sands and Nambiar 1983). In contrast, Nambiar (1990) states that herbaceous crops have a strong competitive advantage over trees for soil water and nutrients due to higher relative amounts of roots. Atkinson (1980) gives an estimate of total root length of 35-100 cm cm^{-2} for tree roots and 100-400 cm cm^{-2} for herbaceous crops in the topsoil of temperate regions. Root densities of woody plants, crops, and grasses are generally estimated at 0.1-0.5, 1-5, and 5-50 cm cm^{-3}, respectively.

Trees develop relatively more deep roots in the presence of an herbage layer. The presence of competing root systems in the top soil, either from neighboring trees planted at narrow spacing or from associated pastures, has been shown to increase the rooting depth of trees

Mulches usually encourage roots to grow deep as well as close to the surface (Harris 1983). Soils covered with mulches retain their organic matter (Haynes 1980), have less surface evaporation, and have greater water infiltration (Skroch and Shribbs 1986). Moisture can accumulate under mulch because water vapor in the soil condenses on the cool mulch particles at night. This conserved moisture may be equivalent to 0.1 mm (0.004 in) of rain per day (Harris 1983). Mulches maintain soil water content at a higher level than under exposed soil conditions (Dancer 1964). Greenly and Rakow (1995), in a study with two different wood mulches (chipped pine and shredded hardwood chips) and three mulch depths (7.5, 15, and 25 cm), found no differences between mulch types (soil temperatures declined and moisture levels increased) under both mulches. Stem growth was greater with 7.5 cm mulch depth.

Trees can increase water uptake from localized areas of high soil water content. Because only a limited soil volume is wetted by drip irrigation, it is important that sufficient root growth occur within the wetted volume to take up the water. Research on fruit trees has shown that the smaller wetted area produces a smaller root zone compared to flood or sprinkle irrigation. Fernandez et al. (1991), in a study with olive trees and drip irrigation, found that the highest root densities occur down to 0.6 m depth, the most abundant being the < 0.5 mm diameter roots, and intensive root activity was also found at that depth. In a study of root distribution under drip (trickle) irrigation, Cripps (1976) found that root distribution was affected by moisture and nutrients distribution in the wetted zone. In another study, kiwifruit vines were able to shift rapidly their pattern of water uptake away from drier parts of the root zone and began to extract water from regions where water was freely available (Green and Clothier 1995).

Numerous studies have found that water quantity available to plants in a drying soil depends on the rate at which roots extend throughout the profile. Tree root penetration into deep soil is related to variation in depth of soil moisture as a result of variation in soil texture and soil depth. Roots generally proliferate into soil layers offering the greatest moisture and nutrient supply if also well aerated. Measurement of soil water content has shown that the water extraction or drying fronts downward is closely related to that of the rooting front (Ong 1996). Other important considerations driving water stress are how stomata respond to drying soil and the implications of this phenomenon on tree growth leaf area and stem growth (Nambiar and Sands 1993). The closure of stomata in response to declining soil water is the most important process in the protection of plants from exposure to severe water stress (Turner 1990; Perry et al. 1994). However, stomatal aperture is also sensitive to a number of environmental factors that include water relations, irradiance, temperature, and air water vapor concentration difference.

Stomatal conductance is a sensitive measure of plant water status (Turner 1990; Breda et al. 1995). When water supply in the root is adequate, stomatal opening is determined primarily by irradiance (Punthakey et al. 1984). In contrast, water stress can cause partial to full closure of stomata during day, depending on the degree of stress. Stomatal closure has been reported in plants with partially drought-stressed root systems (Davies et al. 1990), subjected to decreased irrigation frequency (Tan and Layne 1991), and in competition with herbaceous plants (Nambiar and Sands 1993). Midday stomatal closure is characteristic of plant water stress. Midday closure usually develops when low soil water supplies limit water absorption, increasing water potential gradients through the plant.

Water stress is commonly measured as predawn leaf water potential (Clark and Kjelgren 1990). Crombie et al. (1988), in a study of tree response to drought, found seasonal patterns of predawn water potential that differed between species according to root depth. Predawn water potential fell most rapidly in trees with a shallow root system, and between the medium-rooted and deep-rooted species there were no differences in severity of water stress. During initial soil drying, plants tend to alter their metabolism to reduce growth. Gallego et al. (1994), in a study with *Quercus* under two extreme rainfall conditions, found that leaf water potential in the early morning was lower at dry sites than wet sites and stomatal conductance increased during the

Based on the above discussion, little is known about the way in which roots compete for soil water and about the pattern of tree water relations when the soil is allowed to dry. However, there are some indications that the plant may change the root form and size according to soil water and nutrients present in the soil space where the tree is developing in competition with herbaceous plants.

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CHAPTER 2

MAPLE TREE GROWTH (*Acer platanoides*) WATER UPTAKE, WATER RELATIONS, AND ROOT DISTRIBUTION UNDER MULCH AND TURF COMPETITION

Abstract. The effect of turf competition and irrigation on tree response was investigated. Four treatments, turf grass and mulch surface covers under high and low irrigation regimes were used to characterize root distribution, soil and plant water relations and tree growth, in a maple tree (*Acer platanoides*). Soil water content, water uptake, stomatal conductance, and leaf predawn water potential were monitored in three seasons (1994 to 1996), and leaf area and stem growth were measured. Soil water content was measured at three distances from the tree (0.3, 0.6, and 0.9 m) and four depths (0.3, 0.6, 0.9, and 1.20 m). Each year water was withheld for a limited period from the turf to allow the soil water to be depleted. Early in the season, when water content was high, root competition for water was not evident. Later in the season, after tree and turf roots depleted top soil water, competition for water was apparent, particularly during the dry-down period. Water uptake in turf plots occurred mainly in the 0-0.6 m depth and was significantly greater than mulched plots. Soil water content decreased slowly in all soil layers in mulched plots. Predawn leaf water potential started to decrease at the same time soil water content was depleted at the soil surface, and declined to seasonal low values during the dry-down period. Stomatal conductance was higher when water was available, and midday closure was apparent in all treatments in the dawn to dusk studies. Root distribution was in the top layer (0.3 m depth) in mulched plots, and roots with large diameter and also fine roots were visible at this depth. Tree roots in turf plots were found below 0.3 m depth, with less diameter and fewer fine roots. Leaf area and stem growth were significantly greater in trees surrounded by mulch than in trees surrounded by turf. There was no irrigation effect during the three seasons

Introduction

Woody plants are commonly planted in turf grass in landscapes. Woody plants are of generally more importance and higher value than herbaceous plants due to greater investment in time and management to get them to where they are producing or meeting expectations. In arid regions these landscapes are generally irrigated with the amount of water necessary for turf growth. Less attention, however, is given to tree water needs. Trees in landscapes are more subject to water stress than from other causes (Harris 1983). Trees under water stress generally develop a deep root system (Atkinson et al. 1976) in order to obtain sufficient water for shoot development (Kramer 1987).

Tree and grass roots have different root densities and distribution in the soil. Herbaceous roots are concentrated in upper soil layers while woody roots tend to grow primarily in the top meter of soil (Harris 1983). In an established tree and ground cover association, as soon as root systems overlap there will be competition for soil water. In addition, turf will intercept percolating water from rain and irrigation before that water reaches tree roots. The magnitude of this competition will depend on the spatial distribution of soil water content, root density, and root depth in the volume of soil shared by trees and herbaceous plants. Under normal circumstances for trees in turf, nonuniformity of irrigation systems usually provides localized wet spots in which tree roots enhance water uptake such that they take up enough water. Mulch is another common surface cover in landscapes. Mulching has a number of benefits for trees such as reduced weed competition and less surface evaporation (Watson 1988).

Water conservation is becoming more important in landscape management. Conserving water involves improving distribution uniformity of the irrigation and scheduling timing and amount of water application. This results in less over irrigation and fewer localized wet spots in the soil. Trees in these situations maybe more subject to water stress when turf irrigation is more uniform and closely scheduled. Also, when turf irrigation is halted during a drought the potential for increased susceptibility to drought for trees growing in closely scheduled turf is unknown. The objective of this study is to investigate the magnitude of turf and tree water competition, tree water relations response and tree growth under this condition compared with tree with mulch surface cover.

Materials and Methods

Experimental layout. The experiment was conducted from 1994-1996 at the Utah State University, Greenville research farm in North Logan, at 45’ N 111^0 49’ W and 1341 m a.s.l. The soil was a moderately to well drained Millville Silt loam with moderate permeability. Turf sod was laid in spring 1993, and 2.5 m branched Norway maple (*Acer platanoides* “Emerald Queen”) whips were planted shortly thereafter. Trees and turf were allowed to establish for one year, and data collection commenced in the spring 1994. The experimental design was a two-way randomized complete block, with turf (Kentucky bluegrass *Poa pratensis*) and mulch (chipped conifer bark), and high and low irrigation treatments. Each surface irrigation treatment plot was 4.0 x 4.0 m square with a tree planted in the middle, replicated five times.

Two types of irrigation system were used. In turf plots, two spray head sprinklers were located in the center of the plot, approximately 20-30 cm from tree, in the north side, with a precipitation rate of approximately 7 mm/h, that wetted 90% of the entire plot area. An irrigation uniformity test was run in each season (Or and Hanks 1992). Irrigation was scheduled using pan evaporation data and neutron probe readings as a guide. Irrigation application was calculated to replace the soil depleted by the turf grass. This soil has a soil water holding capacity of 0.17 mm water per mm of soil (Or 1990). It was assumed that 50% of the water holding capacity could be depleted without water stress and turf rooting depth at 400 mm. Consequently the objective was to apply 25 mm to the turf grass surface area at each irrigation, using the reference Et from the weather station to schedule irrigation. During the summer, the irrigation system was operated two times a week in the turf high (TH) irrigated plots, and once a week in the low irrigated turf (TL) plots. In mulch plots, a 4-liter/h drip emitter was used, and placed in the center of the plot close to the tree. In mulched plots, the irrigation was operated one time during the summer in the irrigated plots (MH) and none in the low irrigated mulch (ML). Major nutrients were applied at the beginning of each summer; N was applied as urea (tree rate nitrogen 908 $gr/100m^2$). Turf plots were mowed once a week. Weather data were collected from the Utah Climate Center weather station located 200 m from the experimental plots.

Tree water relations/Leaf water potential. The predawn leaf water potential (Ψp) was measured during the 1995-1996 growing seasons with a Scholander-type pressure chamber (Model 3005, Soil Moisture, Inc. Santa Barbara CA). Measurements were made in the five replicate plots in all treatments. Measurements were taken on a single representative mature leaf of each tree. Leaves were excised at the petiole base from the middle of the crown in the east part of the tree; the leaf sample was always taken on the same side of the crown during the three years. Samples were wrapped in a foil aluminum bag immediately after cutting and stored in an insulating box until balance pressure was measured (Karlie and Ritchie 1976). Predawn leaf water potential was measured on a weekly basis throughout the summer starting in July and ending in August. Leaf water potential sampling took about 15 min and was timed to finish shortly before sunrise. The time required for sampling and the subsequent measurements in the pressure chamber was approximately 1-1.30 h.

Midday stomatal conductance (gs) readings were taken 12 times during 1994, with a steady-state porometer (Model 1600, Li-Cor. Inc., Lincoln NE). These studies were conducted at 2-3 day intervals, always between 12:00 and 14:00 h. Measurements were taken on three sun and two shaded leaves at mid-crown level. During 1995 and 1996, dawn to dusk stomatal conductance studies were conducted on July 20 and August10, 1995, and July 10 and August 20, 1996. Data collection commenced at 08:00 h in each day and continued in cycles until 19:00 or

20:00 h. In 1994 and 1996, four sun and two shaded leaves were measured with the steady-state porometer. Leaf and surface temperature (turf and mulch) were measured with an infrared thermometer (Model 210 Everest Interscience Inc., Fullerton CA) concurrent with gs measurements. Each data collection cycle of stomatal conductance and leaf and surface temperatures on all 20 trees took 45-60 min; after a 1-h break, the data collection cycle was repeated.

Soil water content. Soil water content was determined using a neutron probe (CPN Model 503 Hydroprobe Martinez, CA). The probe was calibrated in situ by correlating count ratios with volumetric water content of undisturbed cores determined gravimetrically during installation of access tubes. Three tubes were installed in each plot on the south side of the tree and tubes were spaced at 0.3-m intervals, ranging in distance from 0.3 m to 0.9 m from the truck. Access tubes were installed to a depth of 1.20 m and readings were taken in 0.3-m increments from 0.3 m to 1.20 m. In 1996, one more distance was added (1.50 m) and the 0.3-m distance was dropped from data collection due to tree growth and fewer differences between distances closer to the tree. Soil water depletion was monitored 24 h after an irrigation event, once per week in the TL and mulched plots, and twice a week in the TH plots. Irrigation was withheld once in late summer to allow the soil moisture at the soil surface to be depleted in turf plots during the three seasons, to determine if trees in turf during this period were in stress. During the dry-down period, soil water content data were taken twice per week for all treatments. Water uptake was calculated from changes in water content measured between two dates. Water content in the surface soil layer (0-0.3m) was taken as equivalent to the value of 0-0.3 m depth.

Soil water measurements were taken on 20 dates during summer 1994 for turf plots and 21dates for mulch plots. The time interval ranged from 3 to 5 days between irrigation in both turf treatments, and covered a period from June to September. In 1995 and 1996, the time interval between water content readings ranged from 3-5 days in turf and 8-10 days in mulched plots.

During 1995, 22 and 20 measurements were taken from turf and mulched plots, respectively. In 1996, 11 measurements were collected for both turf and mulch treatments.

Root distribution. Distribution of tree roots was measured in fall 1996. A soil trench, 3.5 m long and 1.2 m deep, was dug 0.1 to 0.2 m away from the tree trunk. One trench per tree and two trees per treatment were exposed for root count using a backhoe. After excavation the wall was washed by a pressurized spray of water to expose 1-2 cm of roots. A wooden frame (1.0 x 1.0 m) divided in 10 x 10 cm sections was attached to the wall and all exposed roots were drawn, and woody roots greater than 1.0 mm diameter were counted and their diameter measured. The frame was moved along the wall, so all roots in each section were counted. Grass roots were easily distinguished from tree roots due to their greater density, vertical orientation, and brown color.

Tree growth. Stem diameter was measured at the end of 1995 and 1996 seasons, where two measurements were taken N-S and E-W with the electronic digital caliper (Model P6394 SHAN, China) and then both measurements were averaged. This measurement was done at 0.25 m above the soil surface at the end of the 1995 and 1996 growing seasons.

Leaf nitrogen content were measured on 25 leaf samples per treatment in October 1995, in June and November 1996. In June 1996, leaf N content was measured because foliage became light green for trees in turf. The Utah State University Soil Testing Lab performed leaf analysis.

At the end of each summer and before a natural defoliation, all trees were defoliated manually and a 25 leaves subsample was collected. The leaf area of the subsample was measured with a leaf area meter (Model CI-203 CID Inc., Vancouver WA.) and then both bulk and subsampled leaves were dried on the oven at 20^0C, and weighed. Total area was the product of bulk weight and subsample area:weight ratio.

Data analysis. The leaf water potential, leaf area, stem diameter, and stomatal conductance were analyzed as randomized block designs using the ANOVA procedure in

MINITAB. The soil moisture data were analyzed using a split-split-split plot design, with the whole plot being the surface cover and the irrigation treatments and the subplot soil moisture by tubes (distances 0.3, 0.6, and 0.9 m from tree) and the sub-subplot treatments were the depths which soil moisture was taken (0.3, 0.6, 0.9, and 1.2 m), and sub-sub-subplot treatments were dates in each season. The variance was pooled for soil water content. The whole plot was arranged in blocks with each block being an individual tree. There were two surface covers and two irrigation treatments and five replicates for a total of 20 plots.

Results

Weather data. Rainfall and evaporation data varied substantially among years (Fig. 2.1). Logan typically has little rainfall during the summer growing season, but 1994 was hotter and drier than normal. During the 1994 growing season, precipitation was below average for all months. From May to August, precipitation was 28 mm while average precipitation for the same period is normally 115. Summer evaporation was 956 mm in 1994 and average evaporation is 908 mm.

In contrast to 1994, 1995 was wetter and cooler than the normal average, while 1996 weather data was in-between. During 1995, precipitation from May to August was 194 mm. Evaporation was 834 mm versus an average 908 mm for the same period. In particular, May and June precipitation was twice the average but August and September precipitation was below the average. During 1996, precipitation during the growing season was 125 mm, a little more than the historical average. May precipitation was above average, June was below, and July was above the long-term average. Evaporation was 908 mm, the same as the historical average. During the dry-down period in each year there was no precipitation.

Soil water content. In a comparison of the results between surface covers, soil water use was significantly greater in turf compared with mulch during all three years of the experiment

(Appendix Tables A.1, A.2, and A.3). Soil water use was also significantly different by distance during the three years.

In 1994, water content in both mulched treatments followed each other closely and water content varied little by depth and distance (Fig. 2.2). The effect of irrigation, however, was evident in the top layer in the MH treatment, as water content always increased after irrigation. Water content decreased steadily in the ML plots by 4 to 6% at all depths and all distances. The MH and ML plots showed few differences in soil water content and water uptake early in the season and none later. Water uptake in the turf plots was significantly greater and more variable than in mulch plots due to irrigation. Water uptake also decreased significantly away from the tree in the mulch plots, but did not decrease with distance in turf. At 0.6 m depth there were few differences in water content between turf and mulch treatments. The TH and TL plots extracted significantly more soil water than the mulch plots at 0.3 m than from 0.6 m and 0.9 m, but not at the 0.9 and 1.2 m. TL plots had the lowest soil water content, and this difference was most visible during the dry-down cycle. At 0.9 and 1.20 m depth at all distances the pattern of water content followed the same trend observed in the middle layer, where TL had the lowest soil water content. An irrigation effect in the TH irrigation was evident in the top layer and at all distances.

Overall water content in 1995 was higher compared to 1994, as precipitation was greater than average; 1995 was the wettest of the three seasons and also the coldest. Water content in the mulch treatments again showed little change by depth and distance. An irrigation effect in the MH plot was observable closer to the tree at 0.3 and 0.6 m depth (Fig. 2.3). Water content in the turf treatments showed the same trend as in 1994. Increased water content from irrigation was evident at 0.3 m close to the tree, but there was little increase at 0.6 m depth in the TH plots. A similar irrigation effect was observed only at 0.3 m in the TL plots close to the tree, but less pronounced than TH due to less frequent irrigation. The TL plots had the lowest soil water content at 0.3 m close to the tree. Below 0.6 m depth there was little variation in water content under turf at all distances, and by 1.2 m water content did not vary at all among treatments. The decline in water content in 1995 was much less than the 1994 season because of the 194 mm of rain that fell during the growing season.

In 1996, soil water content under mulch had different behavior than 1994 and 1995 (Fig. 2.4). The mulched plots had a larger change in the water content at 0.9 and 1.20 m depth than previous years. Neither mulch treatment was irrigated in 1996, but in order to differentiate treatments, they are separately labeled. Differences in water content between turf and mulch treatments were greater at 0.6 m and depth and below compared to previous years. Away from the tree, water content under mulch showed little variation at all depths. Water content under turf treatments was higher due to the water applied to establish the additional turf. The pattern of soil water content during this season was completely different than that observed in 1994 and 1995. Irrigation effects were barely detectable at 0.3 m, and then soil water content decreased with time in all treatments and all depths.

Comparing water content and soil water use during the three years, we found that it was significantly different in turf during the three seasons. Differences between distances were minimal in turf plots in 1994. In contrast, during 1995 season differences among distances at 0.3 m depth were larger, but soil water content was equally depleted at all distances at 0.6 and 1.2 m. In 1996 soil water use was different in all distances from the tree except at 0.3 m where water was equally depleted regardless of distance from tree.

The cover x depth interaction was significant because more soil water was depleted by turf at 0.3 m and 0.6 m. There was no effect of irrigation except in 1994, where the irrigation x depth interaction was significant due to the TH trees depleting more soil water content at 0.3-0.6 m compared with TL trees. The distance x depth interaction was not different in 1994. In turf, soil water content was depleted at the same rate at all depths close to the tree, and depletion away from the tree followed the same trend, greater in the top layer and decreasing with depth. Early in the season when soil water content was higher, depletion was higher at 0.3 m in both mulch and turf treatments. Later, after this water was depleted, few differences were found in mulch treatments by distance and depth.

Water uptake during the dry-down period. Water uptake was significantly higher under turf than mulch during the dry-down period (DDP) on all three seasons, but differences were greater in 1994 and the least at 1996. Turf treatments depleted the top layer first, and during the DDP this depletion was also deeper in the soil profile, particularly in 1994 when the DDP was longer. Tree water uptake under mulch was no different between treatments during the DDP all three years, apart from an irrigation effect in 1995, closer to tree in the MH, irrigation was scheduled during the DDP in MH treatment.

During the dry-down period all three years, water was withheld from turf treatments for 18 to 27 days (Fig. 2.5). All treatments showed different water uptake patterns by season, by distance, and by depth. In 1994 DDP was the longest compared with the other seasons, 22 days for TH plots and 27 days in TL plots. Tree water uptake in the mulch treatments during the DDP was minimal and varied little by distance and depth. Water uptake in turf plots was significantly higher than under mulch during the DDP. TH and TL plots had the same trend at all distances, with the highest water uptake at 0.3 and 0.6 m depth and the lowest at 0.9 and 1.20 m depth. Tree water uptake in the TL plots was significantly lower than the TH plots at 0.3 and 0.6 m depth, but not at 0.9 and 1.2 m.

In 1995, tree water uptake varied less among treatments than during the 1994 DDP. The MH plots had more water uptake (irrigation effect) close to the tree in the top 0-0.6 m and significantly more uptake occurred compared to ML plots (Fig. 2.5 d). In general, water uptake in both mulch treatments varied little by depth and distance from the tree (Figs. 2.5 e and 2.5 f). Withholding irrigation during the 18-day dry-down period resulted in the same trend in both turf treatments at 0.3-0.6 m depth and all distances. Farther and deeper from the tree, water uptake was sometimes greater in the TL plots, but all values only varied between 0-2%. There were some differences between turf treatments, as more water was depleted in the in TL plots at 0.3 and 0.6 m from the tree, but no differences were found between high and low irrigation. Both treatments deplete water in the top soil layer, but depletion decreased by depth. TL and TH trees depleted nearly the same amount of water at 0.6 and 0.9 m distances at all depths.

Water uptake during the 1996 dry-down period under mulched plots did not differ between treatments, and increased at 0.9-1.2 m depth compared to the top layers (Figs. 2.5 h, 2.5 i, and 2.5 j). Turf water uptake decreased with depth and distance away from the tree, and was not significantly different between high and low irrigation. Tree water uptake in turf treatments was greater than mulch plots only at 0.3-0.6 m depth. Water uptake in the turf treatments was lower than in 1994 and 1995. Tree water uptake in mulch treatments was greater in the 1995 season but below 0.9 m there were no differences.

Roots. Four to seven primary lateral roots comprised the lateral portion of the root system of the trees in mulch. Viewed from above, all laterals roots and their branches formed a triangular-shaped root network in the mulch (Figs. 2.10 and 2.11). The ML trees had major branches of the main lateral roots that were longer and more coarse (>5 cm diameter). The MH tree exhibited thicker roots growing parallel and close to the soil surface, compared to the ML trees. Most maple roots in the mulched plots were found at 0-0.40 m below ground level. Large roots (>10 cm) were most commonly found below the soil and very close to the stem. The rooting pattern was different for trees in the ML treatments, with lateral roots growing more obliquely downward. These oblique roots penetrated to depths of 0.40-0.6 m and appeared to increase in number at 0.1 m depth very close to the tree. Roots with a 3-5-cm diameter were most abundant, and there were greater numbers of fine roots (<1mm) at 0.3 m depth that were clearly visible along the length of the trenches. Root number and root size decreased at 0.80-1.00 m depth.

The rooting patterns of maple trees under turf grass competition were different from trees growing in mulch. Root extension averaged only about 1.20 m on both sides of the stem tree. Both fine and woody roots exhibited a similar rooting pattern under turf. From 6-10 vertically spreading primary lateral roots formed the main components of the root system. These vertical roots were mainly found at 0.3-0.4 m depth in the same area where turf roots developed. Fine roots were fewer in numbers at the top 0-0.3 m soil layer. Roots were noticeably concentrated immediately below the sprinkler. Turf roots were almost entirely confined to the top 1.0 m, with a particularly high density between 0.45-0.6 m. Thus all turf roots and most of tree roots were located in the top 1.0 m.

Surface covering affected root distribution and volume (Fig. 2.6). Root distribution and lateral roots under turf treatments were found mostly at 0.3 to 0.6 m depth. Few roots were visible at 0.8-0.9 m under the tree, and laterals extended outward 0.8-1.0 m. Root distribution for the TL trees was highest in the 0.3-0.6 m depth, and laterals extended only to 0.6-0.8 m. Mulch irrigated trees had more roots along the trench, the only exception being at 1.2 m depth where no roots where found in all treatments. All treatments gave different proportions of root volume (m^3m^{-3}), varying in form especially between mulched and turf plots (Figs. 2.6 and 2.7). The highest root volume for TH trees was at 0.3-0.6 m depth compared with TL trees with fewer roots in the topsoil layer, and more roots below 0.3 m.

Distribution of roots with different diameters varied with depth on all treatments (Figs. 2.8-2.11). The distribution of fine roots (<1.0 mm) was more uniform than that of coarse roots. Fine roots were concentrated in the 0 to 0.3 m depth in mulched plots and were greater in number than for the trees in the turf. Development of fine roots by the MH trees was evident in the top 0.3 m along the length of the trench. The ML trees developed fine roots at 0.3 m but fewer in number than the MH treatment. Tree fine roots were less visible in number in turf plots than in mulched plots. From 0.2 m to 0.3 m there was approximately 15% more fine roots in the TL than in TH, primarily because with less water available the turf roots developed less. Root distribution of trees was not uniform, as some areas had a high number of roots while others were unoccupied. Trees in turf also had fewer roots and smaller root diameter compared with the roots from the mulched plots.

A comparison of rooting patterns of the four treatments showed that root number and root volume were highest under mulch at all depths below the soil surface. At 0.6 m from the tree trunk, root volume in soil layers below 0.6 m was higher under mulch than turf, and in all treatments roots penetrated to 0.9 m depth (Figs. 2.8, 2.9, 2.10, and 2.11).

Plant water relations/Water potential. Seasonal variation of predawn leaf water potential (Ψpd) over the 1995 and 1996 seasons is represented in Fig. 2.12. In general, all treatments in both years had less negative values early in the season (July), reflecting the adequate soil water at this time. During the dry-down period, Ψpd declined from minimum low of -0.55 MPa. Variation in Ψpd followed the pattern of irrigation and rainfall in all treatments. Trees in the mulched plots during 1995 season generally had more negative Ψ pd than those in turf. Prior to the dry down period Ψpd of the MH trees was significantly higher than all other treatments. During the dry down Ψpd declined in all treatments, reaching the lowest points between -0.4 to -0.55 MPa, with mulched trees marginally lower than turf. After irrigation, Ψpd recovered to -0.3 to -0.4 MPa. TH trees showed rapid Ψpd response to replenishment of soil water from rain or irrigation. The TL trees showed a lag between irrigation and change in Ψpd, and on some dates there was no response. Analysis of variance showed that Ψpd was significantly different between surface cover treatments ($P<0.05$), as Ψpd of the mulched trees was lower than those in turf. There was no irrigation effect on Ψpd.

In 1996, Ψpd of all treatments was less negative due to high soil water content. All treatments showed the same pattern with no differences between surface cover and irrigation treatments. Water potential declined from -0.2 MPa in June to -0.4 to -0.5 MPa by early August. During the dry down period Ψpd declined from about -0.35 to -0.5 MPa, with no differences among treatments.

Stomatal conductance. Midday stomatal conductance (gs) measurements of trees in turf and mulch surface covers and irrigation treatments followed an oscillating pattern similar to Ψ predawn in 1994, but with greater differences among treatments (Fig. 2.13). From mid-July to early August, prior to the dry-down period, there were no differences in gs among treatments. At the beginning of the dry period, the MH trees had the highest stomatal conductance. During the dry-down period, gs declined in all treatments, apart from one anomalous data point in the ML trees. Conductance of the TH trees was significantly higher than the other treatments during the dry down. In the TL trees, stomatal conductance fell from 100 to 20 mmole m^2 s^{-1} despite less negative Ψpd. In contrast, gs of the TH fell only 130 to 80 mmole m^2 s^{-1}. After the dry-down period, gs responded to irrigation in the TH but there was little response in TL trees. In general, gs of the TH treatment had significantly higher gs than the other treatments.

Treatment differences in gs were not as apparent in 1995 and 1996 in dawn-to-dusk studies at the start and end of the dry-down cycles. On all dawn-to-dusk studies, a clear diurnal pattern of decreasing stomatal conductance beginning around solar noon was evident in all treatments (Fig. 2.14). On the initial dawn-to-dusk study on August 10, 1995, gs was not significantly different among treatments. The weather was partially cloudy with relatively high humidity for this region. After the mid-morning maximum, gs fell to a mid-afternoon low concurrent with cloudiness, increasing to nearly mid-morning levels by late afternoon. A week later without irrigation, dawn-to-dusk gs under sunny conditions again showed little differences among treatments. The pattern of gs during the day was different from the initial dawn-to-dusk study. At mid-morning MH, gs was significantly lower than the other treatments. Mid-morning gs was not as high as the previous study, and the lowest value did not occur until late afternoon.

Both dawn-to-dusk studies in 1996 were conducted under cloudless skies (Fig. 2.15). On July 30, at the start of the dry-down period, mid-morning gs was higher than the two dates in 1995. Midday depression in gs was not large, and actually the highest values for the day occurred in late afternoon. Only gs in the MH trees early in the day was significantly different from the other treatments. From midday on there were no significant differences in gs among treatments. On August 20, during the dry-down cycle, overall gs values were lower than on July 30. At mid-morning the highest values of gs were reached at 80 mmole m^2 s^{-1} in all treatments, with the trees in turf having significantly higher gs than those in mulch through most of the day.

Tree growth/Stem diameter. Stem diameter growth over two years differed significantly between treatments (Table 2.1). Trees in turf exhibited less growth during two consecutive years compared to trees in mulch. In 1995, significant differences between cover treatments showed trees in the mulch to have approximately 6 mm greater trunk growth than trees in turf. In 1996, the differences in trunk diameter were 10 mm between trees in mulch versus those in turf and were significantly different. There were no statistically significant differences between irrigation treatments.

Leaf nitrogen content. Competition from turf surface cover significantly decreased the nitrogen concentration in maple leaves (Table 2.2). Leaf nitrogen (%) was higher for mulched trees than for those in turf in all measurements. In fall 1995, leaf nitrogen was significantly greater by 0.3% for trees in mulch compared to those in turf. Differences in N % were highly visible the following spring at the beginning of the summer season, as leaves of maple growing with turf grass had a noticeably lighter green color than trees in mulch. Results of N analysis of leaf agreed with the visual color differences, as trees in mulch had nearly 1.0% more N than those in turf. Despite fertilization, mulch trees had a higher leaf N by fall 1996 after normal seasonal decline in concentration. No irrigation effect on N % was found.

Leaf area. Total leaf area development was very similar among the four treatments, and differences did not appear until 1995 (Table 2.3; Appendix Table A.7). In 1994 after one year of establishment, overall leaf area was about 2.5 m^2, while ML trees had 26%, 24%, and 71% more leaf area than MH, TH and TL trees respectively. There were no differences among turf treatments. In 1995, trees in turf treatments had significant lower leaf area compared with those in mulch tree.

Following the trend established in 1995, trees in mulch had significantly more leaf area than those in turf in 1996. Differences between groundcover treatments were much greater than the previous year. Trees in turf increased their leaf area 35% in 1995 and 98% in 1996. By contrast, the trees in mulch had a 71 % increase total leaf area in 1995, but a nearly 200% increase in 1996. There was no irrigation effect on total leaf area.

Discussion

Soil water content. The soil water content under mulch decreased progressively with time by depth and distance. Before the dry-down period, water uptake in both MH and ML treatments occurred predominantly from the upper 0.3 m of the soil. However, as soil water content in this area declined (Figs. 2.2, 2.3, and 2.4), the greatest proportion of water uptake was between 0.6-0.9 m depth. During and after the dry-down period, there was no further change in water content in the upper 0.3 m in both mulch treatments. Turf treatments presented a different pattern in water content than mulch treatments over the three seasons as more water was extracted at 0-0.6 m depth. The highest depletion during the dry-down period was at 0.3 m depth followed by the 0.6 m depth in both turf treatments. An irrigation effect in TL treatments was detectable in the top layer compared with the TH treatment where water percolated deeper. Water uptake behavior developed similarly in both turf treatments, but TL plots had less water at the end of the dry-down cycle.

These results confirm those of previous studies, which have shown that the soil water content is less in soil under turf grass than under mulch (Watson 1988). Soil water differences between distances from tree were not different in turf plots and were less deeper in the soil. Water uptake was similar in the surface layer in both turf treatments due to intermingling of tree and turf roots. Near the soil surface, at depth 0-0.3 and 0.3-0.6 m, there was rapid water depletion and soil drying after each irrigation. A similar decrease occurred deeper in the soil (0.6 m), indicating that water uptake was also occurring at this depth, at least during the dry-down period.

Water uptake during the dry-down period. Differences in the water extraction patterns during the soil drying-out period are indicative of differences in root distribution and root length density among the four treatments. Fig. 2.5 shows that the water content mainly decreased from the soil surface and 0-0.6 m depth during the dry-down period in turf treatments, and below 0.6 m in mulch treatments. During 1995, water depletion was less than 1994 during the summer and dry-down period, and in 1996 depletion was the highest compared with 1994 and 1995. In 1996, mulch and turf treatments exhibited the same water extraction pattern that was deeper and decreasing with time, compared to 1995. Thus the pattern of root water uptake during the dry-down period coincided approximately with the distribution of fine roots in the maple. Throughout the summer season, soil water content at 1.20 m depth changed little, evidence that there was a little water uptake by the tree at this depth. This is supported by the root distribution obtained at the end of the experiment, which showed a very few roots below 0.9 m depth in all treatments (Fig. 2.10), as Breda et al. (1995) found in an oak tree.

Roots. Tree root volume was greater near the soil surface in mulched trees as found by Sands and Mulligan (1990). Horizontally spreading lateral roots were substantial in mulch treatments, and were located at the soil surface as noted by Strong and La Roi (1983) and Watson (1988). Mulched trees had more fine roots close to the soil surface than turf trees, as noted in sugar maple tree by Watson (1988). The differences in root distribution and root volume between layers for each treatment were reflected in differences in the rate of water uptake between layers. In mulch treatments, the majority of the roots, and larger diameter roots were found in the 0.3 m depth, with many fewer found below 0.6 m. These results are similar those reported by Watson (1988) for sugar maple and by Nambiar (1983) in *Pinus radiata*. Under ML conditions maple root distribution was concentrated at 0-0.6 m depth, while MH was at 0-0.9 m depth, consistent with the results of Hughes and Gandar (1993) in apples. The only difference in root growth between the mulched trees was that MH main roots grew parallel to the soil surface and were greater in number, probably due to more irrigation water, similar to the results of Dancer (1964) and Haynes (1980). By contrast, the more oblique root development of the ML trees was apparently due to exploration for water as suggested by Belsky (1994).

Root distribution with turf competition was substantially different from mulched trees, as they were found deeper with less root diameter in both the high and low irrigation treatments. Numerous studies have found that turf outcompetes tree roots, and grass inhibits tree fine root production at the soil surface (Atkinson and Coldrick 1976; Landsberg and McMurtrie 1984; Watson 1988; Sands and Mulligan 1990; Bi et al. 1992; Belsky 1994). Roots were concentrated in the wetted zone close to the tree in mulched plots and below the sprinkler position in turf plots, findings compatible with the results of Fernandez et al. (1991) with olive trees. Gregory (1987) stated that the addition of water by irrigation changes both the amount and distribution of roots compared with crops under rain-fed conditions. In this experiment, turf grass roots suppressed tree root development at depths above 0.3 m, results that are in agreement with those of Eastham and Rose (1990) where they found the lowest concentration of tree roots within the pasture root zone, and the greatest concentration of tree roots below the pasture roots.

Plant water relations/Water potential. At the time water content became limiting in the first layers, Ψpd of Norway maple started to decrease. Changes in leaf water potential of the TH paralleled changes in water content of the surface soils. Predawn leaf water potentials in the

TL trees began to fall quickly after irrigation and during the dry-down period. In turf, these values ranged from -0.4 to -0.6 MPa in the low and high irrigation treatments. There were marked differences in leaf water potential between those turf treatments early in the season and during the dry-down period, as TH trees had less negative values than the TL trees the greatest. The ML trees showed less severe water deficits that developed more slowly than in the MH trees. Gradually decreasing Ψpd revealed a slight effect of water stress that accumulated throughout this period. During 1995, ML had less negative values compared with MH. During the dry-down period, both treatments behaved equally, but ML always showed less negative values of Ψpd.

Stomatal conductance. The seasonal and midday trends in stomatal conductance were primarily a result of the different surface covers and irrigation treatments. Stomatal conductance early in the season was higher in all treatments, with no significant differences between surface cover and irrigation treatments. Higher conductance is associated with plentiful soil moisture, such as Torrecillas et al. (1988) found in almonds. Variation in midday stomatal conductance from day to day generally follows changes in soil water status during drought as found by Perry et al. (1994).

Stomatal conductance measurements in the mulch treatments contrasted with those of the turf treatments. Trees surrounded by mulch consistently had higher stomatal conductance during mid-morning, similar to the findings of Watson (1988) in sugar maple with mulch cover. On some dates, gs in mulched plots decreased more quickly, thus reducing the time of maximum stomatal opening. During dry periods, gs behaved differently. There was a decrease in stomatal opening during the dry-down period in all treatments during the 1994, 1995, and 1996 seasons. This corresponds to that observed in many other studies, such as Perry et al. (1994) in Loblolly pine and Kramer (1987). Seasonal changes in stomatal behavior can be attributed to changes in both leaf area and root dynamics, leaf age effects, and soil water status. After the dry-down period, gs increased with irrigation.

Tree growth. There was a substantial suppression of maple growth due to the presence of turf (Table 2.1). The growth was greatest in the mulched trees. Stem diameter growth is proportional to the amount of assimilates used, and this was reflected in the mulch treatment, which increased stem diameter of maple over the three years of the study. Perry et al. (1994) stated that competition influences not only the distribution of growth but also the amount of carbon fixed per unit of leaf area, as competition increases the productivity decrease. Nilsson and Albrektson (1993) found that allocation of carbon to stem wood production, and probably also fine root production, has high priority for trees under high competitive stress.

Reduction in leaf area in turf treatments can be explained by competition in water uptake in the root zone between turf and trees, because water deficits reduced shoot growth (Turner 1990; Davies et al. 1990). Turf competition for water during the growing season contributed to the significant decrease in leaf area, which was almost half of that of the mulch trees in 1996. These results are similar to those by White and Newton (1989), Allen et al. (1990), Misra and Sands (1992), Sands and Mulligan (1990), and Nambiar and Sands (1993). Mulch appeared most favorable for tree growth as stem diameter and leaf area were significantly greater compared to turf treatments, results that agree with those found by Greenly and Rakow (1995) in a study with pine and mulch surface cover.

In summary, we have found that turf competed for water with Norway maple. There was no irrigation effect in the turf and mulch treatments. More negative values of leaf water potential were measured during the dry-down period in mulch treatments, probably due to less soil moisture at the soil surface. Trees surrounded by mulch also had the greatest leaf area compared with turf treatments, and more leaf area means more transpiration and thus more water consumed. Higher values of stomatal conductance were measured early in the season in both turf and mulch treatments; later those values were reduced in both treatments during the dry-down period.

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Table 2.1. Stem diameter growth in Norway maple in response to different surface covers and irrigation treatments during 1995 and 1996. Values are the mean of five replicates.

	Diameter growth (mm)	
Treatment	October 1995	November 1996
Turf high	40.2	50.4
Turf low	38.7	49.2
Mulch high	43.7	60.7
Mulch low	46.6	62.8
Surface	*	*
Irrigation	NS	NS
Surface x Irrigation	NS	NS

NS no significance * significance ($P<0.05$)

TABLE 2.2. Leaf nitrogen concentration (%) in Norway maple in response to different surface covers and irrigation treatments during 1995 and 1996. Values are the mean of five replicates.

	Leaf (Nov. 1995)	Leaf (Jun. 1996)	Leaf (Nov. 1996)
Treatment	N (%) Total	N	N (%) Total
Turf low	1.59	1.6	1.41
Turf high	1.24	1.43	1.64
Mulch low	1.79	2.36	1.86
Mulch high	1.70	2.27	1.88
Surface cover	*	*	*
Irrigation	NS	NS	NS
Surface x Irrigation	NS	NS	NS

Table 2.3. Leaf area (m^2) of Norway maple in response to surface covers and irrigation treatments during 1994, 1995 and 1996. Values are the mean of five replicates.

	Leaf area (m^2)		
Treatment	1994	1995	1996
Turf high	2.57	3.21	6.54
Turf low	1.85	2.89	5.15
Mulch high	2.53	3.79	12.63
Mulch low	3.18	5.76	15.63
Surface	NS	*	*
Irrigation	NS	NS	NS
Surface x Irrigation	NS	NS	NS

NS no significance * significance ($P<0.05$)

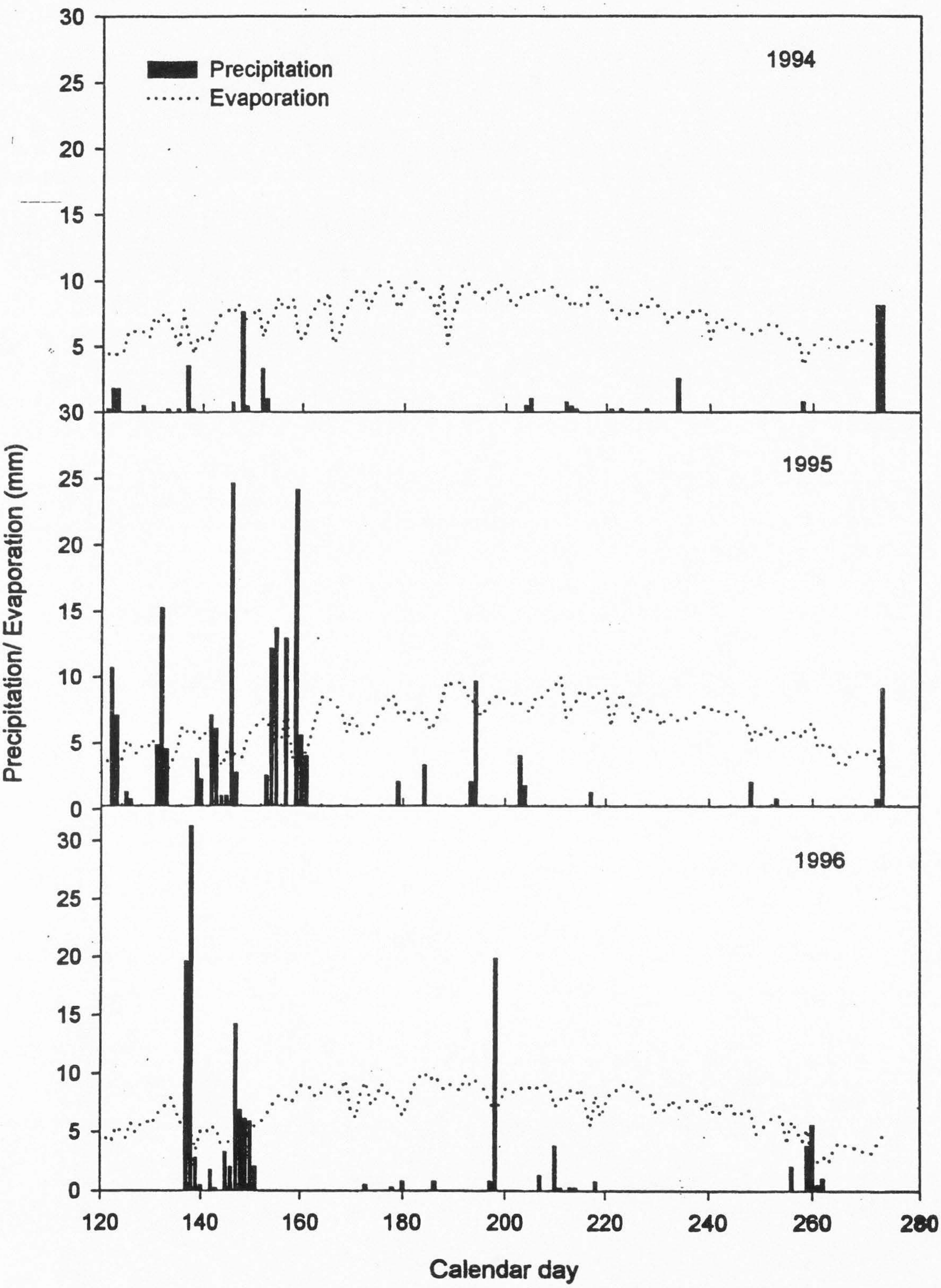

Figure 2.1. Precipitation and evaporation (mm) at the Utah State University Greenville farm from May to September in 1994, 1995, and 1996.

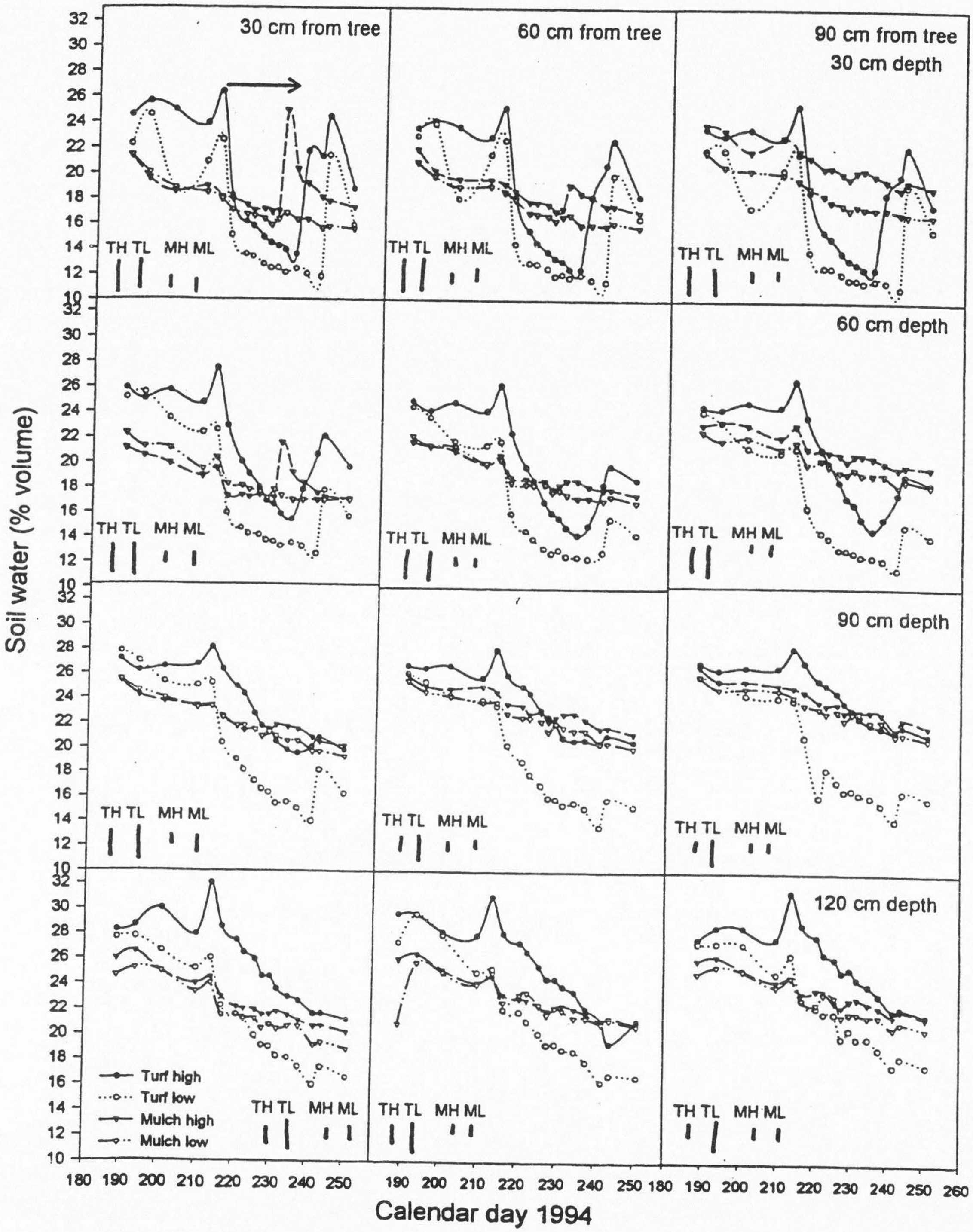

Figure 2.2. Soil water (% volume) by depth and distance in Norway maple with different groundcovers during 1994 under two irrigation regimes. Points are the average of five replicates. (Pooled variance in each treatment equal to length of bar.) Length of dry down period →

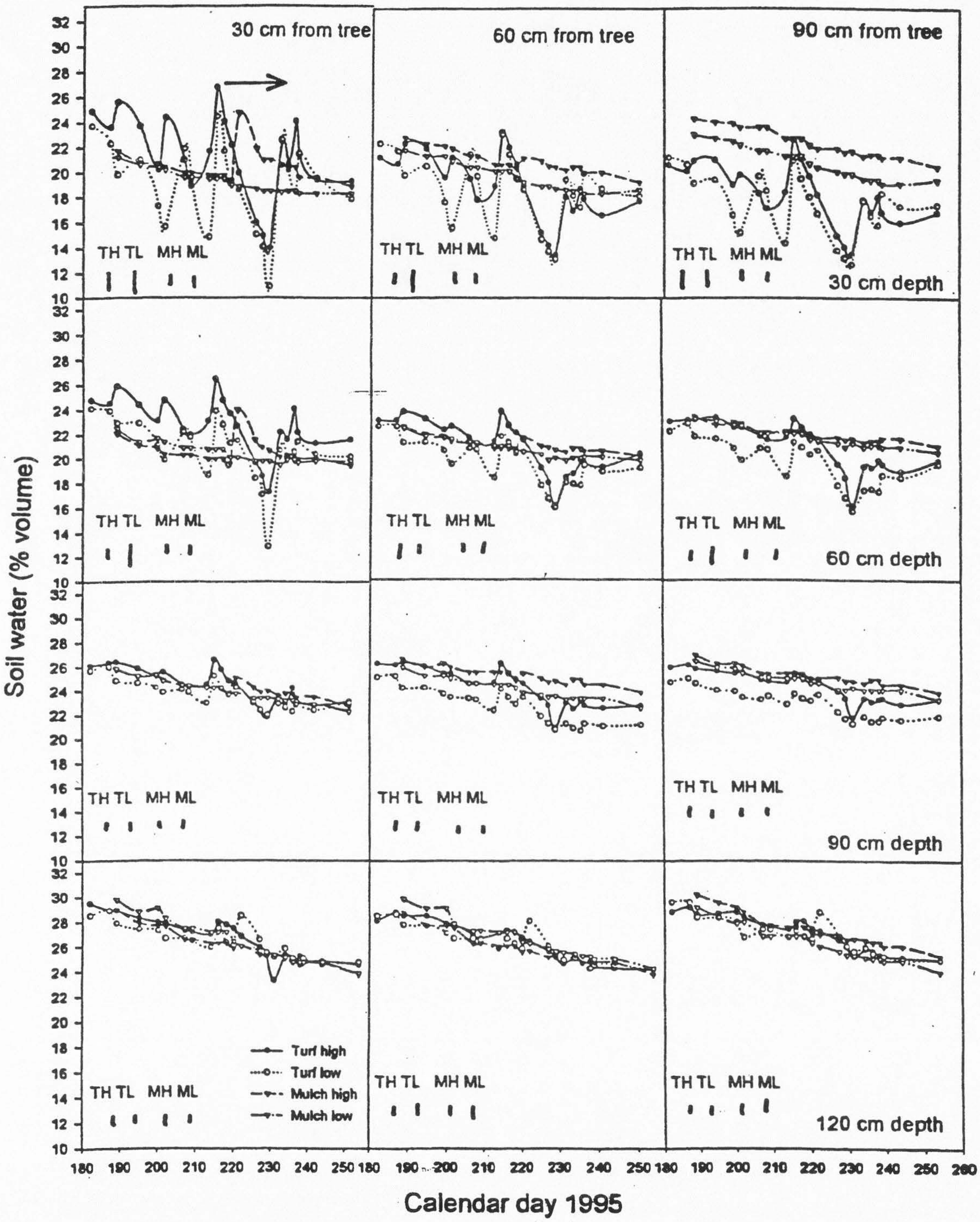

Figure 2.3. Soil water (% volume) by depth and distance in Norway maple with different groundcovers during 1995 under two irrigation regimes. Points are the average of five replicates. (Pooled variance in each treatment equal to length of bar.) Length of dry down period⟶

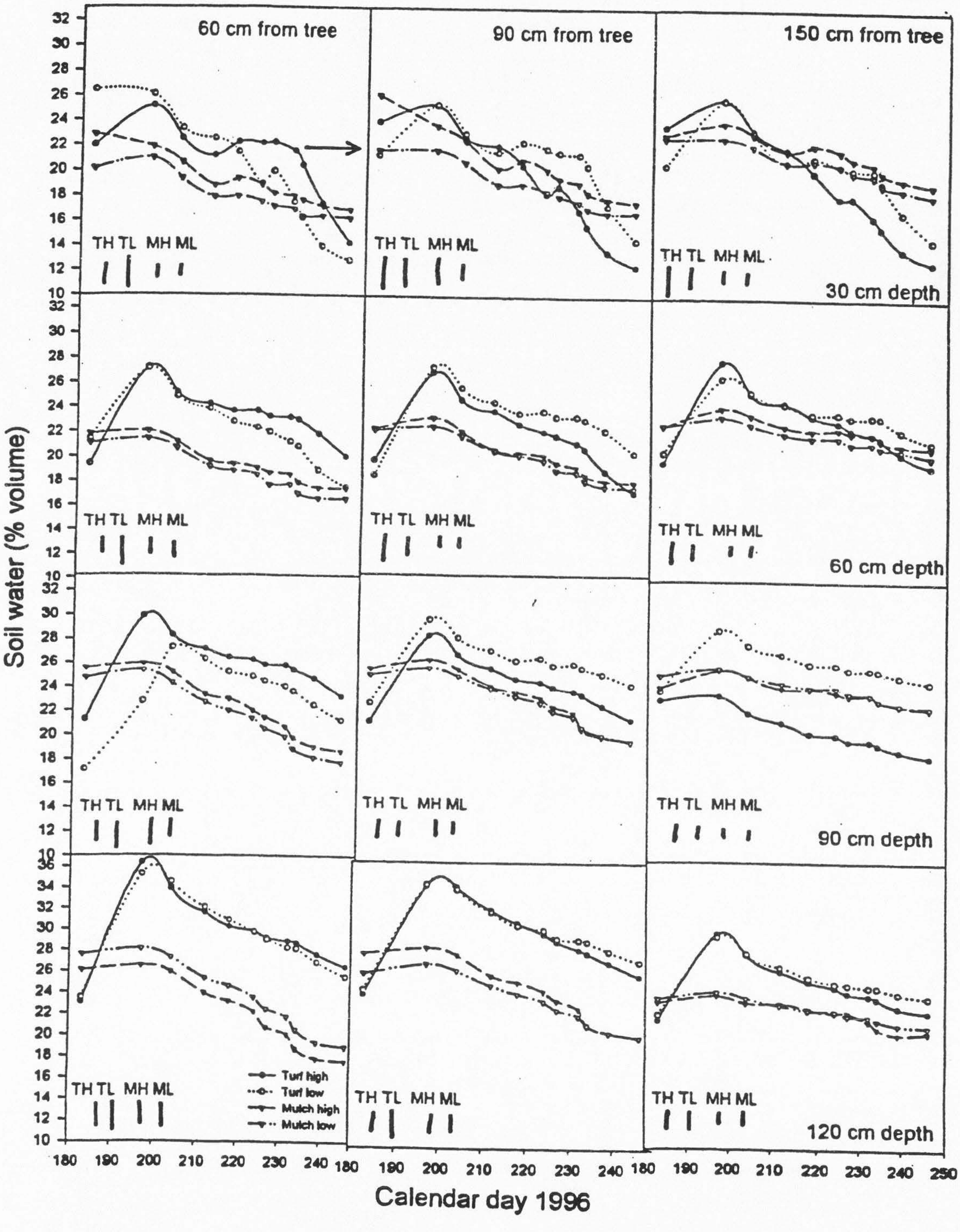

Figure 2.4. Soil water (% volume) by depth and distance in Norway maple with different groundcovers during 1996 under two irrigation regimes. Points are the average of five replicates. (Pooled variance in each treatment equal to length of bar.) Length of dry down period ⟶

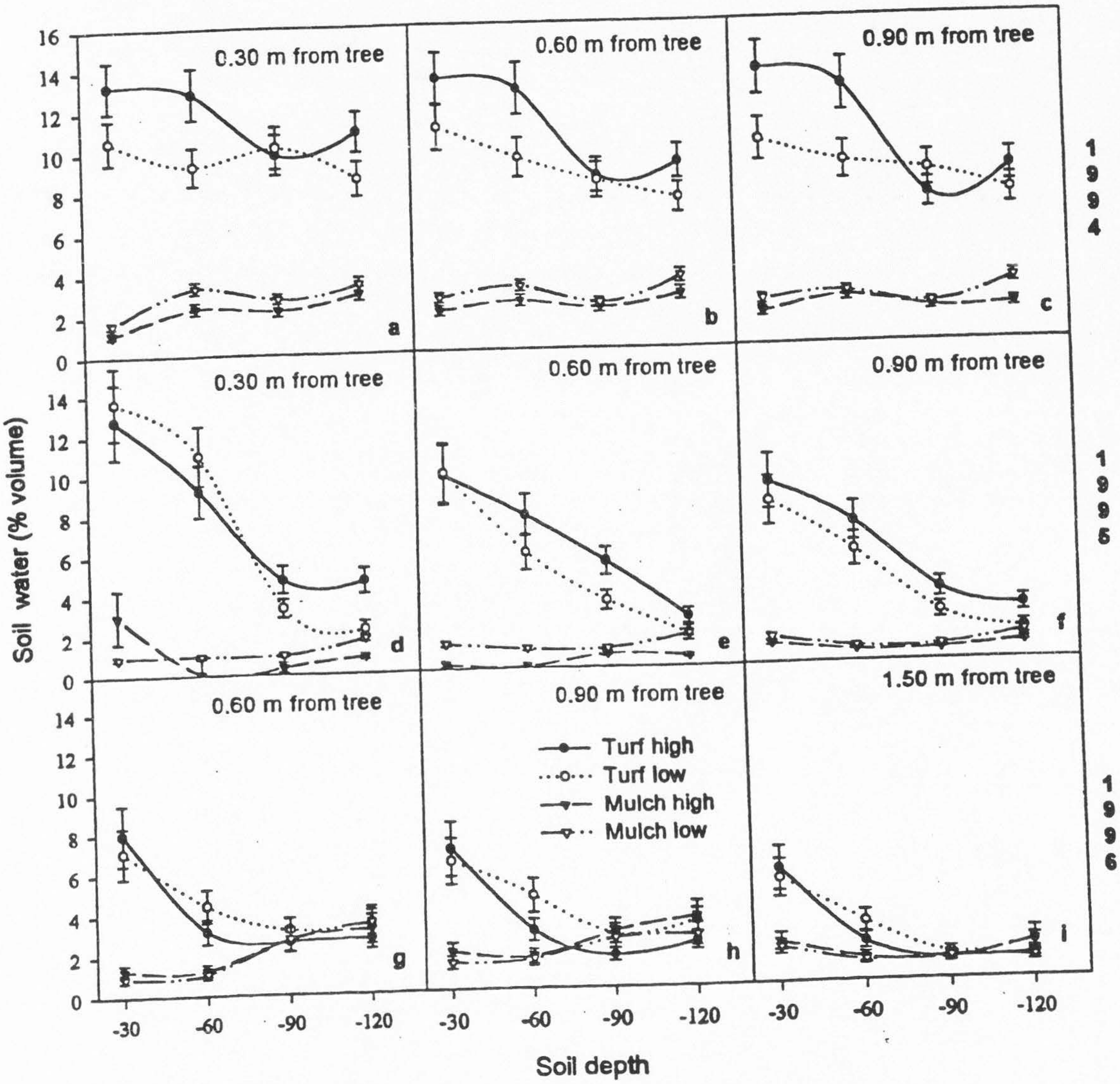

Figure 2.5. Water uptake (% volume) during a dry-down period in Norway maple growing in turf and mulch surfaces in 1994, 1995, and 1996 at different distances and depths. Values are the average of five replicates with standard error bars.

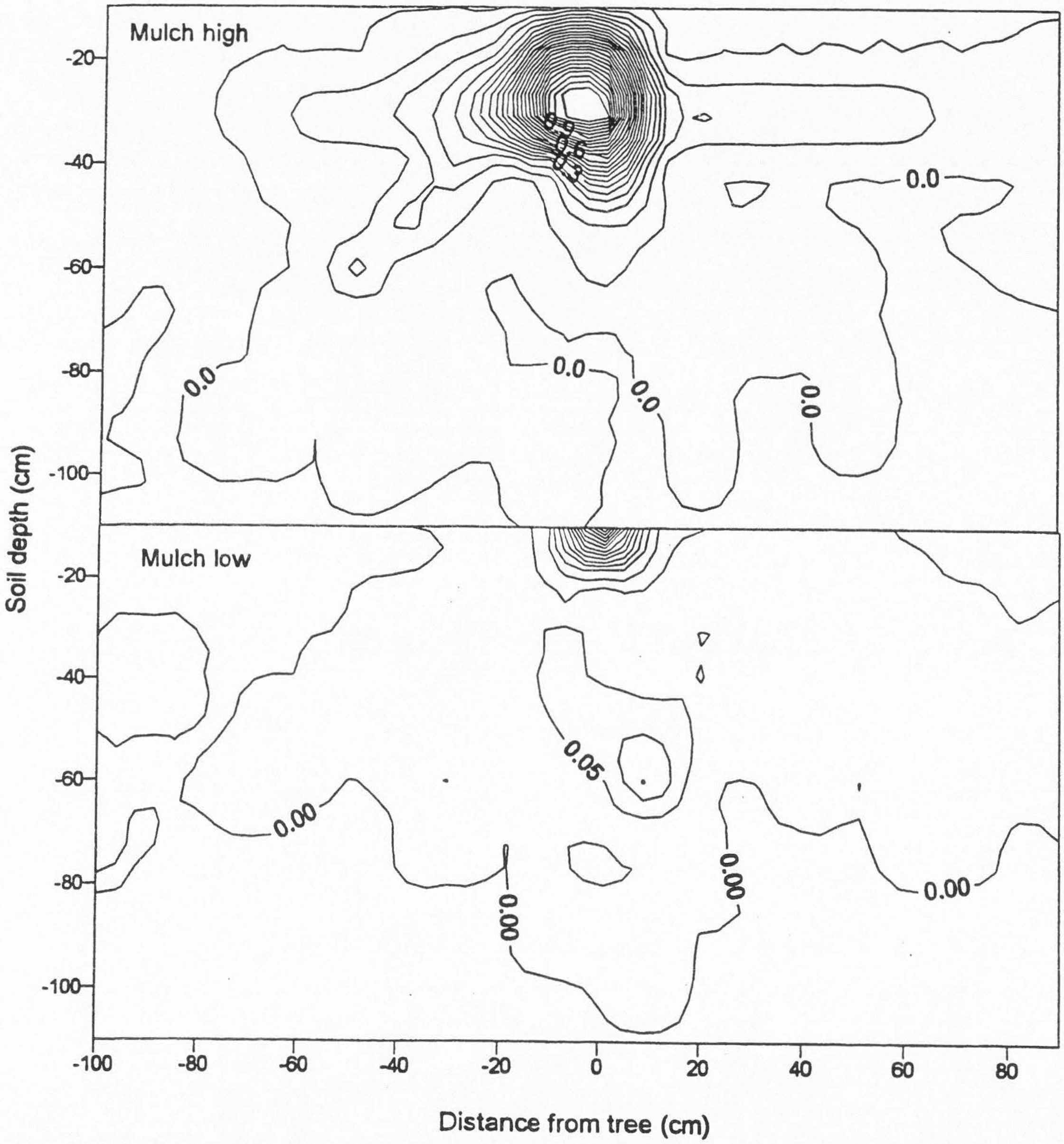

Figure 2.7. Ratio of root volume/soil volume in Norway maple in response to mulch surface cover and irrigation treatments. Values are the average of roots from two trees at the same distance and depth.

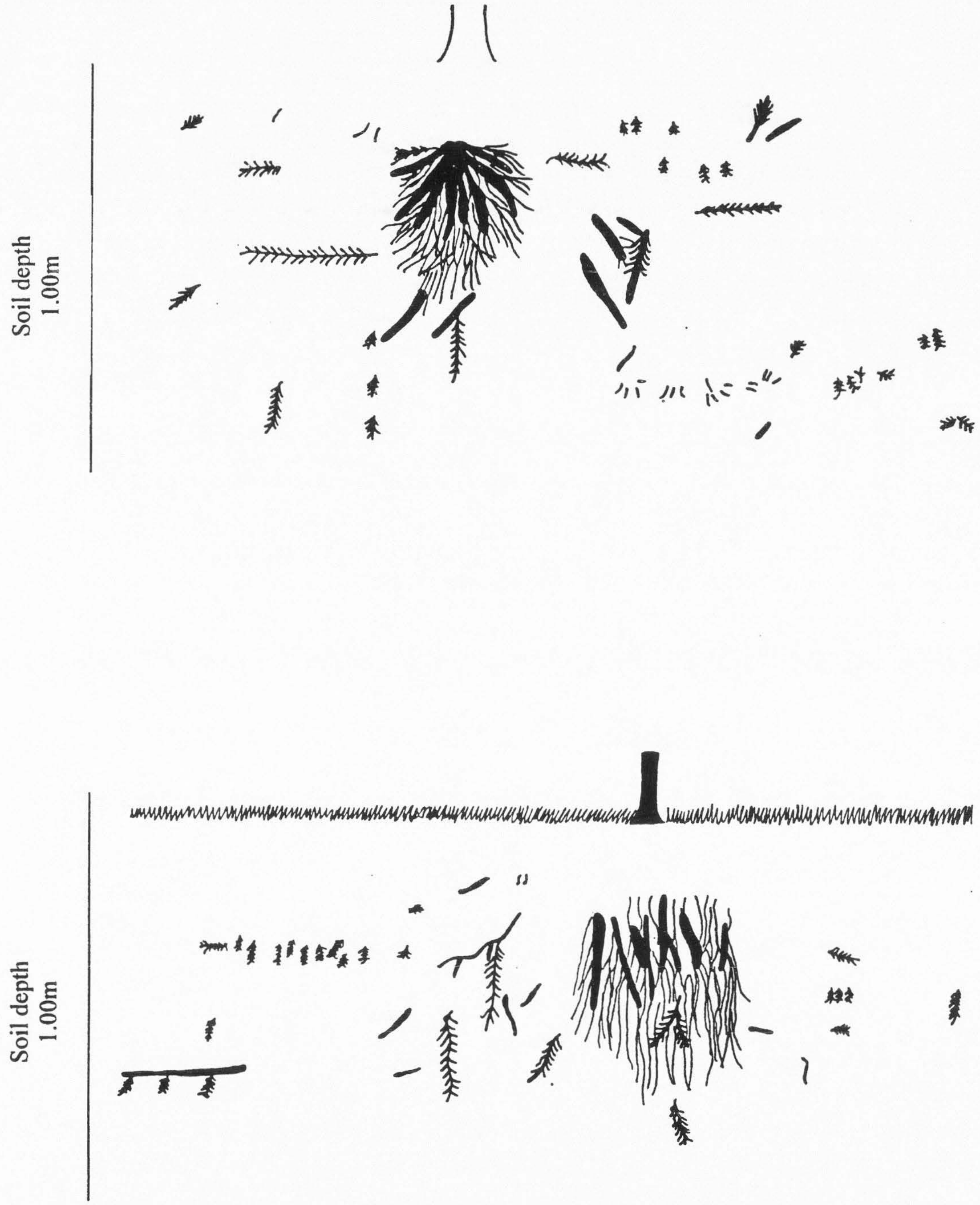

Figure 2.8. Root system diagram of two Norway maples with turf surface cover and high irrigation treatment.

Figure 2.9. Root system diagram of two Norway maples with turf surface cover and low irrigation treatment.

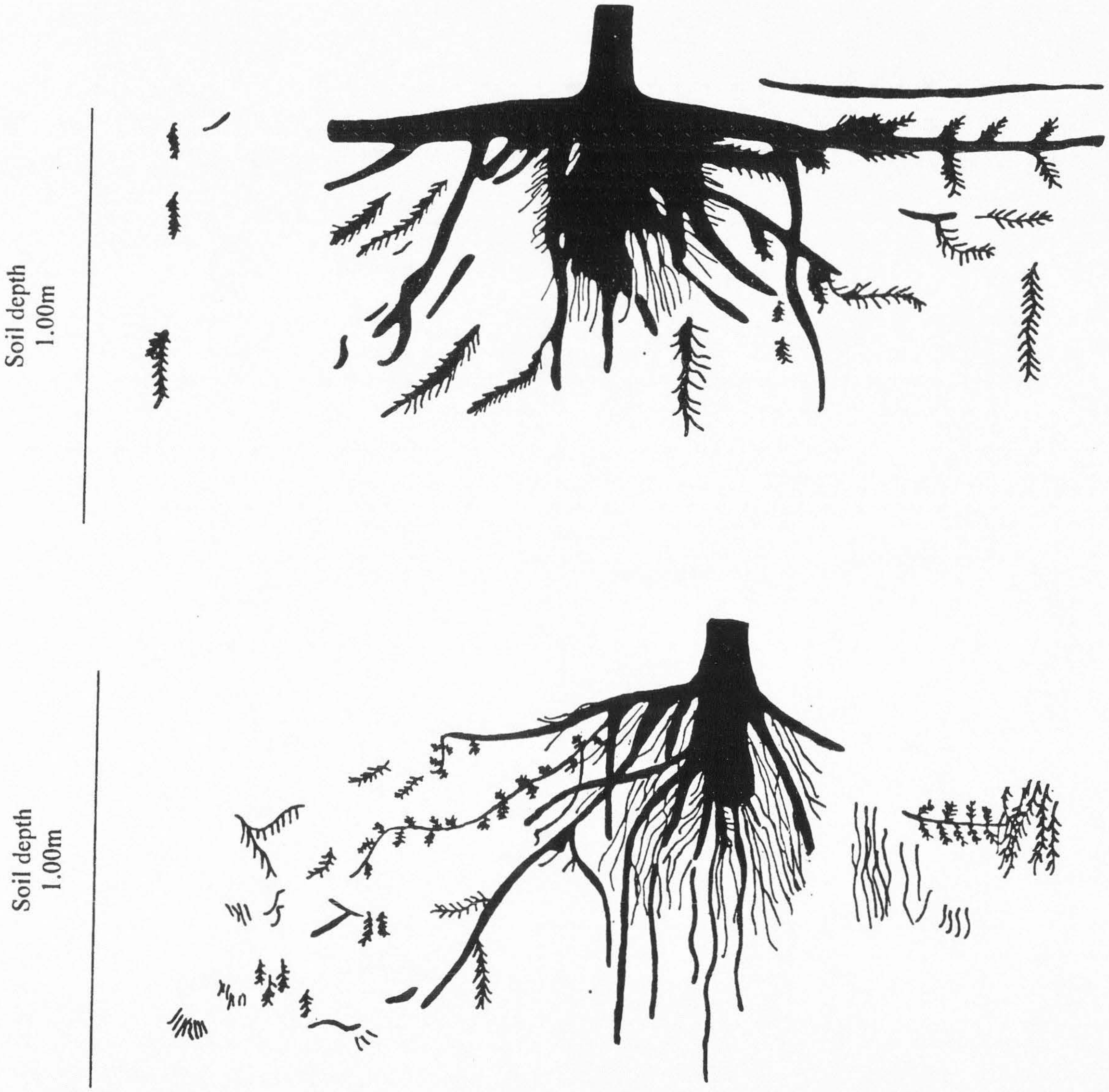

Figure 2.10. Root system diagram of two Norway maples with mulch surface cover and high irrigation treatment.

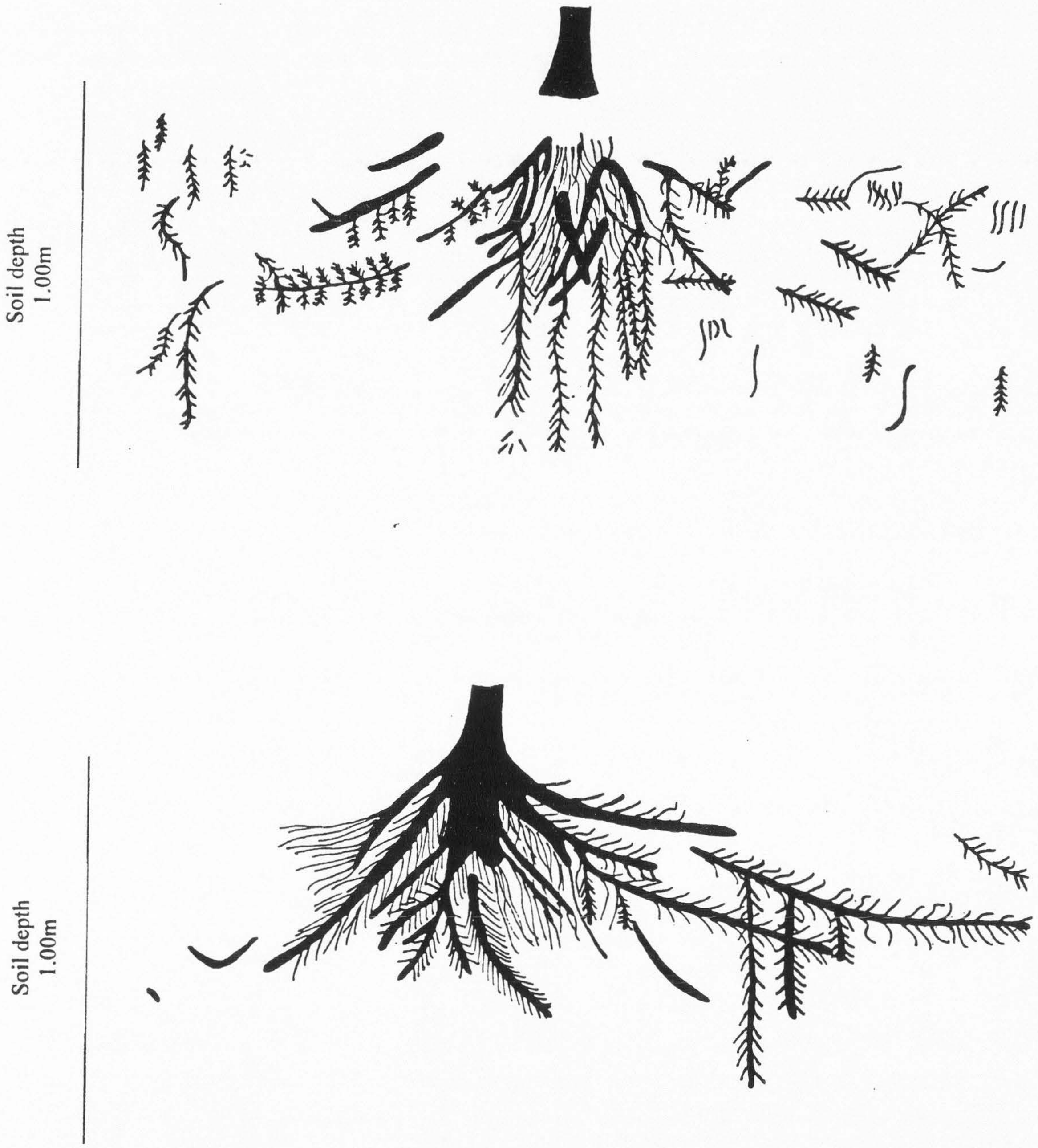

Figure 2.11. Root system diagram of two Norway maples with mulch surface cover and low irrigation treatment.

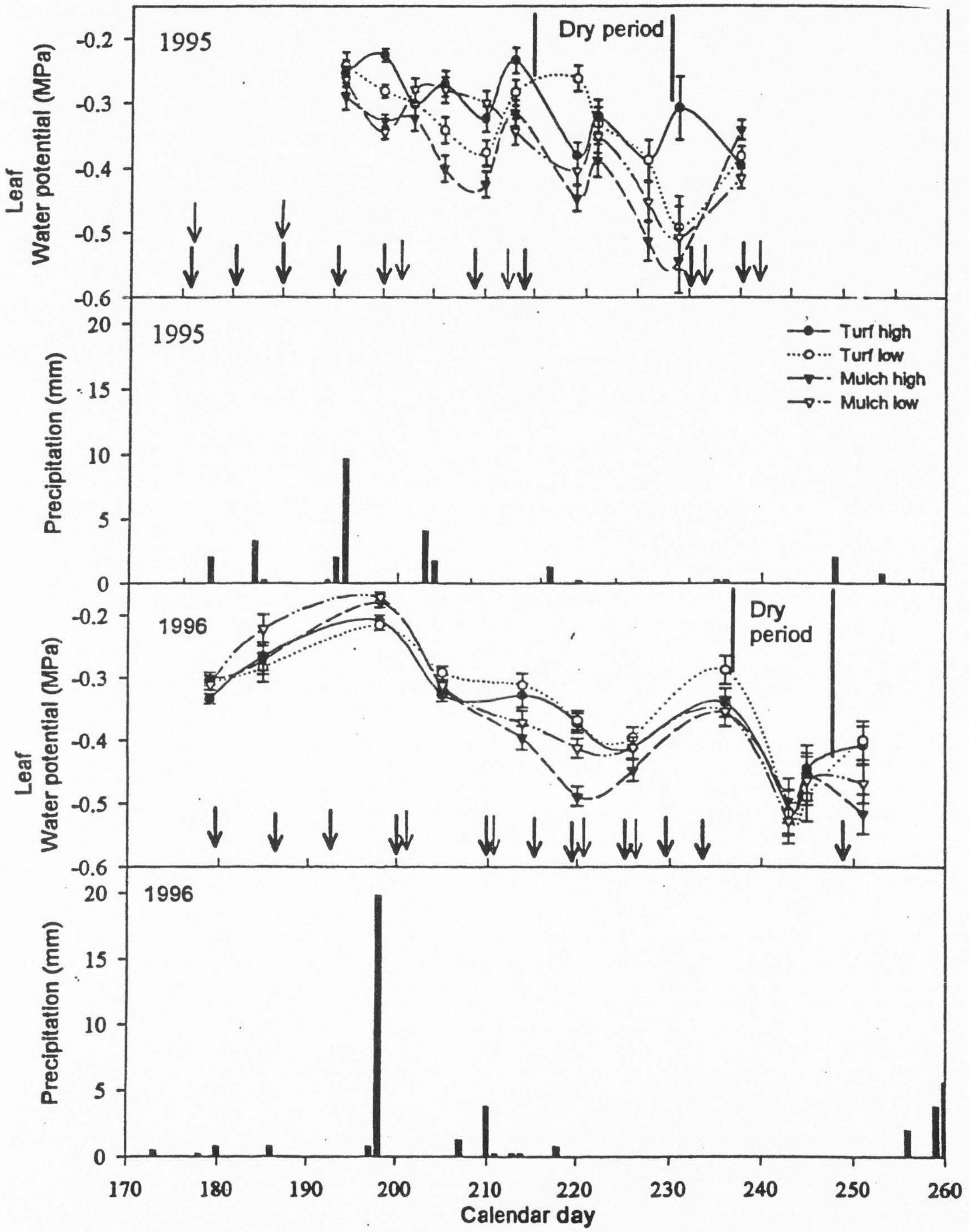

Figure 2.12. Predawn leaf water potential (MPa) in Norway maple in response to turf and mulch groundcovers, irrigation, and precipitation during 1995 and 1996 seasons. Data points are average of five replicates. (With standard error bars)
TH irrigation ⟶ TL irrigation ⟶

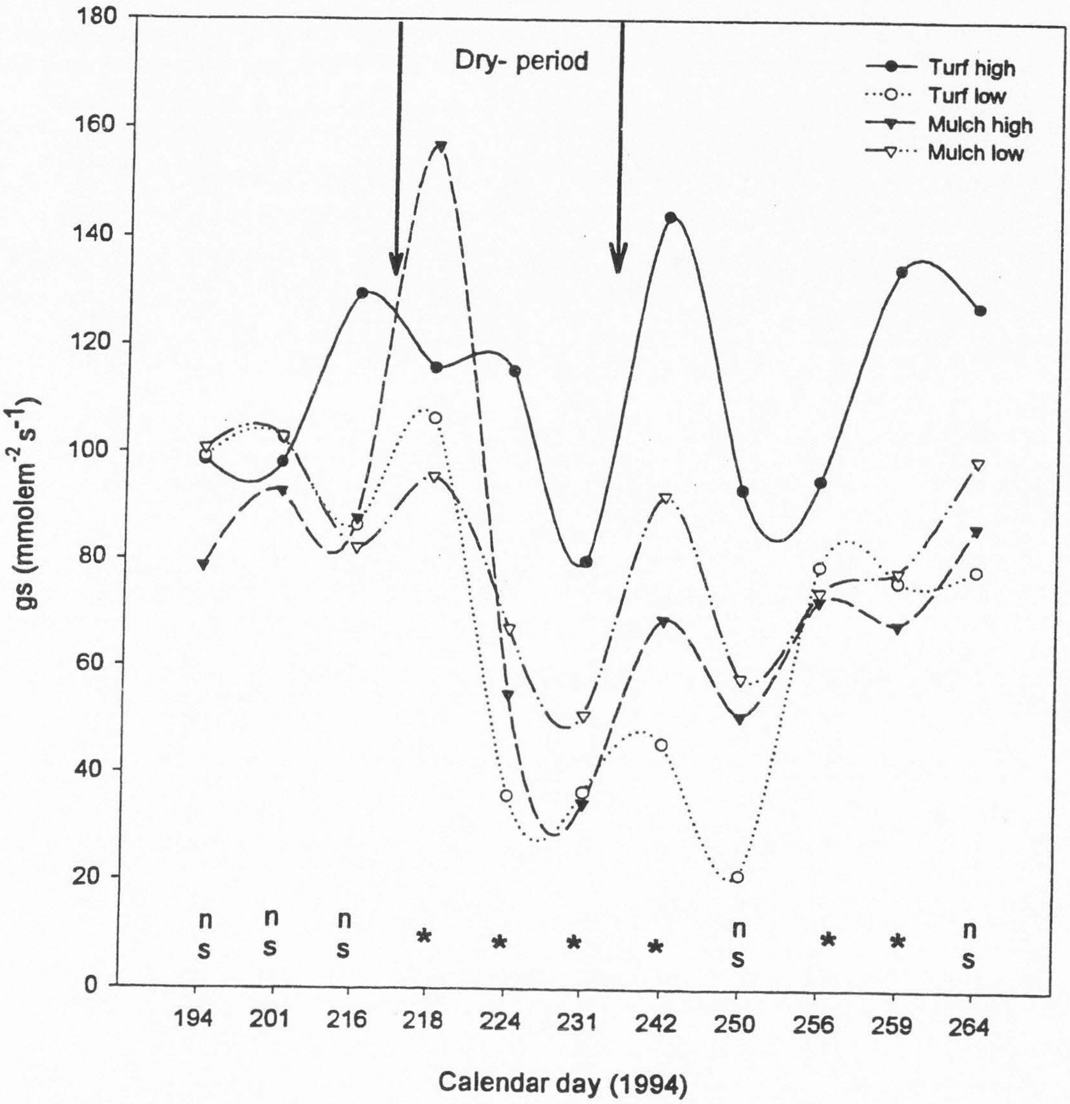

Figure 2.13. Midday stomatal conductance (gs) in Norway maple growing in turf grass and mulch surface covers irrigated at two levels in 1994. Points are means of 25 measurement. (ns, *, Means treatments are non significant or significant at $P<0.05$ respectively.)

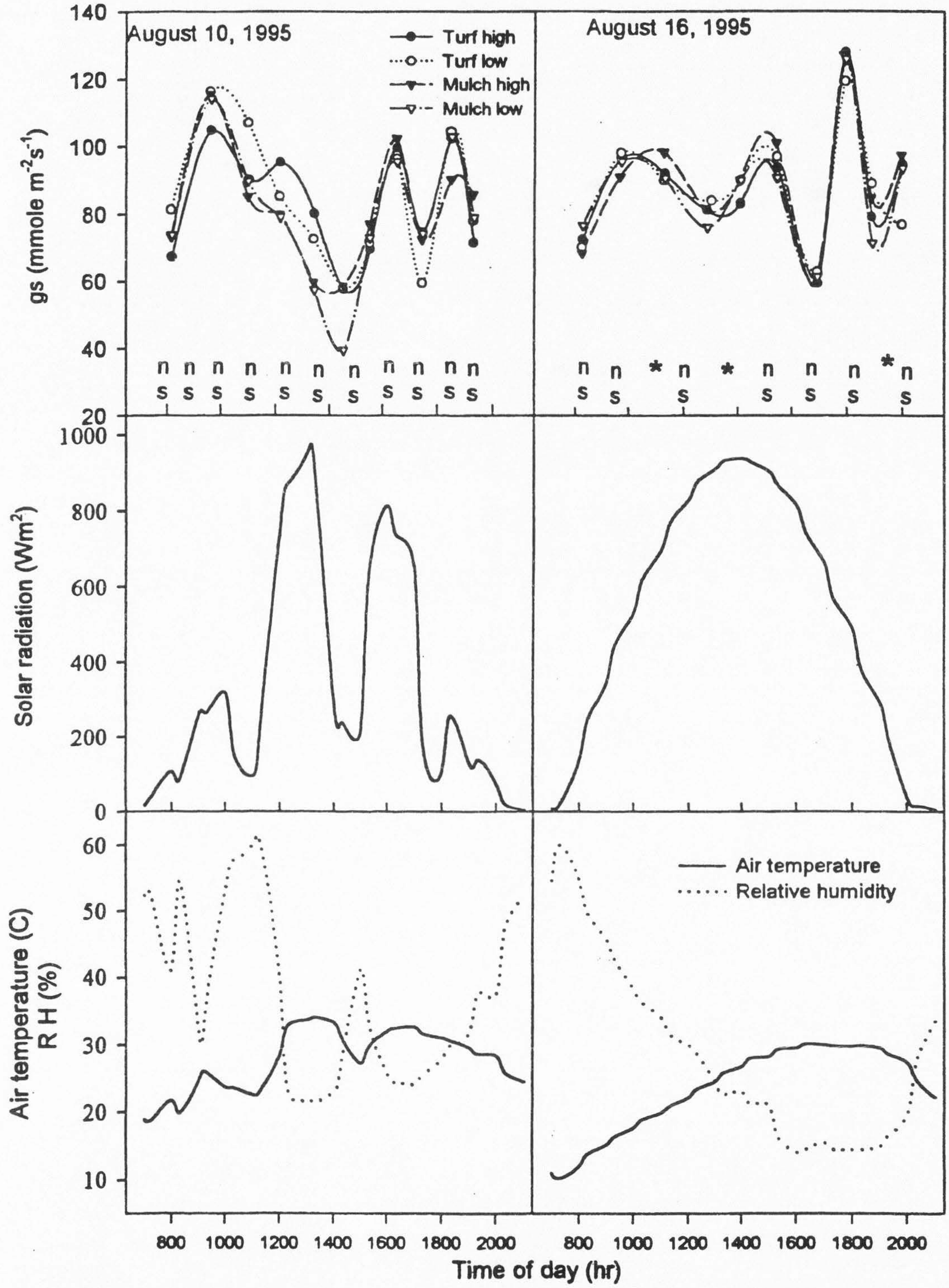

Figure 2.14. Dawn-to-dusk stomatal conductance for Norway maple growing in turf and mulch surface covers and solar radiation, air temperature, and relative humidity on August 19 and 16, 1995 (ns, *, Means treatments are non significant or significant at P<0.05 respectively.)

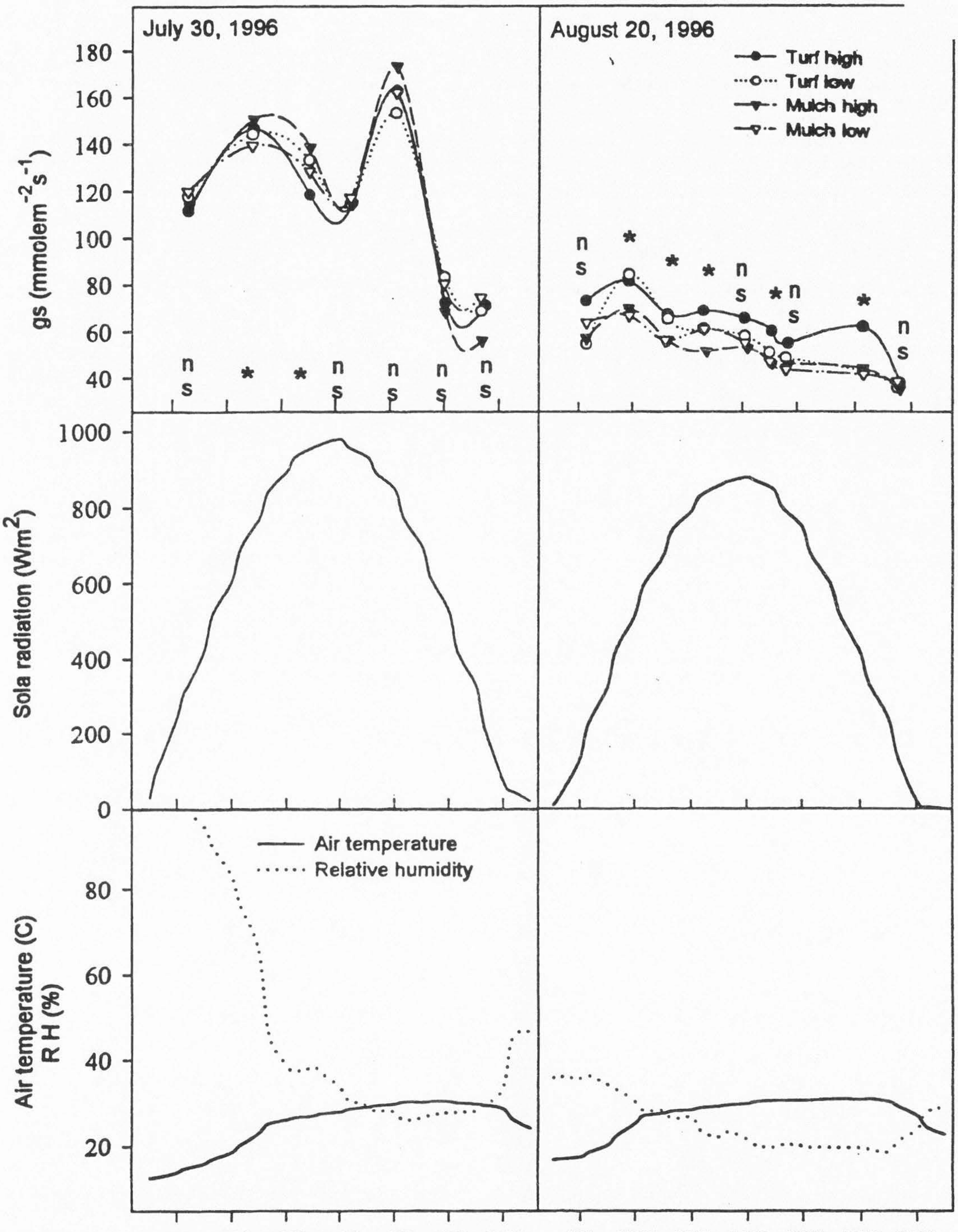

Figure 2.15. Dawn-to-dusk stomatal conductance for Norway maple growing in turf and mulch groundcovers and irrigation treatments and solar radiation, air temperature, and relative humidity on July 30 and August 20, 1996 (ns, *, Means treatments are non significant or significant at P<0.05 respectively.)

CHAPTER 3

WILLOW TREE GROWTH (*Salix matsudana*) WATER UPTAKE, WATER RELATIONS, AND ROOT DISTRIBUTION UNDER BARLEY AND BARE SOIL CONDITIONS

Abstract. Willow (*Salix matsudana* var. Tortuosa) growth, water relations, root distribution, and water uptake were measured without and with competition for water from barley (*Hordeum vulgare*). Soil water content and water uptake were measured periodically during three seasons (1994-1996) in a quarter section of tree rooting volume. Nineteen access tubes were installed in four lines radiating from the tree at five distances (0.3, 0.6, 0.9, 1.50, and 2.10 m) and four depths (0.3, 0.6, 0.9, and 1.20 m). Stomatal conductance, leaf predawn water potential, and tree growth were also monitored. Trees under competition extracted water deeper in the soil, consistent with the pattern of rooting. After the barley crop had depleted soil water content at the soil surface, both treatments had the same water uptake. The root systems of trees in the bare soil treatment extended laterally and were concentrated near the soil surface while those grown with barley extended deeper. Fine roots were visible at 0.3 m depth in the bare soil treatment but few roots were found near this depth in the barley treatment. Trees grown in the presence of barley grew deeper and restricted lateral root growth. Predawn leaf water potentials behaved similarly in both treatments, decreasing concurrent with soil water depletion at soil. Trees with bare soil had higher stomatal conductance early in the season compared to those grown with barley.

Introduction

Initial development of plant root systems appears to be under genetic control, but soon is modified by soil factors such as density, texture, moisture nutrients, temperature, and plant factors such as root competition and crown close (Harris 1983). The rooting pattern and distribution of a plant are dependent on biotic (competition) and abiotic (resources ability) factors. Variability of root form is ruled by the heterogeneous soil environment, leading to a wide spectrum of root morphologies in different species and different genotypes within a population. Within any habitat, and to meet plant resources needs, root architecture plays an important role. Its configuration and distribution in the soil must be effective in acquisition of water and nutrients to support top growth and continued root expansion (Newton and Cole 1991). Roots link all functions above and below the ground surface during plant growth (Protopapas and Bras 1987). These functions are complex because roots must deliver water and nutrients that have been absorbed simultaneously from deep and shallow soil layers, from moist and partially dry soil, and from soil zones of different biological, chemical, and physical properties.

Factors influencing the depth of the main root distribution are related to nutrients and water uptake (Fayle 1975; Kramer 1987). Fibrous roots tend to develop higher root density to explore the substrate intensively, while taproot systems explore the site with less density but more extensively. The main distribution area of roots in the soil generally occurs in the upper soil profile (Sands and Mulligan 1990). Long lateral roots provide structural support for the tree, while short roots are active in the absorption of water and nutrients (Strong and La Roi 1983). The plane of lateral roots varies with crown size, age, and tree density. This plane is found in the upper 1 m of the soil (with exceptions) with sinker roots reaching far greater depths (Sands and Nambiar 1983; Belsky 1994).

When soil water levels are lower in the upper soil profile but ample in subsoil, soil water will be moved (hydraulic lift) from lower to higher in the soil profile (Caldwell 1990; Dawson 1993; Dawson 1996). Also, hydraulic lateral transfer by roots is performed when some roots are partially wetted and the other roots are in a dry soil. Nutrient supply has a pronounced influence on size and morphology of the root system (Nambiar and Sands 1983) and water content of the soil can have a direct influence in the growth rate and distribution of roots, and interactions of these two variables can affect growth of the whole root growth.

Root system morphology and fine root distribution are cardinal factors in determining the magnitude of inter-species competition (Bi et al. 1992). It is commonly noted that fine roots develop deeper in the soil, following the wetting front. Rainfall, irrigation, and soil texture primarily determine the rate of percolation of water through the soil. Nutrients are transported with the water such that the effect of the two factors on deep root development may be difficult to distinguish. Baker and VanBavel (1988) investigated whether plants with partially irrigated root systems could deliver water to unirrigated plants through overlapping of root systems. They concluded that water moves through cotton root systems from wet to dry soil.

Individual roots compete with others roots for photosynthate within plants, and for water and nutrients between plants. This competition depends on how many others roots are present, the size and development stage of shoots, canopy light interception, and the age of the root itself (Gregory 1987). Competitive relationships between root systems can be analyzed in terms of total root biomass, and root morphology and architecture, to assess rooting distribution at specific depths (Landsberg and McMurtrie 1984).

The acquisition of water and nutrients is one of the major functions of roots and is a clear example of the close interrelation between morphology and function. Under water stress it is well known that trees develop relatively deeper roots (Atkinson 1980). In an established tree and ground cover association, as soon as root systems overlap there will a competition for water, and the magnitude of this competition will depend principally on soil moisture content, root density, and root depth between trees and herbaceous plants.

In order to achieve the soil moisture necessary for growth, a tree must expand root volume to exploit soil moisture. How tree growth and water relations are affected when growing with a competing herbaceous species that depletes all water in the top soil layers, and the effect of competition on root distribution under such conditions are the objectives of this study.

Materials and Methods

Experimental layout. The experiment was conducted at the Utah State University, Greenville Research Farm in North Logan, at 45' N 111^0 49' W and 1341 m a.s.l. The soil was a Millville Silt loam, with moderately to well drained and moderate permeability. Willow trees (*Salix matsudana* Kiodz. F. tortuosa Rehd var Tourtosa) were planted in 1991 as 30 mm diameter bare-root, branched whips. Trees were regularly irrigated from 1991-1993. Spring barley was sown in spring 1994, and in the second year volunteer seeds were allowed to regrow, and in 1996 a new barley crop was sown. The area occupied by the barley crop around each tree was a square with approximately 2.5 m per side with the tree in the center.

Treatment plots consisted in two soil cover conditions, barley crop (*Hordeum vulgare* "Spring") and bare soil. Each treatment was replicated three times, in a randomized block design. Two types of irrigation system were used. In the bare soil condition, two micro-sprinklers were located approximately 0.2-0.3 m from tree with a precipitation rate of approximately 7 mm/h, which wetted 90% of the entire surface area. Trees with competition were drip irrigated with two emitters per tree to ensure that barley was not irrigated. Trees were irrigated when the tree exhibited water stress symptoms of decreased water potential and lower stomatal conductance, and using the neutron probe readings as a guide. Irrigation application was calculated to replace soil water depleted by trees in both treatments. Trees in both treatments were irrigated once each summer.

Soil water content. Soil water content was determined using a neutron probe (CPN Model 503 Hydroprobe Martinez CA). The probe was calibrated in situ by correlating count rates with volumetric water content of undisturbed cores during installation of access tubes. Water depletion and uptake were monitored in 19 neutron probe access tubes, for a total of 76 measurements for each tree at each reading. Neutron probe tubes were installed in a quarter section of the surface area around each tree with four lines radiating from the south side of the tree and spaced at 0.3, 0.6, 0.9, 1.50, and 2.10 m intervals. Access tubes were installed to a depth of 1.20 m and readings were taken in 0.3-m increments from 0.3 m to 1.20 m.

Neutron probe measurements were taken at approximately weekly intervals over the three summer seasons. Readings were collected over the same day when schedule allowed, occasionally over a 2-day period, with the three trees in bare soil on the first day and then the three trees growing with competition on the second day. All readings, including those for calibration, were made with 16-s counts. Plant water uptake was calculated from changes in water content measured at each access tube. Water content in the surface soil layer (0-0.3 m) was taken as equivalent to the value of 0-0.3 m depth.

Tree growth and tree water relations. The effect of barley competition on leaf area was measured over the three seasons. During 1994 and 1995, all trees were defoliated manually and a subsample of 25 leaves was separated. The leaf area of the subsample was measured with the leaf area meter (Model CI-203 CID Inc., Vancouver WA.) and then both sample and subsample were dried in an oven at 40^0 C, and then weighed. Total area was the product of bulk weight and subsample area:weight ratio. During 1995 and 1996, total leaf area was measured with a leaf area index meter (Model 2000, Li-Cor., Inc., Lincoln NE). A stem core was taken at the end of the 1996 summer season at 0.25 m above soil surface to know differences in stem growth in both treatments.

Leaf water potential was measured with a Scholander type pressure chamber (Model 3005, Soil Moisture, Inc., Santa Barbara CA). Samples consisted of nine replicates per treatment. Leaf samples were taken from the middle of the crown in the east part of each tree on the same side during the three years. Samples were wrapped in a foil aluminum bag immediately after cutting and stored in an insulating box until balance pressure could be measured (Karlie and Ritchie 1979). Predawn leaf water potentials were taken throughout the summer on a weekly basis starting in July and ending in August each year. Collecting leaf samples took about 10 min and was timed to finish shortly before sunrise. The time required for sampling and the subsequent measurements in the pressure chamber was approximately between 15-30 min.

During 1994, midday stomatal conductance measurements were taken on 11 dates from July 8 to September 21, using a steady-state porometer (Model 1600, Li-Cor. Inc., Lincoln NE). These studies were conducted on 5-8 day intervals, between 12:00 and 14:00 h daytime, where three representative sun leaves and two shaded leaves were measured in each tree. Dawn-to-dusk stomatal conductance studies were conducted on August 2 and September 11, 1995, and August 6 and August 22 of 1996. Data collection began at 08:00 h each day and ended at 20:00 h. Four sun leaves and two shaded leaves were measured with the steady-state porometer, and at the same time leaf and surface temperature (barley and bare soil) were measured with an infrared thermometer (Model 210 Everest Interscience Inc., Fullerton CA). Each cycle of stomatal conductance readings and leaf and surface temperature readings on all six trees took about 30-45 min. After an hour break, data collection resumed on the same tree.

Root distribution. The effect of barley competition on tree root distribution was measured at the end of the 1996 growing season. A soil trench 6.0 m long and 1.5 m deep was dug at 0.1-0.2 m close to the tree trunk. Two willow trees per treatment were partially excavated and the roots exposed. The trench was opened with a backhoe, and then the wall was washed with a pressurized spray of water to expose most of the roots. Since tree roots were not visible in the barley competition treatment, it was necessary to carefully remove 0.25 to 0.45 m of soil from the trench face to find and expose some roots. In contrast, roots in the bare soil treatment were readily visible when the trench was opened. A wooden frame (1.0 x 1.0 m) divided in 0.1 x 0.1 m sections was attached to the wall and all exposed roots were drawn, measured, and counted. The frame was moved along the trench, and bigger and thicker roots in each section were counted and drawn. Root diameter was taken for roots larger than 1.0 mm diameter with an electronic digital caliper (Model P6394 SHAN, China). Fine roots were considered less than 1.0 mm diameter.

Data analysis. The soil moisture data, due to complexity, was analyzed using a split-split-split plot design, with the whole plot being the soil conditions treatments; the subplot the soil moisture by tubes (lines); and the sub-subplot the depth where soil moisture was taken (0.3, 0.6, 0.9, and 1.20 m). The whole plot was arranged in blocks with each block being an individual tree. Predawn leaf water potential, stomatal conductance, and tree parameters growth were analyzed with the SAS procedure (Statistical Analytical Systems, North Carolina). Change of water content between data dates was also plotted as a 3-D map. Since water in the topsoil was taken at 0.15 m, the program extrapolated water content to soil surface when water content was much lower.

Results

Weather data. Rainfall and evaporation data varied substantially among years (Fig. 2.1). Logan typically has little rainfall during the growing season, but 1994 was hotter and drier than normal. During the 1994 growing season, precipitation was below average. For example, during the period from May to August, precipitation was 28 mm, while average precipitation for the same period is 115 mm. Similarly, evaporation was 956 mm and evaporation average was 908 mm, respectively, for 1994.

In contrast, 1995 was wetter and cooler than normal, while 1996 weather data were intermediate. During 1995, precipitation from May to August was 194 mm and the historical average is 115 mm, and evaporation was 834 mm compared to the average of 908 mm. May, June, and July precipitation was all above average and evaporation was below average; in particular, May and June precipitation was twice the normal. During 1996, precipitation during the growing season was 125 mm, a little more than the historical average. May precipitation was above average, June was below, and July was again above the long-term average. Evaporation was 908 mm, the same as the historical average.

Soil water uptake. There were few significant main treatment effects on water uptake. The effects of cover (bare soil versus barley) and line radiating from the tree were not significant any year, and distance away from tree was only significant in 1996 (Appendix Tables A.4, A.5, and A.6). Differences in water content by depth and time were significant all three years. The effects of the different lines were negligible, as only time x cover x depth was significant in 1994 amongst all interactions terms involving the line measurements. Differences in water uptake by time were significant, and expected as a result of the midseason irrigation every year. Depth and distance were also significant every year, clearly a result of greater water uptake closer to the tree in the top layer of soil.

In 1994, during the period of June 29 to August 1, soil water uptake was around 0-2% volume in both treatments with no differences close to the tree (Fig 3.1). Tree water uptake was greater with competition farther from the tree. Differences were apparent after irrigation, as the cover x time x depth and cover x time x distance terms were significant. During the period of August 1 to September 1, soil water uptake from trees in the barley treatment was greater at the soil surface (7%) and closer to the tree, while it fell to 3-4% farther and deeper from the tree (Appendix Figs. A.1 and A.2). By contrast, soil water uptake by trees in bare soil appeared not to change as measurements were taken closer to the tree. At 0.6 m distance, however, higher water uptake was measured at 0.3 m depth, which then decreased by depth. At 0.9 m from the tree, there were no differences between treatments by depths. At 1.5 and 2.10 m, tree water uptake was different as it was higher at all depths under the bare soil than with competition.

Overall, soil water content in the 1995 season was higher due to above average rainfall (Fig. 2.1). In the bare soil treatment the average water content in the top 0.3 m of the root zone was about 0.18 to 0.24 m^3m^{-3} (Appendix Fig. A.3). Differences in water uptake for the cover x depth interaction was significant all season. As in 1994, the cover x depth x time and the cover x distance x time interaction terms were significant. After 40 days of withholding water, the surface layer and subsurface dried down to an average of water content about 0.16 to 0.18 m^3m^{-3} in the 0.3 to 0.6 m depths and 0.3, 0.6, and 0.9 m distances. Before irrigation there were no differences in the soil water content between treatments at the soil surface at 0.3, 0.6, and 0.9 m from the tree (Appendix Figs. A.3-A.4).

Soil water uptake was greater under bare soil than barley competition at all distances and depths, apart from differences at 0.3 m close to the tree after irrigation (Fig. 3.2). Water uptake increased by depth, a pattern completely different than that observed during 1994. Each treatment had the same trend by depth and distance. Water uptake at 0.3 m was less, and increased up to about 8% volume for all distances from the tree. By contrast, under competition, water uptake at all depths and distances was much lower, between 1-3% volume, apart from the effect of irrigation close to the tree (Appendix Fig. A.4).

Differences in water uptake between treatments were greater in 1996 than in 1994 and 1995 (Fig. 3.3). Both treatments followed the same trends by distance and by depth, and the cover, depth, and distance interaction terms were significant. Water uptake by trees was lower in the soil surface and increased with depth in the bare soil treatment before irrigation. Soil moisture content ranged from 16-20% volume in bare soil treatment at the soil surface and 18-23% volume in the subsoil (Appendix Figs. A.5 and A.6). Water uptake under bare soil followed the same pattern as in the 1995 season, where the highest soil water content was at 0.9 m depth at 1.50 and 2.10 m away from the tree. Soil water content was lower at 0.3-0.6 m at all distances. On August 1, during the dry-down period, soil water content decreased the most at deeper layers, and less change was measured at the soil surface (Fig. 3.3). An irrigation effect was detected at all distances at 0.3 and 0.6 m, particularly with bare soil, where it increased to 6-8%. The barley crop depleted the soil water from the soil surface down to 0.70 m depth. The irrigation effect was only a 4-6% increase, at 0.3-0.9 m depth. Tree water uptake under competition was substantially less than under bare soil (Fig. 3.3).

Cross section of water uptake. Water uptake for four time periods each year was plotted topographically for an average soil cross section radiating from the tree (Figs. 3.4-3.6). In 1994, during the first two periods, all depths and all distances had the same water uptake, around 1% in 8 days. During the third measurement period (August 1-10), the greatest water depletion during the season was near the soil surface, about 0.04 m^3 m^{-3} at 0.3-0.6 m depth and 0.3-0.6 m distance. At 0.6 m distance and 0.9 m depth, depletion was about 0.02 m^3m^{-3} during the same period of time, and all others distances and depths had the same depletion (0.01 m^3m^{-3}). From August 1 to September 1, after the irrigation, water uptake followed a pattern similar to the first days of August (Fig. 3.4). At 0.6 m depth and 0.6 m distance, water uptake was 0.03 m^3m^{-3} and from soil surface until 0.4 m depth water uptake was 0.02 m^3m^{-3} at all distances. Below 0.7 m depth, little water was taken up in this layer.

Water uptake under competition during the first two periods at all distances and all depths was similar, between 0.01 and 0.02 m^3m^{-3}. During the third period, higher water uptake was measured from the tree to 0.5 m distance at all depths, about 0.04 to 0.05 m^3m^{-3}. Overall during August, water uptake was higher in the first 10 days than water uptake in bare soil, following the same pattern of greater uptake close to the tree at all depths, and less far away. The least water uptake was around 0.70 m distance at all depths.

In 1995 the water uptake pattern was completely different from 1994 under bare soil (Fig. 3.5). During July the highest water uptake occurred below 0.9 m at each distance, and the least water uptake was below the soil surface, about 1% during the first 8-day period and 0.5% during the second 17-day period. Water uptake during the third period showed a similar pattern as July, less water uptake at all distances and all depths. During July 11 to August 17 (36 days), the highest water uptake was observed below 0.6 m at all distances.

Under competition, water uptake followed the same trend as bare soil in 1995, with the highest water uptake at 0.6-1.2 m depth and little water uptake closer to the surface (Fig. 3.5). During July and the first week of August, water uptake was about 1.5% volume from deep in the soil and 0.05% closer to the surface. During the period between July 11 to August 17, before irrigation, the highest depletion rate was below 0.7 m depth at all distances, and the lowest close to the soil surface. During this year, a similar decrease in soil water content was measured in both treatments. After the barley crop senesced, the soil water content at soil surface remained unchanged, and thus there was very little water uptake at this depth. Early in the season, high soil water content was measured in both treatments at the deeper layers.

In 1996 under bare soil, the amount of extracted water was similar during the three periods with water uptake at 1% volume or below at all distances and depths. Water uptake accumulated over the 50-day period was highest below 0.9 m at all distances, decreasing closer to the surface and closer to the tree. Under competition, uptake was initially closer to the surface and farther from the tree. Soil water content levels appeared to be related to uptake by barley, as all water uptake occurred at the depth and distance where barley roots were located. During July 3-19, the highest water uptake was measured farther, 1.3 m distance, and deeper, 0.8 m, from the tree, indicating barley was taking up water. The lowest water uptake measured was close to the tree. During August 1-14, less water uptake occurred at all depths and distances.

Soil water uptake was significantly different for the various depths during the three years. The most water used was at 0.3 and 0.6 m, and decreased with increasing depth under bare soil. Under competition water uptake was deeper than 0.70 m depth and farther from tree. Cover did not have a significant effect on soil water uptake all three years, probably because the barley crop depleted water in the topsoil layer.

Roots. General morphology of the tree root system with competition was different compared to tree roots in bare soil. Trees with competition had fewer lateral roots that were larger, and more vertically oriented roots that grew deeper, compared to trees in bare soil. Few roots of trees under competition were initially visible. By contrast, in bare soil many tree roots were clearly visible after trenching. Treatments gave different proportions of tree root volume that varied in form (Fig. 3.7). The differences in root distribution and root surface volume between layers for each treatment were reflected in similar differences in the rate of water uptake. Trees in bare soil had the majority of their roots at 0.3 m, and fewer below 0.6 m. Under competition, roots were found deeper in the soil, with greater root diameter. The distribution of roots of different diameters varied with depth in both treatments.

The barley crop apparently restricted root development at 1.20 and 1.50 m away from tree. Most of the root volume was found closer to the tree at 0.3 and 0.6 m distance and below 0.3 m to 0.6 m, then decreasing with depth. Trees in bare soil had root volume extending at 1.50 m. The most root volume under bare soil was found between 0.2 m to 0.5 m, with highest root volume from 0.3 to 0.9 m away from the tree.

The distribution of fine roots was more uniform under bare soil than under competition (Figs. 3.8 and 3.9). Fine roots under bare soil were found close to the soil surface and laterals roots were mainly found at 0.3 m. Fine roots were fewer in trees under competition in the surface layer, where barley roots were more abundant. Depth of tree root penetration was greatest under competition than under bare soil. Maximum tree rooting depth was approximately 1.50 m under competition and under bare soil tree root depth was 0.7 m.

In a comparison of rooting patterns of both treatments, root number and root volume were highest under bare soil at all depths below the soil surface. Root distribution and root volume of willow tree in bare soil were concentrated close to the soil surface at 0.2 m depth. The biggest difference between treatments was that tree roots under competition grew deeper and tree roots under bare soil had lateral roots and fine roots growing parallel to the soil surface.

Water relations and tree growth/Water potential. Predawn water potential (Ψ pd) varied little between treatments. A similar seasonal pattern can be seen for both treatments. Initially, Ψpd was about -0.7 MPa, and it decreased to -1.0 MPa as water was depleted within the rooting zone (Fig. 3.10a). Ψpd increased to -0.7 MPa by early August, then fell to -1.0 MPa just before irrigation. Following irrigation in August, Ψpd in both treatments increased from -1.0 MPa to -0.7 MPa. There were no differences between treatments.

During 1995 (Fig. 3.10 b), Ψpd was less negative than 1994 and leaf Ψpd in trees in the bare soil were less negative than those with competition. Seasonal low Ψpd was reached in mid-July at -0.7 MPa, for both treatments. Following rain, Ψpd in bare soil recovered to nearly -0.5 Mpa, while Ψpd under competition remained about -0.65 MPa. All trees were irrigated when Ψpd under competition reached -0.7 Mpa, although Ψpd of trees under bare soil showed less stress. After irrigation Ψpd in both treatments recover to nearly -0.4 MPa.

Water potential in 1996 showed no differences between treatments on any date (Fig. 3.10c). Seasonal high values occurred in mid-July at around -0.35MPa, then decreased about -0.6 MPa through July into mid-August. By late August, both treatments fell to seasonal low values around -0.8 MPa. Following irrigation, Ψpd rose to-0.35 MPa, similar to initial values. During the summer, both treatments were slow to exhibit water stress after surface soil water was depleted. Analysis of variance showed that Ψpd was not significantly different between treatments in 1994 and 1996 season, although in 1994 trees under competition tended towards more negative Ψpd (P=0.11).

Stomatal conductance. In 1994, midday stomatal conductance (gs) was not different between treatments through most of the summer (Fig 3.11). On days 217 and 259, the gs of trees with competition was significantly higher by approximately 10 mmole $m^{-2}s^{-1}$. On day 210 (end of July) just before irrigation, gs dropped in both treatments to a low value of 18 mmole $m^{-2}s^{-1}$. The effect of irrigation was detectable when gs increased in both treatments to the highest levels of the season, then declined again.

Similar to 1994, gs varied little between treatments in 1995 during two dawn-to-dusk studies. In general, stomatal conductance was highest in mid-morning and lowest in afternoon before irrigation on August 2 under cloudless conditions (Fig 3.12). During mid-morning, bare soil trees had higher gs, 140 mmole $m^{-2}s^{-1}$, compared with 70 mmole $m^{-2}s^{-1}$ for the trees with competition, and subsequently gs fell to about 60 mmole $m^{-2}s^{-1}$ through the day. Trees without competition had significantly higher gs on three occasions. After irrigation under cloudy skies on September 11, gs was overall higher than the previous study date, but again showing partial closure through the day. Conductance of trees in bare soil was significantly higher for only one measurement.

In 1996, two dawn studies were conducted on days 218 and 234 under cloudless conditions (August 6 and 22) (Fig. 3.13). In early August at mid-morning, gs was 90 mmole $m^{-2}s^{-1}$, then fell to about 68 mmole $m^{-2}s^{-1}$. By late August, and before irrigation, gs was lower than August 6 (Fig. 3.13). Midmorning gs were 60 mmole $m^{-2}s^{-1}$, then declined to minimum values of 30-35 mmolem$^{-2}s^{-1}$ by late afternoon. There were no significant differences between treatments on either date.

Tree growth. Competition had marked effects on tree growth (Table 3.1). Stem core diameter was 12 mm greater in the bare soil treatment than the barley competition treatment. Similarly, leaf area of trees in bare soil was significantly higher than trees with competition. Leaf area nearly doubled between 1994 and 1996. Leaf area was 34% greater for trees under bare soil than those with competition in 1994. In 1995 leaf area followed the same trend, as trees in bare soil had 43% more leaf area than those with competition. The greatest leaf area index (LAI) was also for trees in bare soil during the 1995 and 1996 seasons compared with tree with competition.

Discussion

Soil water uptake. Soil water content was already depleted at the soil surface under bare soil and barley competition treatments, according to soil water measurements, by late June or early July. Water content decreased progressively during the growing season in both treatments, and soil water uptake followed similar trends across years. No differences were found between lines radiating from the tree during the three seasons. Tree water uptake under competition was deeper than under bare soil. Barley competition depleted most of the soil water at 0.6 m and farther from the tree (0.6 m to 2.10 m distance), decreasing water uptake in this zone of soil all three seasons. In contrast, trees under bare soil depleted soil water according to root growth and distribution. For example, during 1994, water uptake was closer to the tree, while in 1995 and 1996, there was a greater amount of water taken up from deeper in the soil in comparison with trees with competition.

In this experiment, soil water uptake showed little variation at the soil surface in both treatments, which was most likely due to soil water being depleted at this depth. Under bare soil, nearly all soil water was used by the tree, with some evaporation contributing to this drying. Without irrigation or rain to replenish soil water close to the surface, there is little water there to extract. The pattern of decreasing water uptake from soil surface has been shown by other authors, including Protopapas and Brass (1987) and Eastham et al. (1990). They reported that water uptake is less at soil surface (dry layers) and greater in deeper layers as the soil water content in upper layers decreased. Kozlowoski (1987) stated that as the soil dries down, the rate of water absorption is reduced by increasing the resistance to water movement in the soil and within the tree.

Soil water depletion appeared to be related to water uptake by tree roots, since the most water uptake was measured at the depth and distance where tree roots were located. During 1994, very little water uptake was measured below 0.9 m depth and 2.10 m distance, since few tree roots were found at depth or distance in trees under bare soil. Soil water content between distances was statistically different; close to the tree it was higher and decreased with distance in the bare soil treatment.

Less water uptake was measured under barley competition, a result supported by the few tree roots found at soil surface and none at 1.5 and 2.10 m away from the tree. Appendix Figs. A.1 and A.2 show that water content decreased mainly at the soil surface and close to the tree during the 1994 season under bare soil, while in 1995 and 1996 water uptake was deeper in the profile, a result supported again with the root distribution found at the end of the experiment. In a study by Grieve (1989), it was found that water uptake is more limited by water availability rather than root density.

Roots. Willow rooting under competition was pushed below barley roots, and in this study the soil was deep enough where tree roots could grow and develop deep enough to extract water without competition. Deep rooting is a strategy when water and nutrients are limited at the soil surface, but also in the presence of herbaceous competition. Deep root development has been shown by Coutts (1987) and Newton and Cole (1991). Tree root growth under competition developed deeper to apparently obtain water, but this came at a cost, as trunk and leaf growth was less under competition. In contrast, tree rooting under bare soil was dominated by horizontally spreading lateral roots, which in general occurred within the upper 0.3 m of soil, where fine roots were found. Roots may be concentrated in the soil profile in response to nutrients and water supply (Strong 1983; Bi et al. 1992; Belsky 1994).

In this study herbaceous roots suppressed woody roots at the soil surface. Water competition was the main factor, while barley crop depleted all soil water content at this layer.

Sands and Mulligan (1990) postulated that root configuration can be modified by changes in the soil environment, especially water and nutrients distribution. Green and Clothier (1995) found that plants have the capacity to adapt to drastic changes in the water status around their root system. Nambiar (1990) stated that a strong competitive advantage between herbaceous and trees for water and nutrients is the amount of roots.

Water relations and tree growth. Stomatal conductance and Ψpd are very sensitive measurements of plant water status (Bradford and Hsiao 1982; Clark and Kjelgren 1990). In this study under bare soil, Ψpd and stomatal conductance were significantly higher when the upper soil profile was wetter, as was the case in 1995. Ψpd was more negative and gs was lower in both treatments in 1994 and 1996 seasons compared to 1995. It would be expected that trees with herbaceous competition would be under greater water stress, but trees in both treatments showed similar levels of Ψpd. Tree root distribution under bare soil was concentrated close to the topsoil surface, and trees with shallower roots are generally more susceptible to drought (Punthakey et al. 1984; Breda and Crombie et al. 1988). A clear, partial stomatal closure was measured in both treatments as a result of water stress during 1995-1996, and low gs values in 1994 just before irrigation similar to results of Kramer (1987) and Iacobelly and McCaughey (1993).

Trees in competition were able to maintain similar values of stomatal conductance and Ψpd to those in bare soil. Both treatments had lower water content at the soil surface. As the upper layers were depleted, deeper tree roots under competition enabled the tree to take up more water than trees in bare soil. These results agree with previous studies by Crombie et al. (1988). Mild water stress affects growth such that Ψpd and conductance may not show decreases from water stress if leaf area is reduced first. Leaf area also was less in these trees with competition during the three seasons, less water requirements.

The presence of barley crop reduced willow growth in the three years of this study. Clearly, conditions for regular tree growth occurred in bare soil, as leaf area and stem growth were greater in trees under bare soil than with barley competition. Trees often invest more assimilate into roots and less into shoots when soil water and nutrients are limiting (White and Newton 1989).

In summary, we found that willow trees with competition from barley developed large vertical sinker roots and that fine roots were not visible in the top layer of soil. Willow is a riparian species that tends toward surface rooting, and the presence of a competing root system in the topsoil increased tree root development to deeper in the soil. The barley crop in this experiment was able to restrict woody and fine roots and the lateral spread of roots at the soil surface.

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TABLE 3.1. Stem diameter, leaf area (m^2) and leaf area index (LAI) in willow tree with bare soil and barley competition treatments.

	Stem core diameter (mm)	Leaf area (m^2)		Leaf area index	
Treatments	1996	1994	1995	1995	1996
Bare soil	118	25.72	54.14	1.64	1.75
Barley competition	106	17.18	30.92	1.15	1.54
Surface	*	*	*	*	*

NS no significance * significance at $P<0.05$

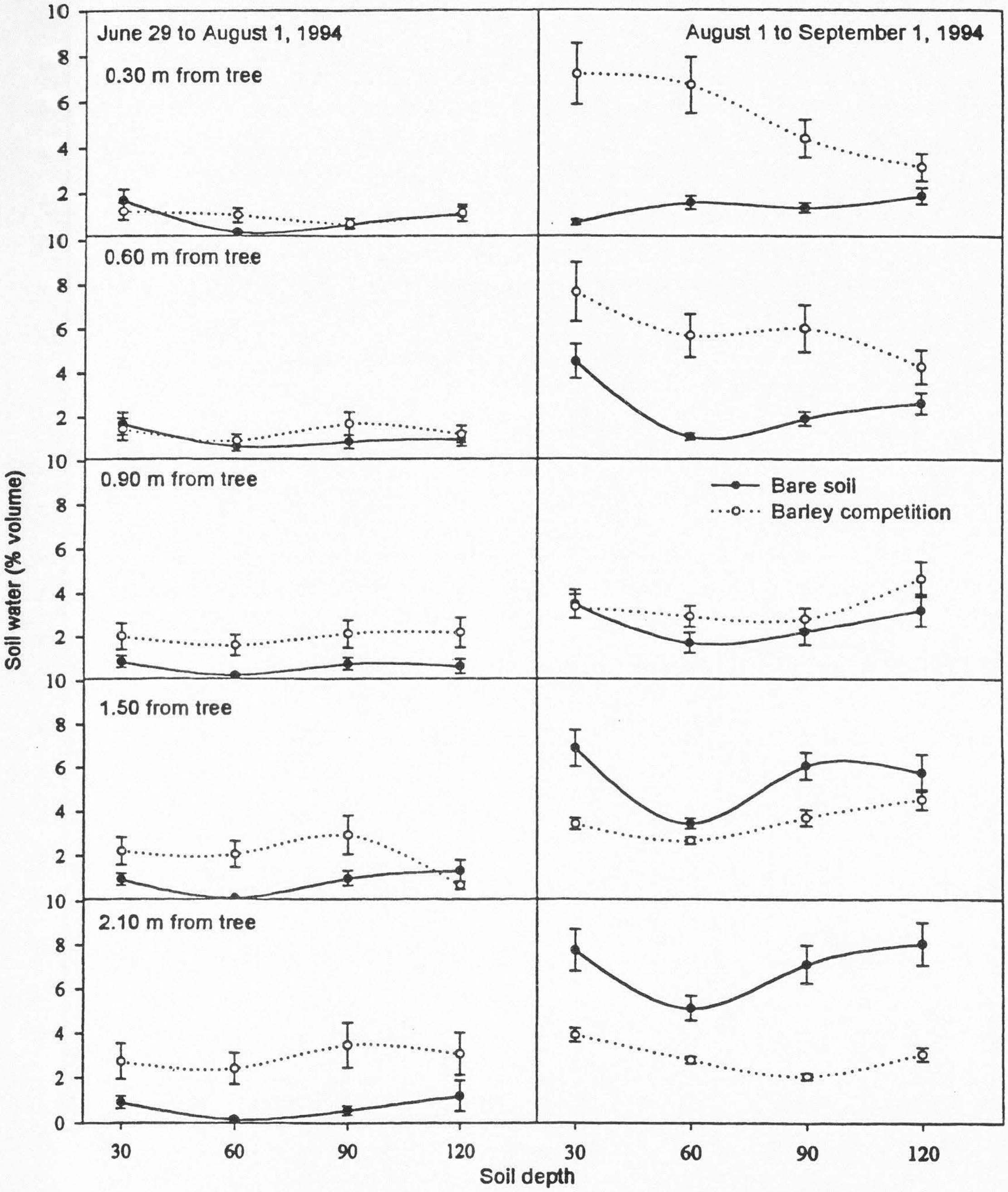

Figure 3.1. Soil moisture difference (%) between two dates, before and after irrigation, in willow trees growing in bare soil and barley competition in 1994. Values are average from four lines per tree, three trees per treatment, and four depths, plus standard error bars.

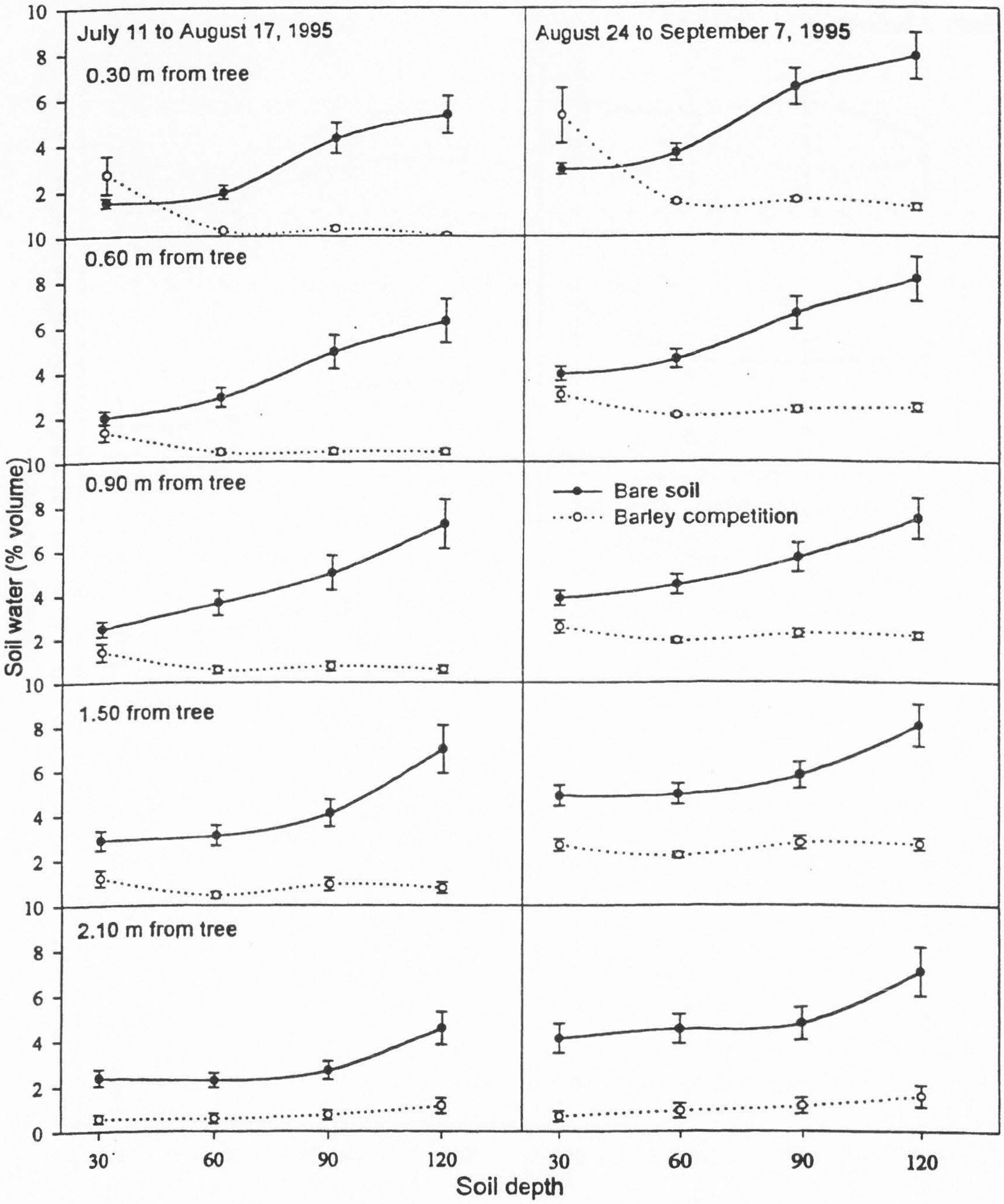

Figure 3.2. Soil water difference (% volume) between two dates, before and after irrigation, in willow trees growing in bare soil and barley competition in 1995. Values are average from four lines per tree, three trees per treatment, and four depths, plus standard error bars.

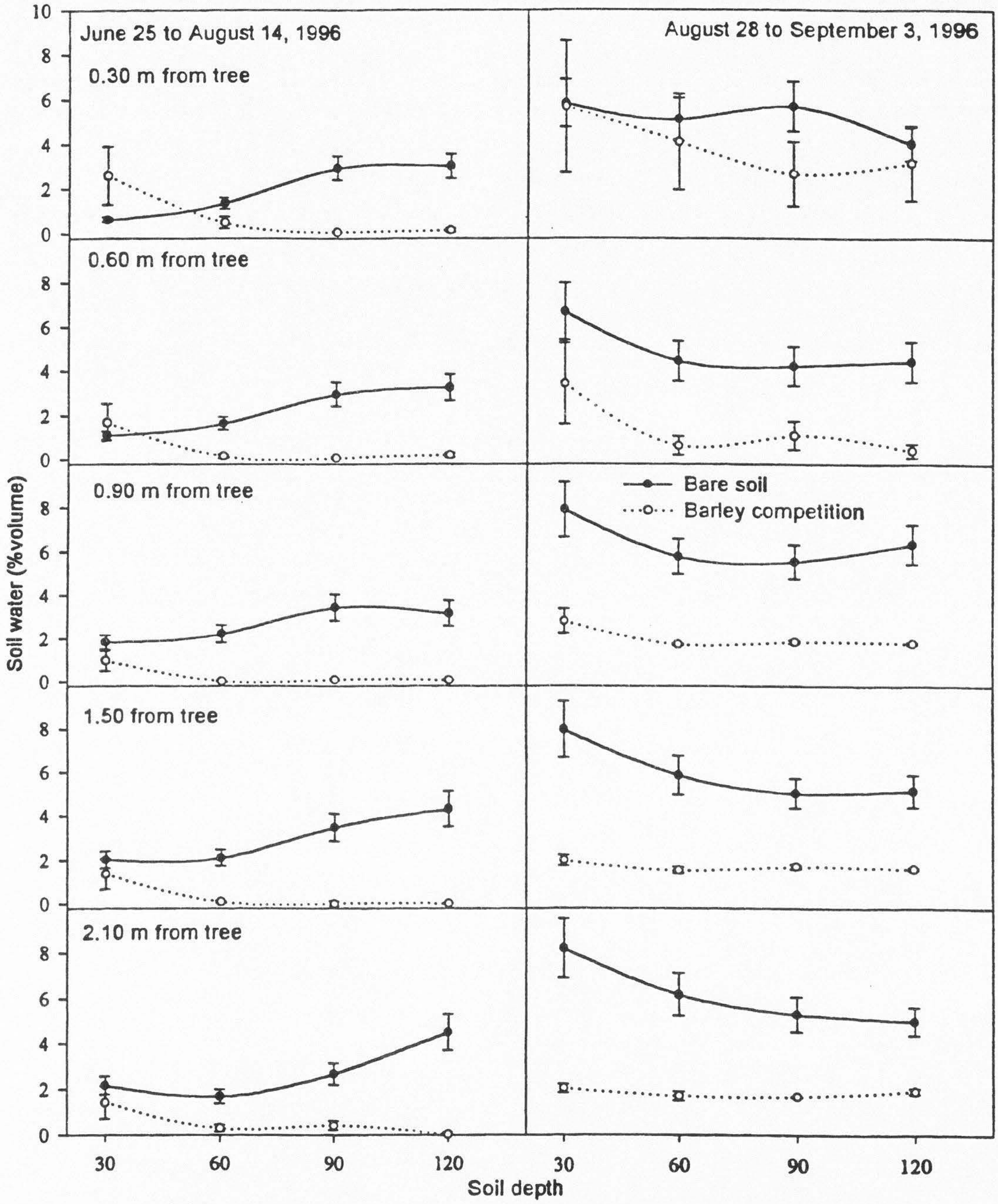

Figure 3.3. Soil water difference (% volume) between two dates, before and after irrigation, in willow trees growing in bare soil and barley competition in 1996. Values are average from four lines per tree, three trees per treatment, and four depths, plus standard error bars.

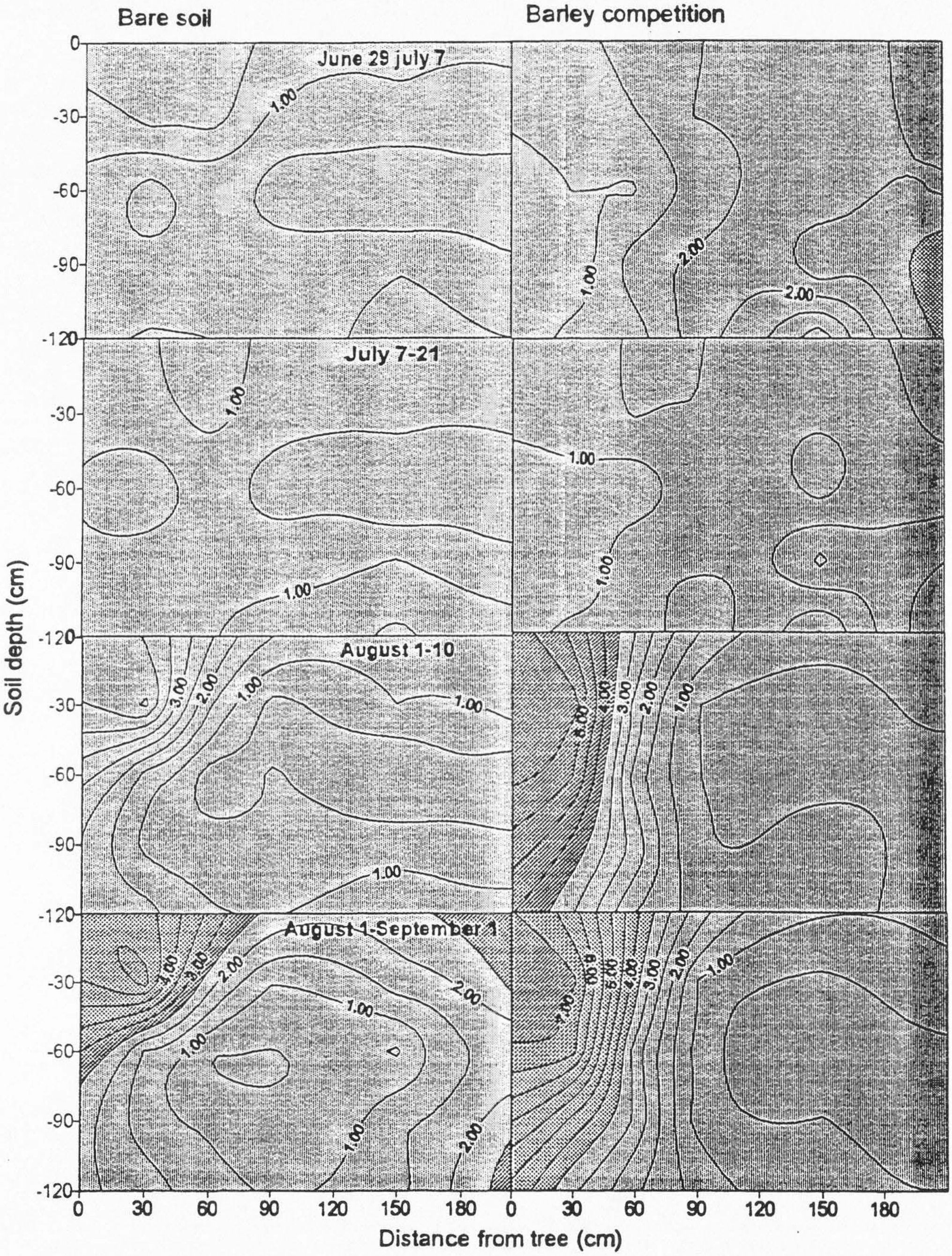

Figure 3.4. Water uptake (% volume) between two dates in willow under bare soil and competition at four depths (0.3, 0.6, 0.9, and 1.20 m) and five distances from the tree (0.3, 0.6, 0.9, 1.50, and 2.10 m) in 1994.

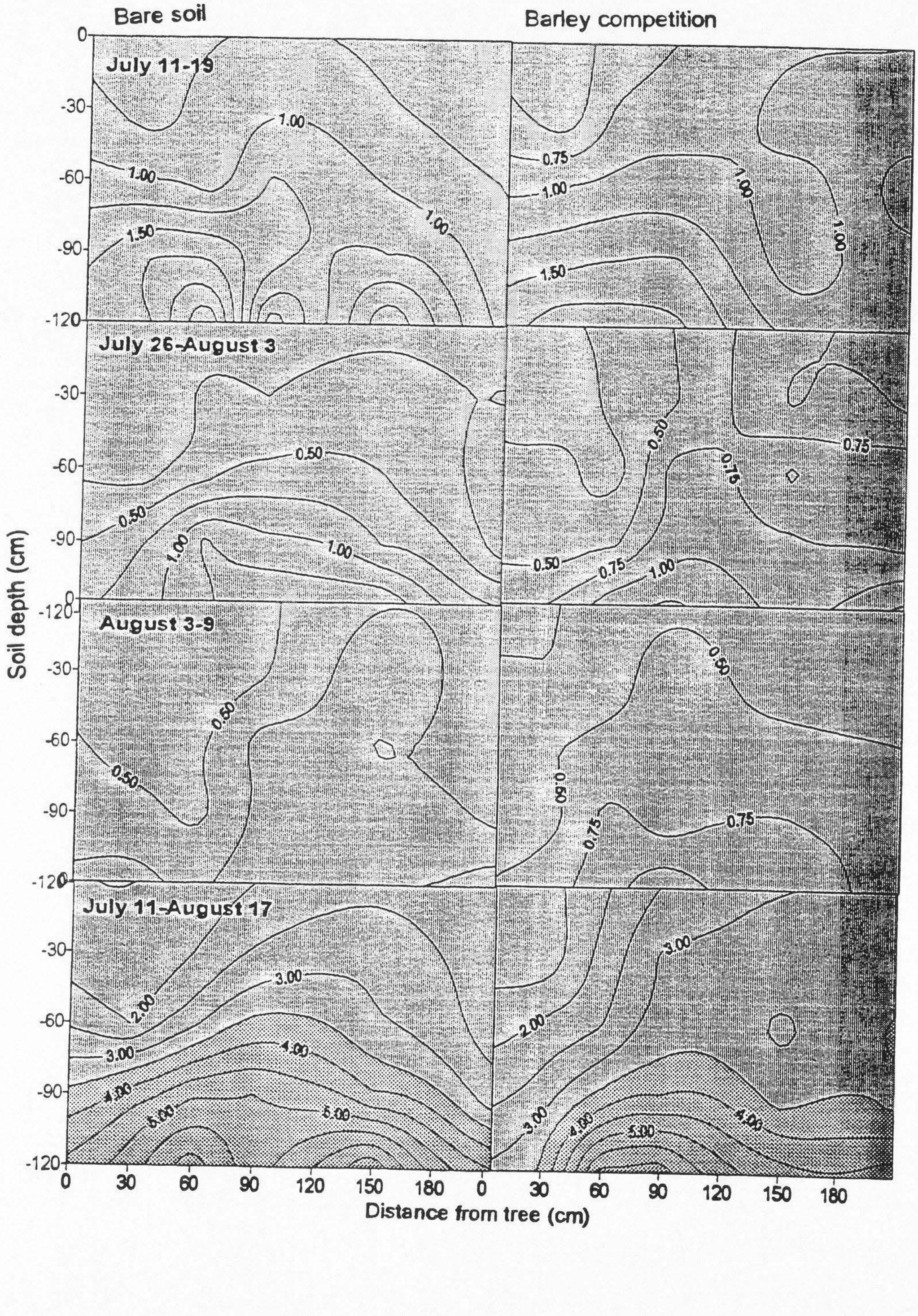

Figure 3.5. Water uptake (% volume) between two dates in willow under bare soil and competition at four depths (0.3, 0.6, 0.9, and 1.20 m) and five distances from the tree (0.3, 0.6, 0.9, 1.50, and 2.10 m) in 1995.

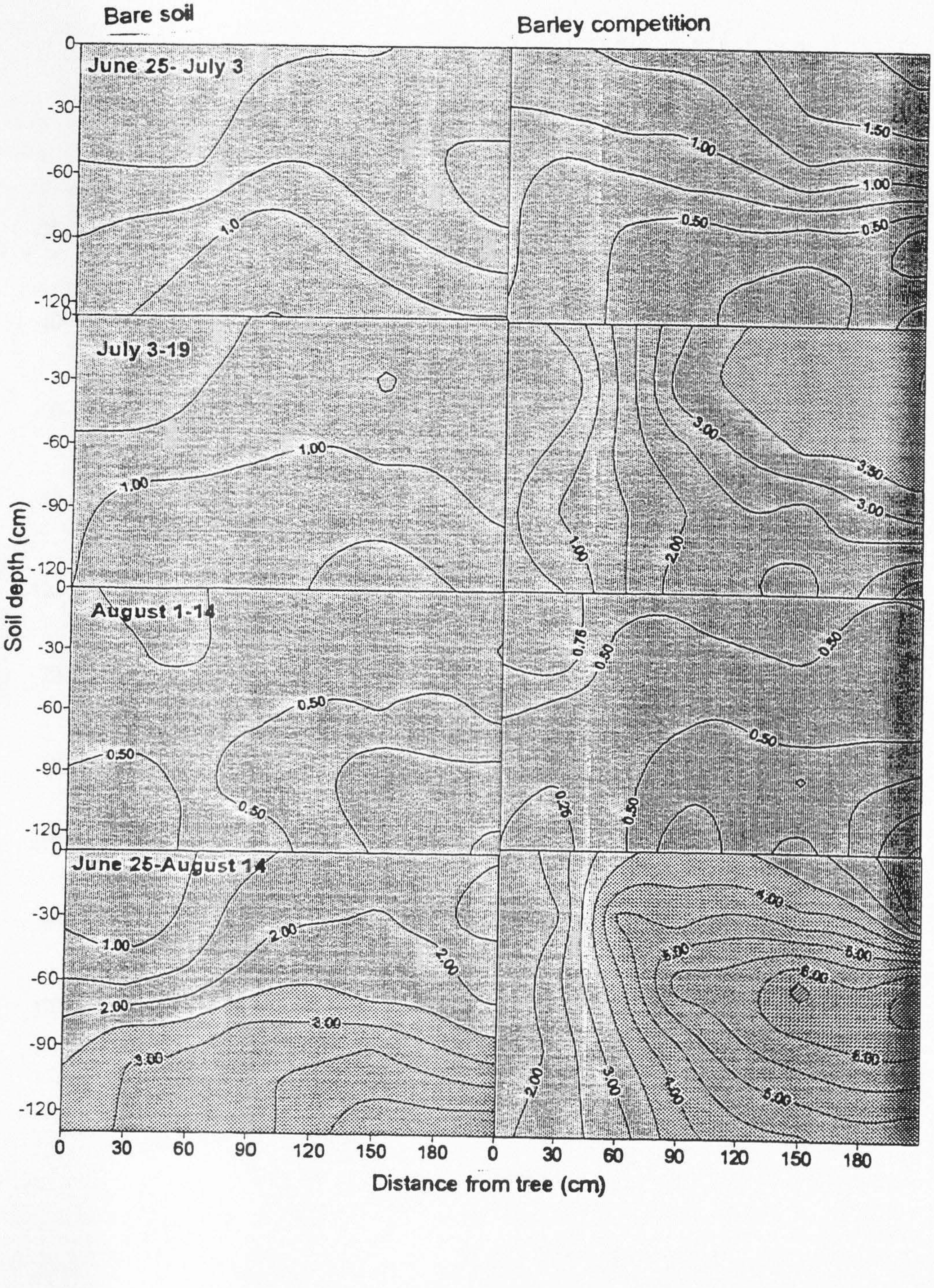

Figure 3.6. Water uptake (% volume) between two dates in willow under bare soil and competition at four depths (0.3, 0.6, 0.9, and 1.20 m) and five distances from the tree (0.3, 0.6, 0.9, 1.50, and 2.10 m) in 1996.

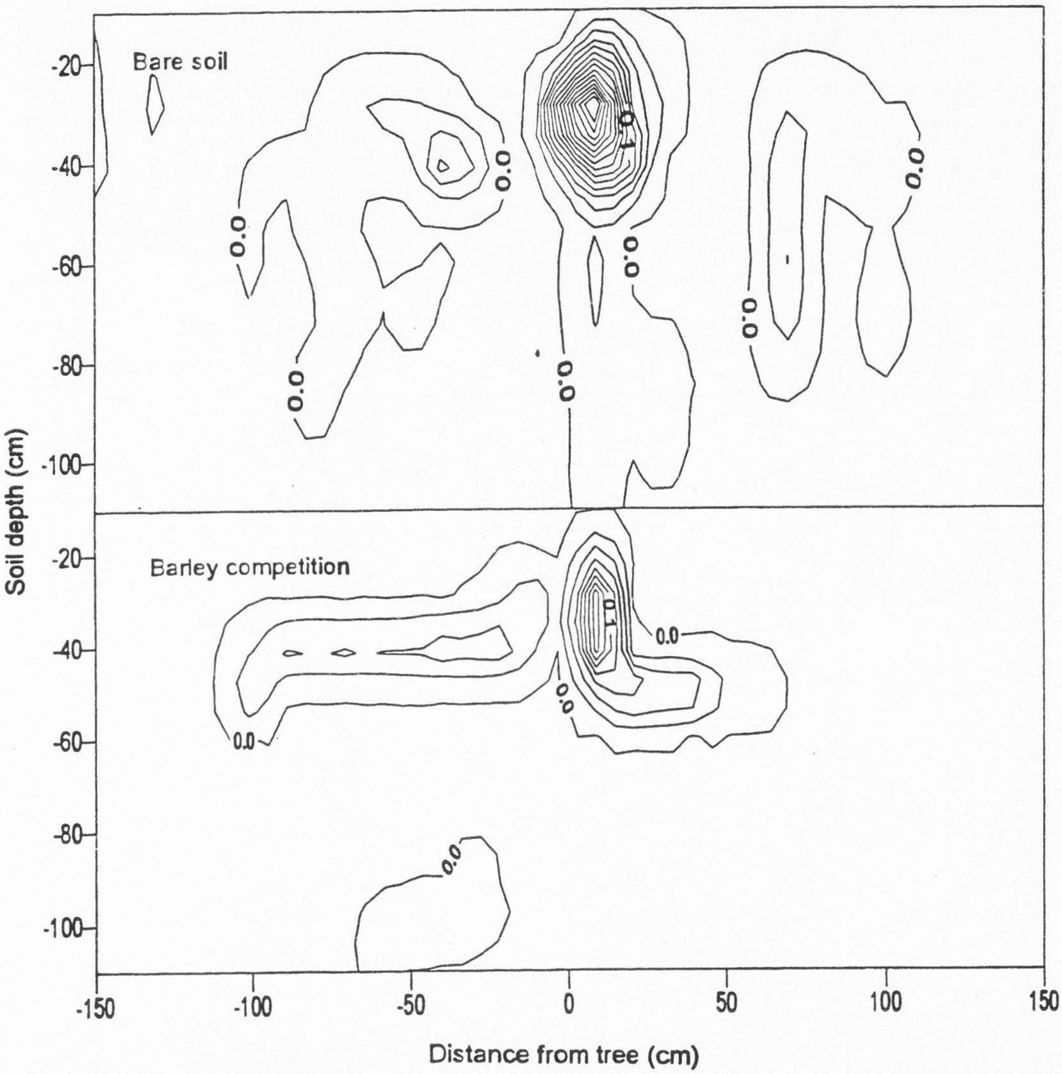

Figure 3.7. Ratio of root volume/soil volume in willow tree growing in bare soil or with barley competition. Values are average of two trees.

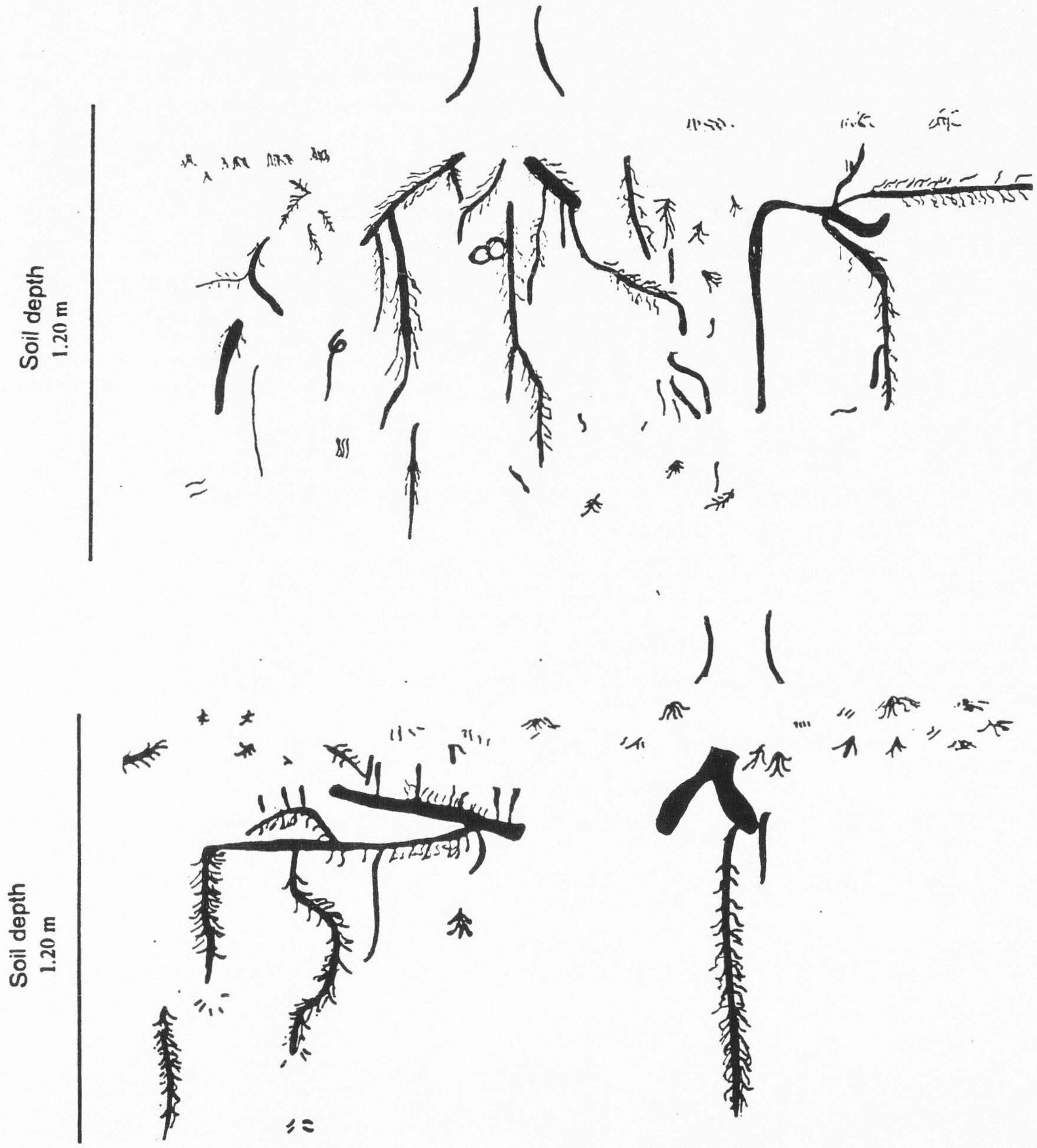

Figure 3.8. Root system of two representative willow trees growing in bare soil.

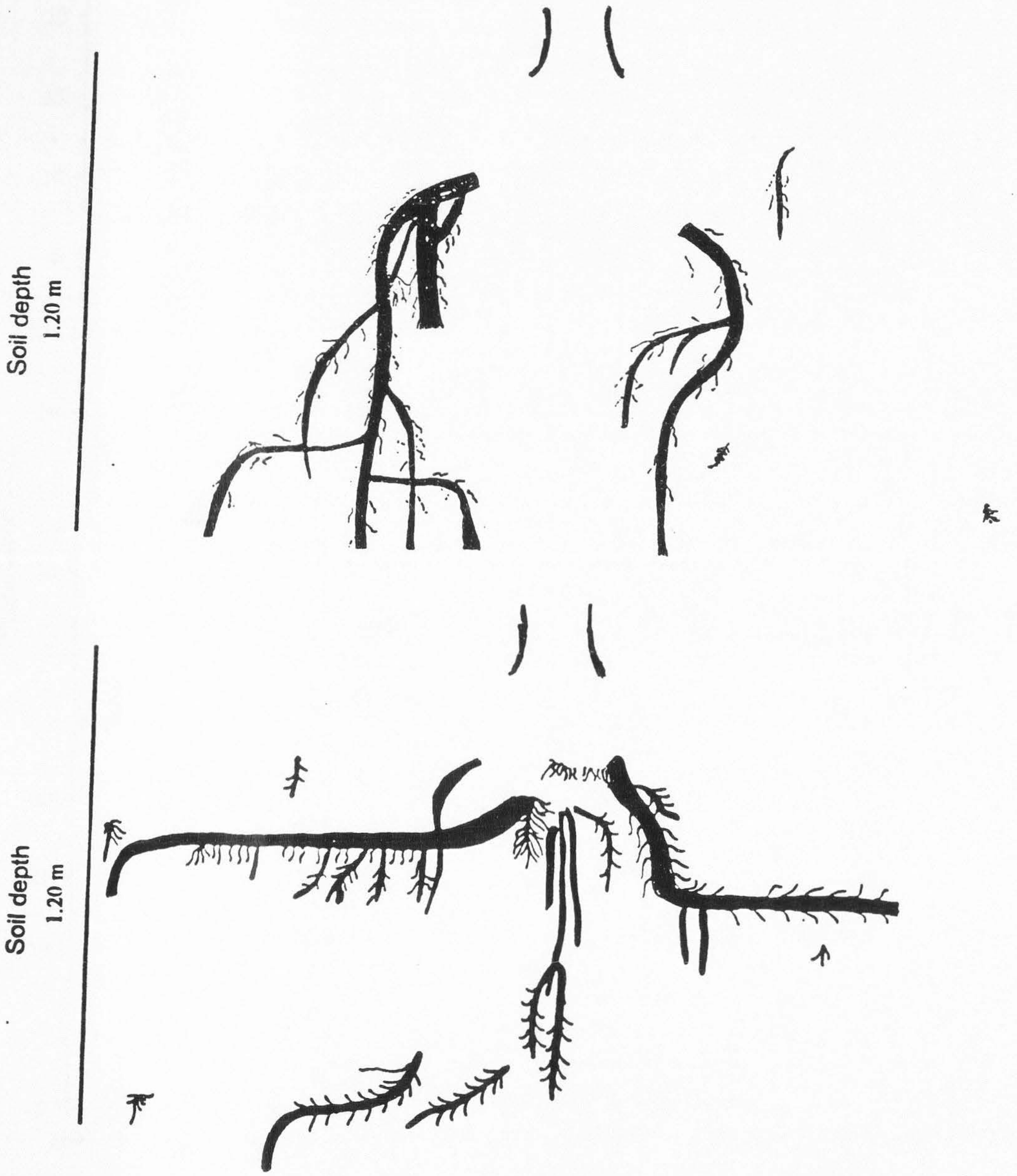

Figure 3.9. Root system of two representative willow trees growing with barley competition.

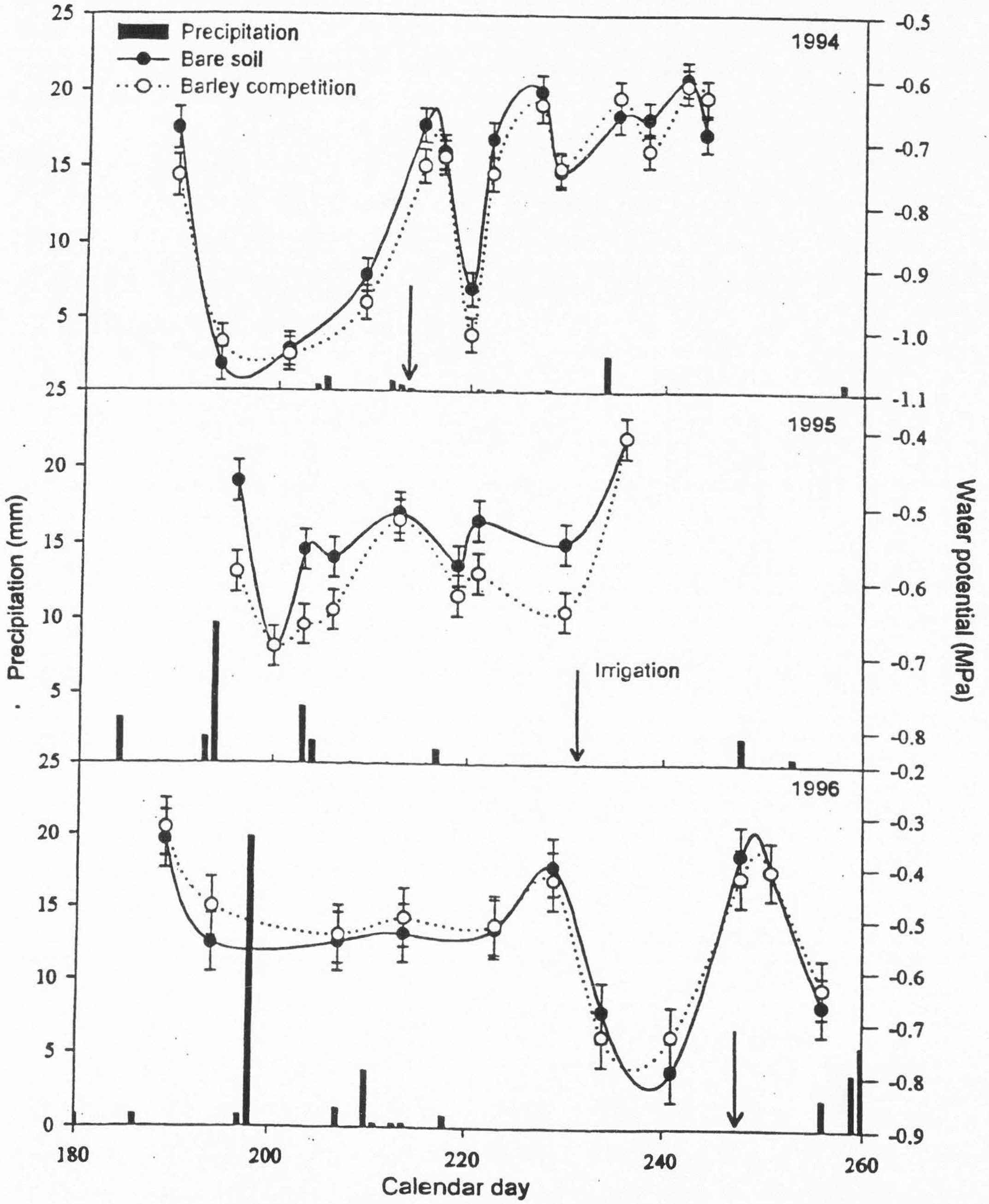

Figure 3.10. Predawn leaf water potential (MPa) and precipitation over three seasons (94-96) in willow growing in bare soil or with barley competition. (Plus standard error) irrigation events are noted by arrows.

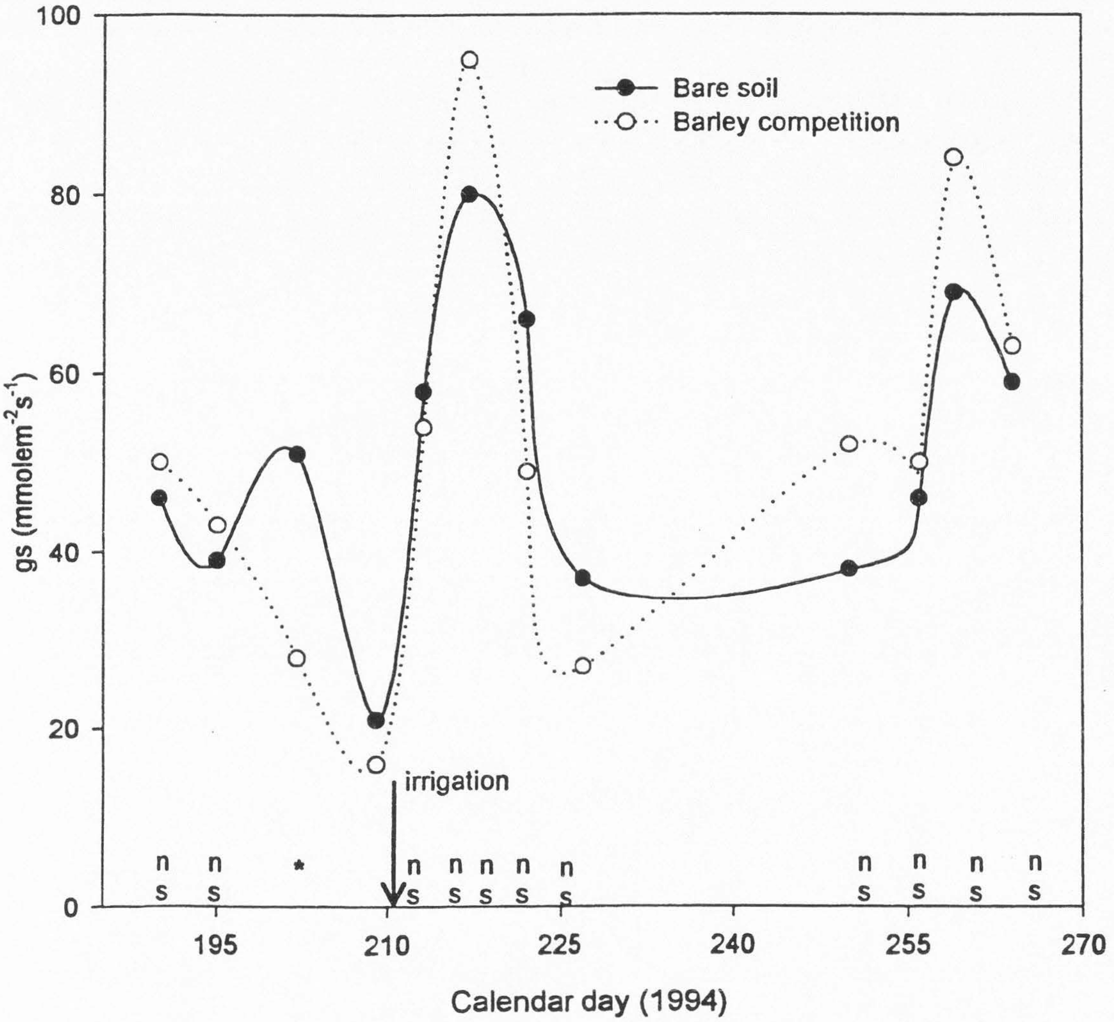

Figure 3.11. Midday stomatal conductance (gs) in willow tree in response to bare soil or barley competition during 1994 (ns, *, Means treatments are nonsignificant or significant at $P<0.05$, respectively.)

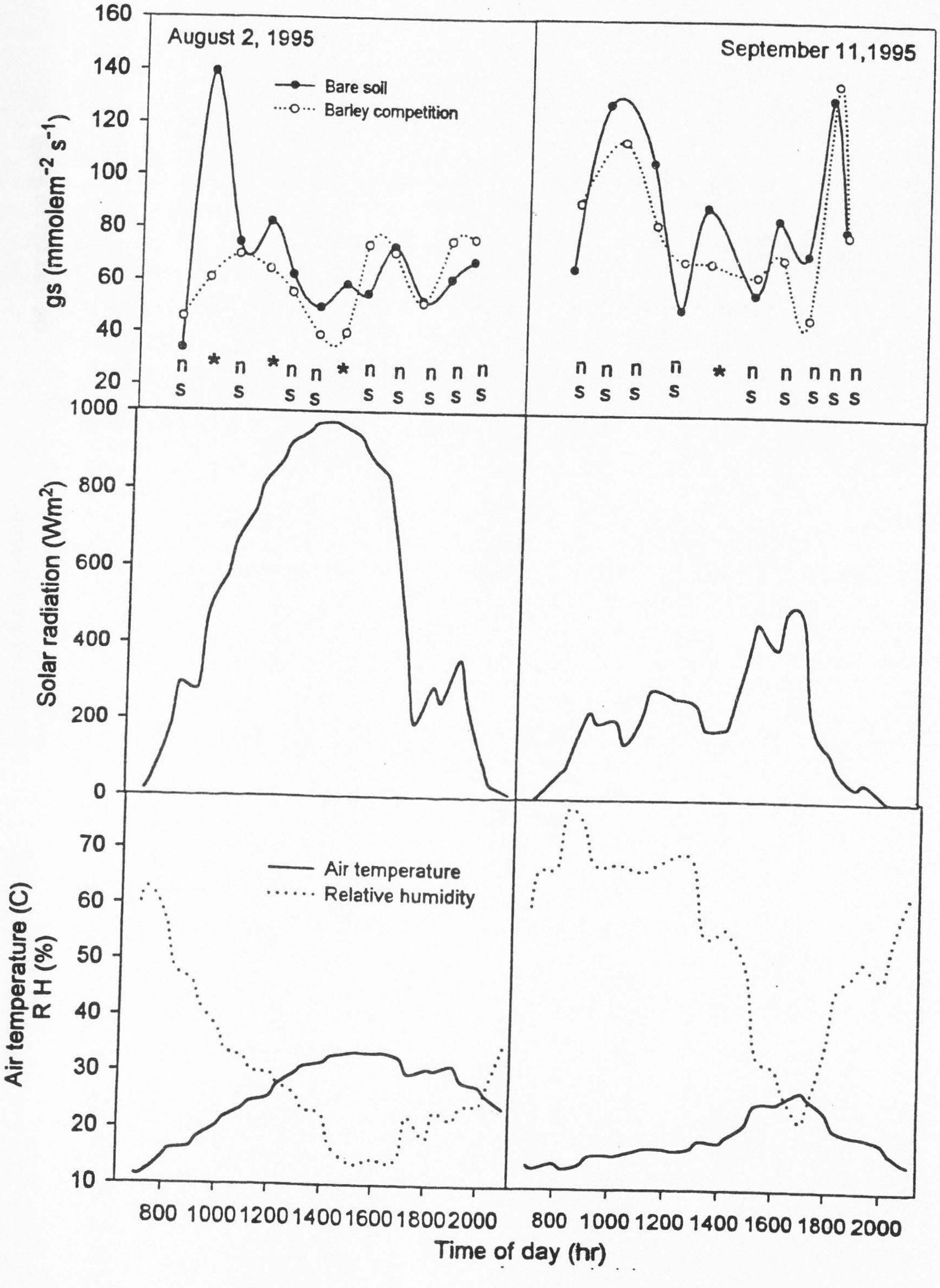

Figure 3.12. Dawn-to-dusk stomatal conductance (gs) in willow growing in bare soil or with barley competition, plus solar radiation, air temperature, and relative humidity on August 2 and September 11, 1995 (ns, *, Means treatments are nonsignificant or significant at P<0.05, respectively.)

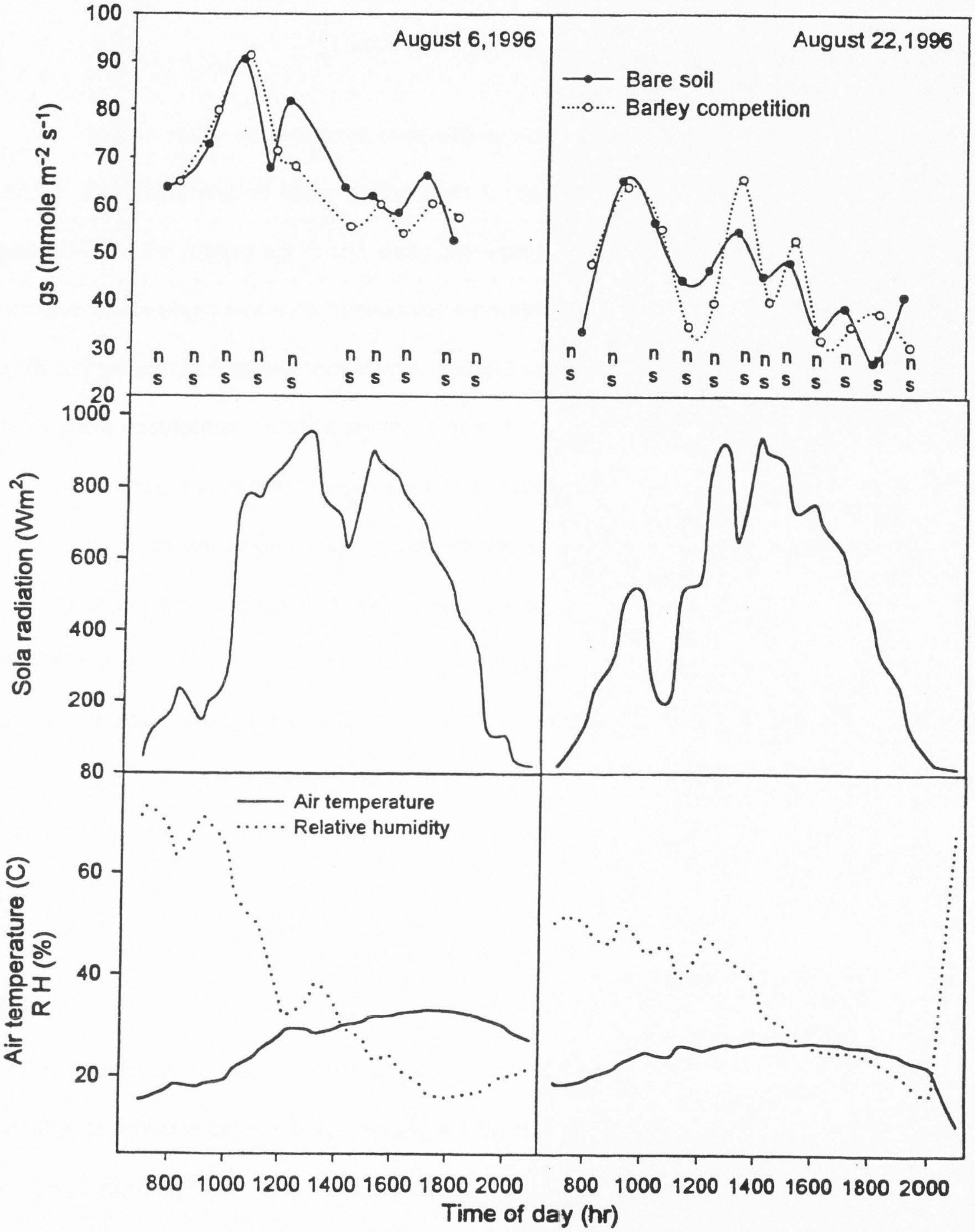

Figure 3.13. Dawn-to-dusk stomatal conductance (gs) in willow growing in bare soil or with barley competition plus solar radiation, air temperature, and relative humidity on August 6 and 22, 1996 (ns, *, Means treatments are nonsignificant or significant at $P<0.05$, respectively.)

CHAPTER 4

SUMMARY AND CONCLUSIONS

In this study we measured competition within maple trees in turf and willow trees in barley. Our objectives of these studies were to determine if trees competing with herbaceous groundcover for rooting space and water are more susceptible to soil water deficits than those without. Other objectives were to measure tree water uptake, and tree root distribution in the soil with and without herbaceous competition, and tree water relations and tree growth response under herbaceous competition during a dry-down period.

Several important conclusions can be deduced from this research.

Early in the season when water content is higher at the soil surface, there were no differences between surface cover treatments, in Ψpd and gs measurements. Later after water was depleted at the soil surface, water stress symptoms were more visible in trees with and without competition as a result of tree root distribution.

The distribution of water uptake at different depths caused water stress that changed with tree root development, and tree roots followed the soil-water drying front. After water content was depleted at the soil surface, less variation was measured in the upper layers.

Norway maple and willow under herbaceous competition were able to maintain similar stomatal conductance and predawn water potential to those trees without competition. Maintaining similar water relations came at a cost, allocating more assimilates for root growth and less to leaf area growth. Considerable and significant reductions in leaf area and stem growth were measured in those trees with herbaceous competition. Trees showed higher water uptake close to the tree, so keeping herbaceous plants as far away from the tree as possible can only help the tree.

Water stress altered the tree root configuration by the presence of herbaceous competition. Roots developed deeper and had fewer fine roots at the soil surface with herbaceous competition. By contrast, without competition root distribution was closer to the soil surface, and trees developed normal growth with more horizontally fine and lateral root development.

Patterns of tree root development changed as a result of competition, and can have an effect on the potential for water stress. Herbaceous competition suppressed root growth within its root zone, pushing tree root development deeper and promoting less lateral root growth. If there is adequate soil volume under the competing roots, a tree can extract that soil water, and thus water stress may not be a factor. If the soil is shallow and tree roots cannot get below the roots of the competition, the tree will be potentially subject to much greater stress.

APPENDIX

Table A.1. Analysis of variance in the soil water uptake at different dates, in Norway maple in response to turf and mulch surface covers and irrigation treatments during 1994.

		1994		
Factor	DF	MS	F	P value
Block	4	16.84		
Cover (C)	1	875.95	199.51	0 **
Irrigation (I)	1	0.302	0.07	0.796 NS
C x I	1	0.703	0.16	0.696 NS
Error	12	4.39		
Distance (L)	2	6.676	4.82	0.042 **
Error	8	1.386		
C x L	2	2.505	2.13	0.141 NS
I x L	2	0.035	0.03	0.97 NS
C x L x I	2	0.753	0.64	0.536 NS
Error	24	1.177		
Depth (D)	3	39.796	4.64	0.022 **
Error	12	8.569		
C x D	3	69.195	5.6	0 **
I x D	3	5.333	3.9	0.01 **
C x I x D	3	6.633	4.85	0.003 **
L x D	6	0.529	0.39	0.884 NS
C x L x D	6	0.362	0.26	0.954 NS
I x L x D	6	0.649	0.47	0.83 NS
C x I x L x D	6	0.899	0.66	0.682 NS
Error	132	1.368		
Date (T)	5	259.45	60.54	0 **
Error	20	4.286		
C x T	5	108.77	129.52	0 **
I x T	5	16.83	20.5	0 **
C x I x T	5	15.77	18.79	0 **
L x T	10	3.14	3.74	0.001 **
C x L x T	10	1.402	1.67	0.083 NS
I x L x T	10	0.158	0.19	0.997 NS
C x I x L x T	10	0.446	0.53	0.87 NS
D x T	15	31.45	37.45	0 **
C x D x T	15	26.685	31.77	0 **
I x D x T	15	1.399	1.67	0.051 *
C x I x D x T	15	2.456	2.92	0.002 **
L x D x T	30	1.417	1.69	0.048 *
C x L x D x T	30	0.726	0.86	0.61 NS
I x L x D x T	30	0.683	0.81	0.667 NS
C x I x L x D x T	30	0.513	0.61	0.869 NS
Error	940	0.84		
Total	1439			

Table A.2. Analysis of variance in the soil water uptake at different dates, in Norway maple in response to turf and mulch surface covers and irrigation treatments during 1995.

		1995		
Factor	DF	MS	F	P value
Block	4	11.04		
Cover (C)	1	620.28	38.47	0 **
Irrigation (I)	1	5.12	0.32	0.582 NS
C x I	1	66.28	4.11	0.065 NS
Error	12	15.122		
Distance (L)	2	52.108	30.51	0 **
Error	8	1.708		
C x L	2	0.886	0.39	0.681 NS
I x L	2	14.401	6.35	0.006 **
C x L x I	2	11.96	5.27	0.013 **
Error	24	2.268		
Depth (D)	3	131.39	23.36	0 **
Error	12	5.624		
C x D	3	77.381	43.97	0 **
I x D	3	2.664	1.51	0.215 NS
C x I x D	3	10.67	6.07	0.001 **
L x D	6	9.346	5.31	1.00E-04 **
C x L x D	6	1.336	0.76	0.603 NS
I x L x D	6	2.085	1.18	0.321 NS
C x I x L x D	6	4.263	2.42	0.03 **
Error	132	1.76		
Date (T)	5	97.198	36.23	0 **
Error	20	2.683		
C x T	5	103.87	80.14	0 **
I x T	5	12.738	9.83	0 **
C x I x T	5	5.736	4.43	5.00E-04 **
L x T	10	4.501	3.47	0.002 **
C x L x T	10	1.418	1.09	0.367 NS
I x L x T	10	2.162	1.67	0.083 NS
C x I x L x T	10	5.496	4.24	0 **
D x T	15	9.141	7.05	0 **
C x D x T	15	5.819	4.89	0 **
I x D x T	15	4.666	3.6	0 **
C x I x D x T	15	3.124	2.41	0.002 **
L x D x T	30	1.255	0.97	0.487 NS
C x L x D x T	30	0.891	0.69	0.796 NS
I x L x D x T	30	0.863	0.67	0.816 NS
C x I x L x D x T	30	1.92	1.48	0.105 NS
Error	940	1.296		
Total	1439			

Table A.3. Analysis of variance in the soil water uptake at different dates, in Norway maple in response to turf and mulch surface covers and irrigation treatments during 1996.

	1996			
Factor	DF	MS	F	P value
Block	4	13.483		
Cover (C)	1	776.94	169.87	0 **
Irrigation (I)	1	24.98	5.46	0.038 **
C x I	1	21.023	4.6	0.053 NS
Error	12	4.574		
Distance (L)	2	40.099	108.38	0 **
Error	8	0.37		
C x L	2	0.522	0.67	0.521 NS
I x L	2	0.065	0.07	0.933 NS
C x L x I	2	1.384	1.59	0.225 NS
Error	24	0.87		
Depth (D)	3	51.951	4.81	0.02 **
Error	12	10.802		
C x D	3	113.56	85.89	0 **
I x D	3	1.984	1.5	0.218 NS
C x I x D	3	1.516	1.15	0.332 NS
L x D	6	6.47	4.89	0.0002 **
C x L x D	6	1.406	1.06	0.39 NS
I x L x D	6	0.132	0.1	0.996 NS
C x I x L x D	6	0.688	0.51	0.8 NS
Error	132	1.322		
Date (T)	2	28.261	11.12	0.005 **
Error	8	2.541		
C x T	2	15.33	27.32	0 **
I x T	2	11.054	19.95	0 **
C x I x T	2	12.088	21.82	0 **
L x T	4	0.831	1.5	0.202 NS
C x L x T	4	5.445	9.83	0 **
I x L x T	4	0.616	1.09	0.361 NS
C x I x L x T	4	0.54	0.97	0.424 NS
D x T	6	17.011	30.71	0 **
C x D x T	6	8.174	14.751	0 **
I x D x T	6	5.496	9.92	0 **
C x I x D x T	6	4.045	7.3	0 **
L x D x T	12	0.926	1.67	0.071 NS
C x L x D x T	12	0.909	1.64	0.078 NS
I x L x D x T	12	0.473	0.85	0.599 NS
C x I x L x D x T	12	0.257	0.46	0.937 NS
Error	376	0.554		
Total	719			

Table A.4. Analysis of variance of the soil water uptake at different dates for willow in response to bare soil and barley competition treatments during 1994.

	1994			
Factor	DF	MS	F value	P value
Cover (C)	1	42.768	2.41	0.1955 NS
Error (a)	4	17.744		
Line (L)	3	0.208	0.12	0.9466 NS
C x L	3	1.835	1.04	0.41 NS
Error (b)	12	1.768		
Distance (D)	3	1.917	0.81	0.4946 NS
C x D	3	3.663	1.55	0.2136 NS
L x D	9	0.836	0.35	0.9527 NS
C x L x D	9	1.197	0.51	0.86 NS
Error (c)	48	2.363		
Depth (P)	3	16.712	26.27	0 **
C x P	3	1.308	2.06	0.1069 NS
L x P	9	1.089	1.71	0.0869 NS
C x L x P	9	1.621	2.55	0.0087 **
D x P	9	2.568	4.04	0.0001 **
C x D x P	9	0.378	0.59	0.8044 NS
L x D x P	27	0.346	0.54	0.9701 NS
C x L x D x P	27	0.575	0.9	0.6115 NS
Error (d)	192	0.636		
Date (T)	7	289.891	448.05	0 **
C x T	7	25.684	39.7	0 **
L x T	21	0.801	1.24	0.2069 NS
C x L x T	21	1.098	1.7	0.0246 **
D x T	21	6.762	10.45	0 **
C x D x T	21	3.456	5.34	0 **
L x D x T	63	0.889	1.37	0.031 **
C x L x D x T	63	0.742	1.15	0.1994 NS
P x T	21	5.187	8.02	0 **
C x P x T	21	1.316	2.03	0.0038 **
L x P x T	63	0.77	1.19	0.1488 NS
C x L x P x T	63	0.654	1.01	0.4557 NS
D x P x T	63	0.694	1.07	0.3324 NS
C x D x P x T	63	0.423	0.65	0.9849 NS
L x D x P x T	189	0.45	0.7	0.9991 NS
C x L x D x P x T	189	0.423	0.65	0.9999 NS
Error (e)	1792	0.647		
Total	3071			

Table A.5. Analysis of variance of the soil water uptake at different dates for willow in response to bare soil and barley competition treatments during 1995.

	1995			
Factor	D F	MS	F value	P value
Cover (C)	1	1.705	0.22	0.6635 NS
Error (a)	4	7.223		
Line (L)	3	0.974	1.44	0.2799 NS
C x L	3	1.147	1.7	0.2199 NS
Error (b)	12	0.676		
Distance (D)	3	3.773	2.07	0.1166 NS
C x D	3	6.261	3.44	0.0239 **
L x D	9	0.743	0.41	0.9236 NS
C x L x D	9	0.522	0.29	0.9743 NS
Error (c)	48	1.822		
Depth (P)	3	92.116	107.98	0 **
C x P	3	4.522	5.3	0.016 **
L x P	9	0.677	0.79	0.6259 NS
C x L x P	9	1.187	1.39	0.1949 NS
D x P	9	1.799	2.11	0.0305 **
C x D x P	9	1.46	1.71	0.089 NS
L x D x P	27	0.48	0.56	0.9621 NS
C x L x D x P	27	0.567	0.66	0.8995 NS
Error (d)	192	0.853		
Date (T)	7	628.173	1324.73	0 **
C x T	7	1.045	2.2	0.0317 **
L x T	21	0.702	1.48	0.0741 NS
C x L x T	21	0.42	0.89	0.6047 NS
D x T	21	1.332	2.81	0 **
C x D x T	21	2.172	4.58	0 **
L x D x T	63	0.317	0.67	0.9783 NS
C x L x D x T	63	0.318	0.67	0.9783 NS
P x T	21	26.521	55.93	0 **
C x P x T	21	2.6	5.48	0 **
L x P x T	63	0.447	0.94	0.6108 NS
C x L x P x T	63	0.568	1.2	0.1328 NS
D x P x T	63	1.01	2.13	0 **
C x D x P x T	63	0.684	1.44	0.0144 **
L x D x P x T	189	0.32	0.67	0.9997 NS
C x L x D x P x T	189	0.314	0.66	0.9998 NS
Error (e)	1792	0.474		
Total	3071			

Table A.6. Analysis of variance of the soil water uptake at different dates for willow in response to bare soil and barley competition treatments during 1996.

	1996			
Factor	D F	MS	F value	P value
Cover (C)	1	229.25	4.75	0.0948 NS
Error (a)	4	48.3		
Line (L)	3	1.814	1.68	0.224 NS
C x L	3	0.289	0.27	0.8458 NS
Error (b)	12	1.08		
Distance (D)	3	20.336	10.89	0 **
C x D	3	7.325	3.92	0.0139 **
L x D	9	0.859	0.46	0.8939 NS
C x L x D	9	0.398	0.21	0.9917 NS
Error (c)	48	1.867		
Depth (P)	3	26.51	21.65	0 **
C x P	3	56.515	46.15	0 **
L x P	9	0.362	0.3	0.9741 NS
C x L x P	9	0.305	0.25	0.9863 NS
D x P	9	1.07	0.87	0.5531 NS
C x D x P	9	2.678	2.19	0.0244 **
L x D x P	27	0.48	0.39	0.9974 NS
C x L x D x P	27	0.551	0.45	0.9919 NS
Error (d)	192	1.225		
Date (T)	5	641.495	871.54	0 **
C x T	5	67.372	91.53	0 **
L x T	15	0.584	0.79	0.69 NS
C x L x T	15	0.288	0.39	0.9819 NS
D x T	15	9.522	12.94	0 **
C x D x T	15	4.591	6.24	0 **
L x D x T	45	0.851	1.16	0.2195 NS
C x L x D x T	45	0.489	0.66	0.9599 NS
P x T	15	7.836	10.65	0 **
C x P x T	15	15.867	21.54	0 **
L x P x T	45	0.377	0.51	0.9972 NS
C x L x P x T	45	0.422	0.57	0.9903 NS
D x P x T	45	1.267	1.72	0.0024 **
C x D x P x T	45	1.407	1.91	0.0003 **
L x D x P x T	135	0.329	0.45	1 NS
C x L x D x P x T	135	0.44	0.6	0.9999 NS
Error (e)	1280	0.736		
Total	2303			

Table A.7. Analysis of variance of leaf area in Norway maple in response to turf and mulch surface covers and irrigation treatments during 1994, 1995, and 1996.

	Leaf area	1994			
Factor	DF	SS	MS	F	P value
Block	4	3.9656	0.9914	1.11	0.396
cover	1	2.048	2.048	2.3	0.156
irrigation	1	0.0065	0.0065	0.01	0.933
C x T	1	2.353	2.353	2.64	0.13
error	12	10.7018	0.8918		
total	19	19.0748			

	Leaf area	1995			
Factor	DF	SS	MS	F	P value
Block	4	3.753	0.938	0.73	0.586
Cover	1	14.895	14.895	11.66	0.005
Irrigation	1	3.411	3.411	2.67	0.128
C x T	1	6.544	6.544	5.12	0.043
Error	12	15.335	1.278		
Total	19	43.938			

	Leaf area	1996			
Factor	DF	SS	MS	F	P value
Block	4	27.67	6.92	0.65	0.64
Cover	1	310.31	310.31	28.98	0
Irrigation	1	2.84	2.84	0.27	0.616
C x T	1	15.91	15.91	1.49	0.246
Error	12	128.49	10.71		
Total	19	485.23			

Table A.8. Analysis of variance in the leaf nitrogen content in Norway maple in response to turf and mulch surface covers and irrigation treatments during November 1995, June 1996, and November, 1996.

	Nitrogen	1995			
Factor	DF	SS	MS	F	P value
Block	4	0.084	0.021	0.71	0.598
Cover	1	0.5445	0.5445	18.5	0.001
Irrigation	1	0.2376	0.2376	8.07	0.015
C x T	1	0.0897	0.0897	3.05	0.106
Error	12	0.3532	0.02943		
Total	19	1.3			

	Nitrogen	1996			
Factor	DF	SS	MS	F	P value
Block	4	0.04612	0.01153	0.66	0.633
Cover	1	3.2	3.2	182.27	0
Irrigation	1	0.08712	0.08712	4.96	0.046
C x T	1	0.008	0.008	0.46	0.512
Error	12	0.21068	0.01756		
Total	19	3.55192			

	Nitrogen	1996(Nov)			
Factor	DF	SS	MS	F	P value
Block	4	0.39548	0.09887	1.66	0.224
Cover	1	0.6125	0.6125	10.25	0.008
Irrigation	1	0.07938	0.07938	1.33	0.271
C x T	1	0.05618	0.05618	0.94	0.351
Error	12	0.71684	0.05974		
Total	19	1.86038			

Table A.9. Analysis of variance in the leaf predawn water potential data from Norway maple in response to turf and mulch surface covers and irrigation treatments during 1995 and 1996.

	Leaf water potential 1995				
Factor	DF	SS	MS	F	Pvalue
Block	4	19.2419	4.8105		
Cover	1	7.9206	7.9206	6.6	0.0246
Irrigation	1	0.7875	0.7875	0.66	0.4324
C x T	1	3.0018	3.0018	2.5	0.1398
error a	12	14.4033	1.2003		
date (6)	6	17.6689	2.9448	2.86	0.0302
error b	24	24.7161	1.0298		
C x D	6	4.5229	0.7538	1.21	0.313
I x D	6	5.216	0.8693	1.39	0.23
C x I x D	6	6.7077	1.118	1.79	0.113
Error c	72	44.9827	0.6248		
Total	139	149.1694			

	Leaf water potential 1996				
Factor	DF	SS	MS	F	Pvalue
Block	4	1.7783	0.4446		
cover	1	0.2006	0.2006	0.33	0.5763
irrigation	1	0.5406	0.5406	0.88	0.3667
C x T	1	0.0086	0.0086	0.01	0.922
error a	12	7.3782	0.6148		
date (6)	6	77.645	12.9408	13	0
error b	24	23.8907	0.9954		
C x D	6	8.0579	0.343	2.83	0.016
I x D	6	1.7379	0.2896	0.61	0.721
C x I x D	6	3.5479	0.5913	1.25	0.293
Error c	72	34.1207			
Total	139	158.9065			

Table A.10. Analysis of variance of leaf predawn water potential in willow tree in bare soil and barley competition treatment during 1995 and 1996. (SAS general models procedure).

	Water potential 1995				
Source	DF	SS	MS	F	P value
Model	19	0.334881	0.017625	7.27	0.0001
Error	28	0.067866	0.002423		
Total	47	0.402747			

R-square	C.V.	Root MSE	WP-95 mean
0.8314	-8.5963	0.04923	-0.57

Number of observations	48
Treatments	2
Tree	3
Time	8

	Water potential 1996				
Source	DF	SS	MS	F	P value
Model	43	1.6844	0.03917	12.14	0.0001
Error	22	0.0709	0.00322		
Total	65	1.7554			

R-square	C.V.	Root MSE	WP-96 mean
0.9595	-7.063	0.0567	-0.804

Number of observations	66
Treatments	2
Tree	3
Time	11

Table A.11. Analysis of variance of stomatal conductance in willow tree in bare soil and barley competition treatment during 1995 and 1996.(SAS general models procedure).

	Stomatal conductance 1995				
Source	DF	SS	MS	F	P value
Model	43	69917	1625.9	4.78	0.0001
Error	22	7490.9	340.4		
Total	65	77408			

R-square	C.V.	Root MSE	WP-95 mean
0.90	19.68	18.45	93.72

Number of observations	66
Treatments	2
Tree	3
Time (dates)	

	Stomatal conductance 1996				
Source	DF	SS	MS	F	P value
Model	39	12287.5	315.06	1.03	0.4906
Error	20	6140.85	307.04		
Total	59	18428.3			

R-square	C.V.	Root MSE	WP-96 mean
0.6667	25.45	17.52	68.82

Number of observations	60
Treatments	2
Tree	3
Time (dates)	10

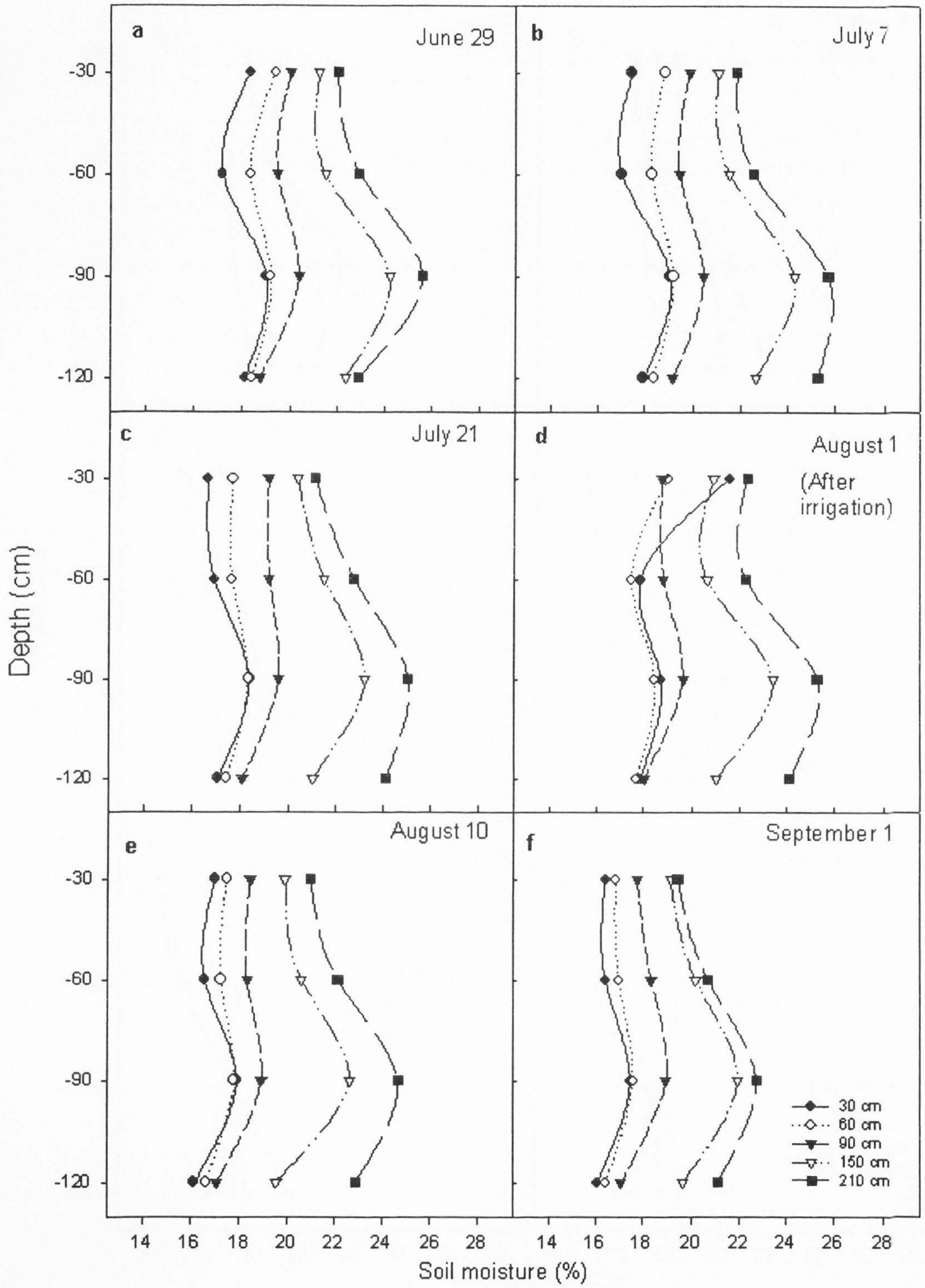

Figure A.1 Soil water (% volume) at different distances (0.3, 0.6, 0.9, 1.5 and 2.10 m) from tree and different depths (0.3, 0.6, 0.9, and 1.50 m) for willow tree under bare soil during the summer 1994.

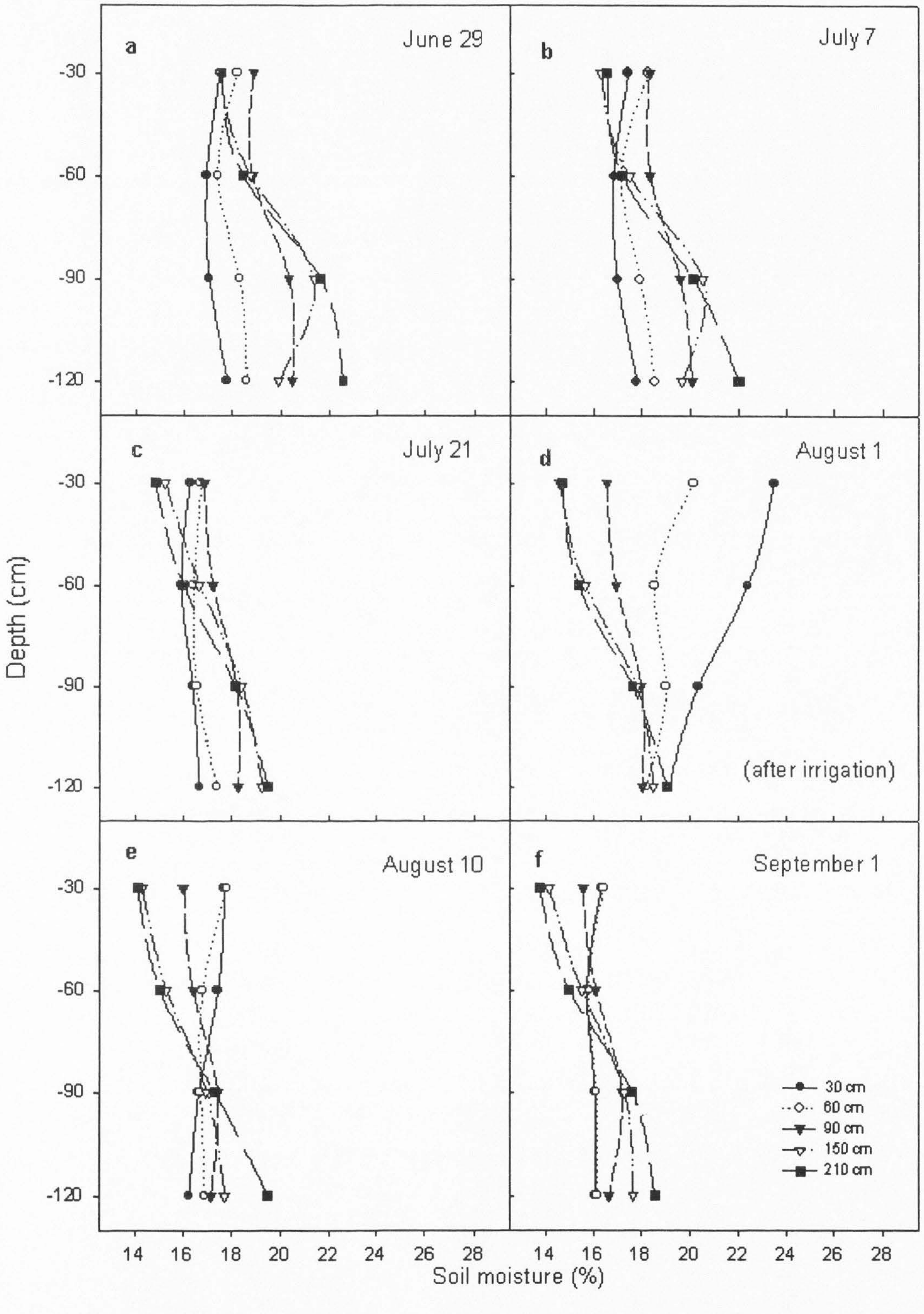

Figure A.2 Soil water (%volume) at different distances (0.3, 0.6, 0.9, 1.5 and 2.10 m) from tree and different depths (0.3, 0.6, 0.9, and 1.50 m) for willow tree under barley competition during the summer 1994.

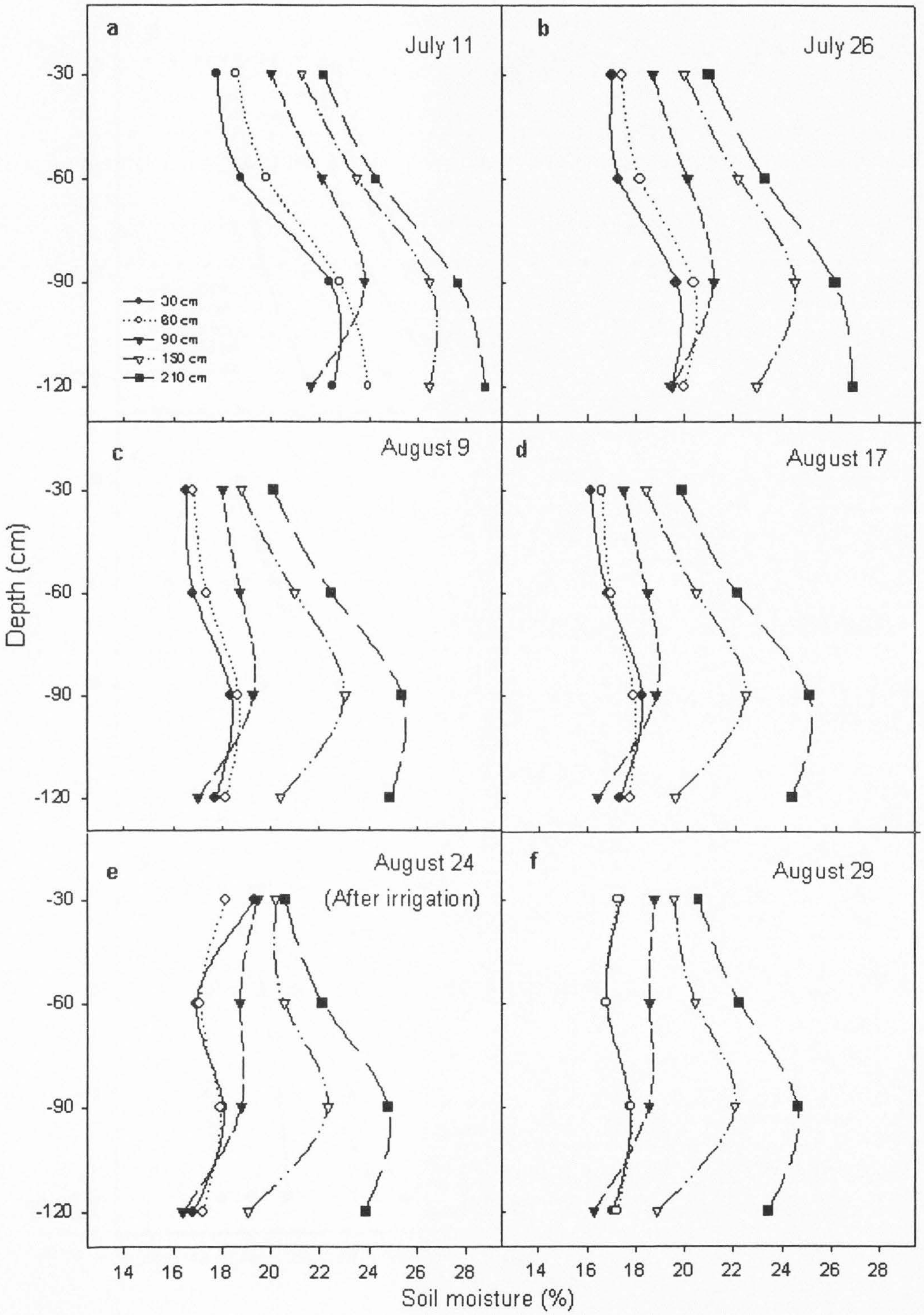

Figure A.3 Soil water (%volume) at different distances (0.3, 0.6, 0.9, 1.5 and 2.10 m) from tree and different depths (0.3, 0.6, 0.9, and 1.50 m) for willow tree under bare soil treatment during the summer 1995.

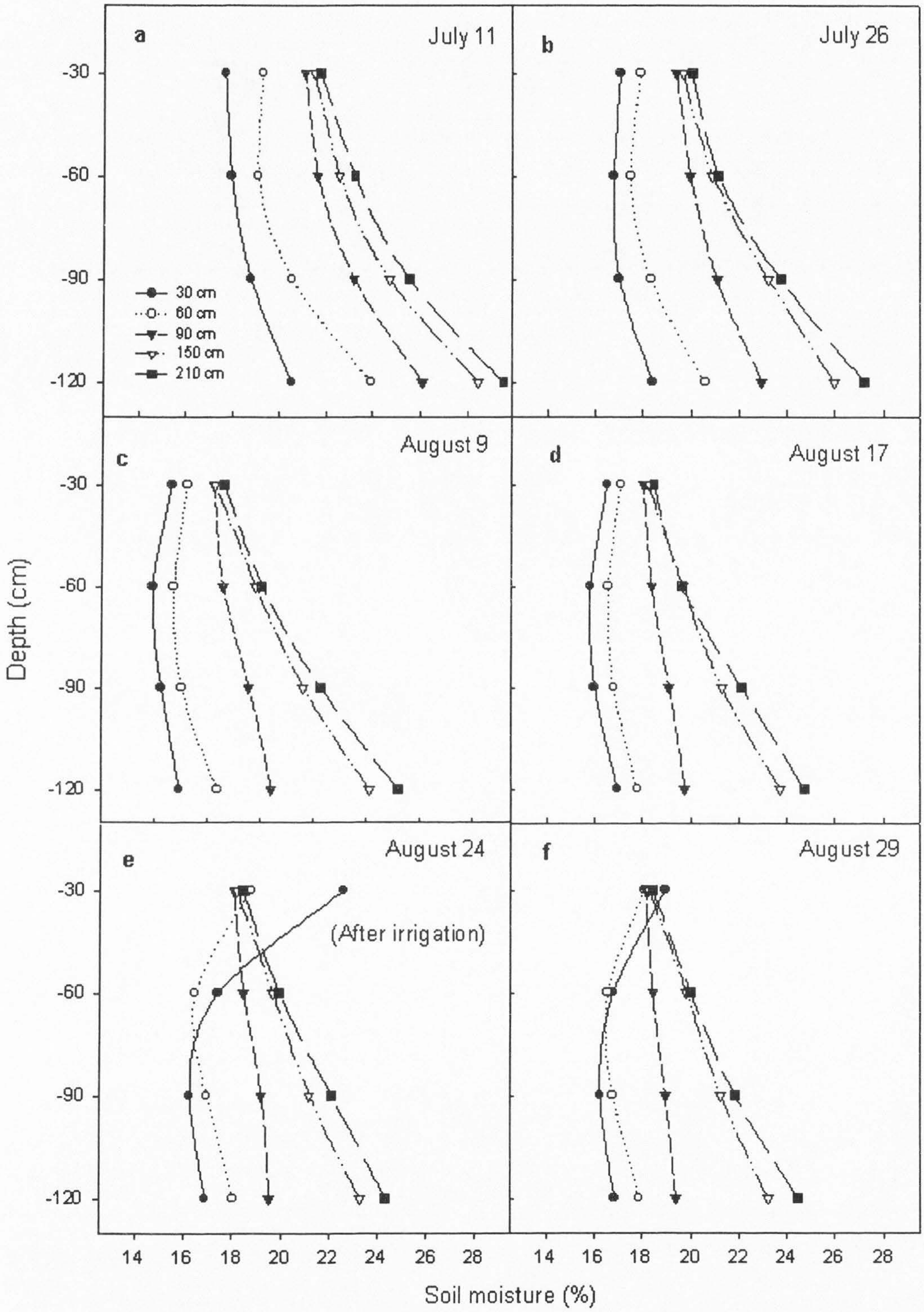

Figure A.4 Soil water (%volume) at different distances (0.3, 0.6, 0.9, 1.5 and 2.10 m) from tree and different depths (0.3, 0.6, 0.9, and 1.50 m) for willow tree under barley competition during the summer 1995.

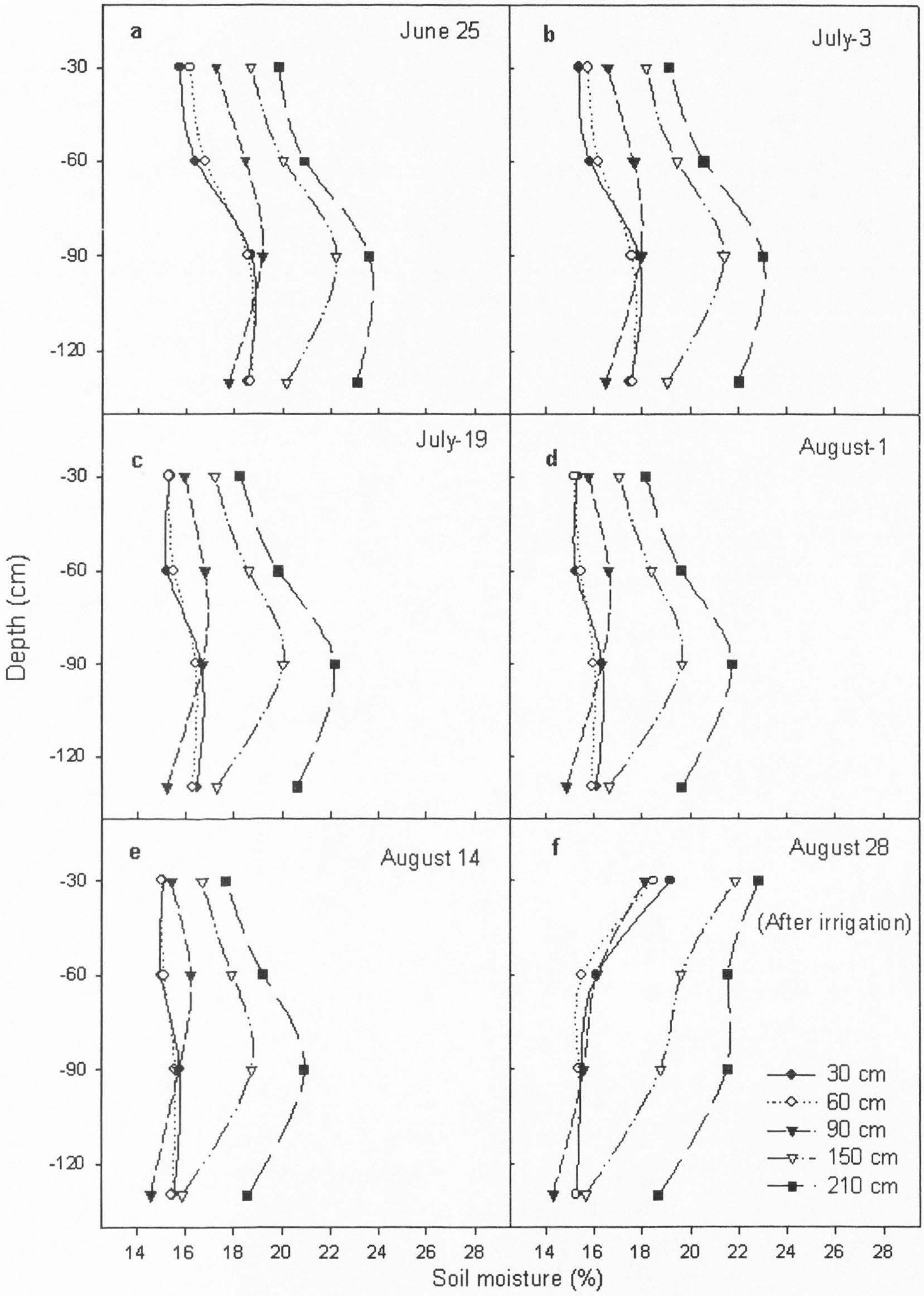

Figure A.5 Soil water (%volume) at different distances (0.3, 0.6, 0.9, 1.5 and 2.10 m) from tree and different depths (0.3, 0.6, 0.9, and 1.50 m) for willow tree under bare soil treatment during summer the 1996.

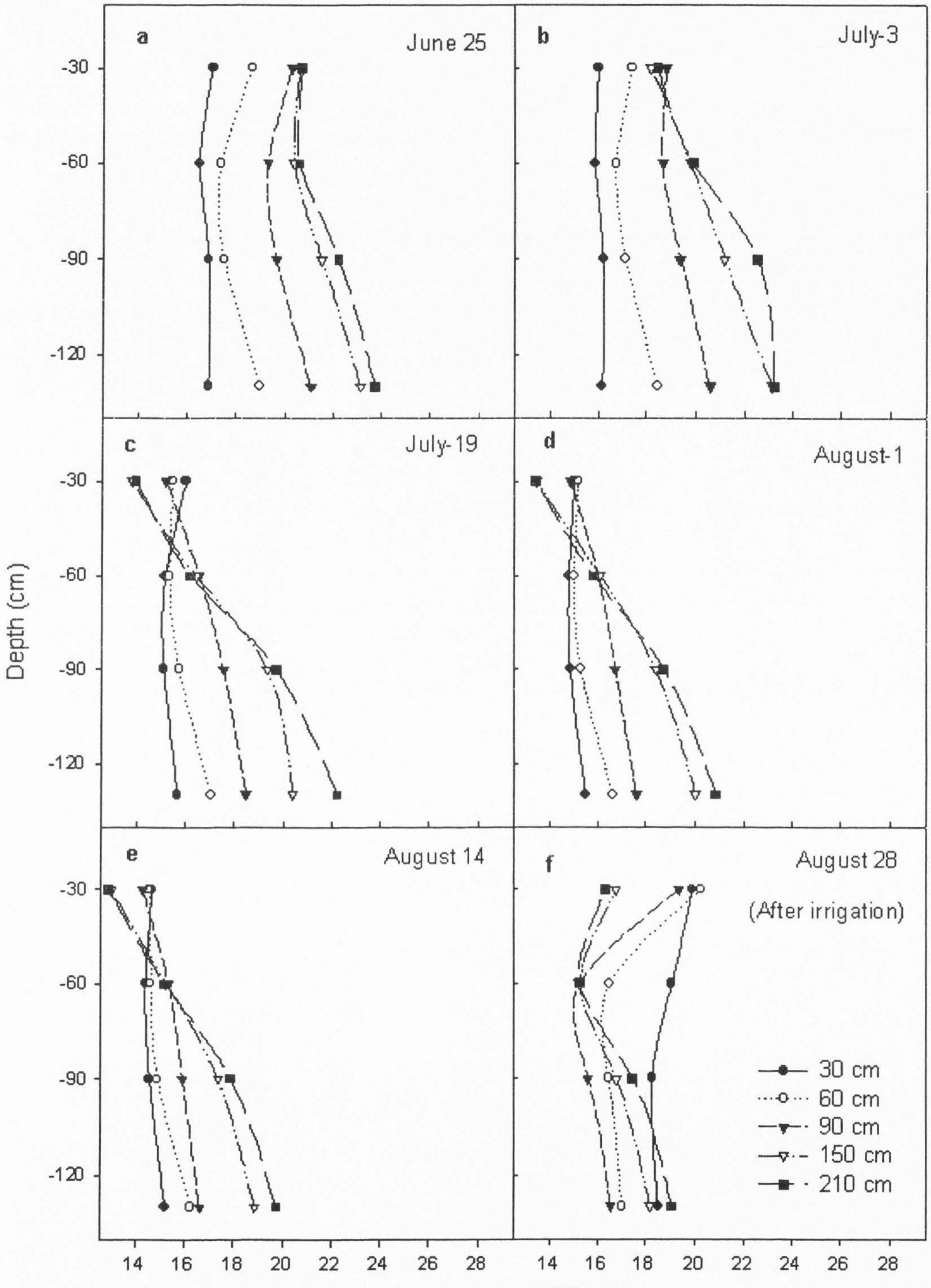

Figure A.6 Soil water (%volume) at different distances (0.3, 0.6, 0.9, 1.5 and 2.10 m) from tree and different depths (0.3, 0.6, 0.9, and 1.50 m) for willow tree under barley competition treatment during the summer 1996.

CURRICULUM VITAE

Bertha Alicia Hernández Leos
(December 1997)

EDUCATION:

BACHELORS DEGREE IN SOILS
Universidad Autonoma Agraria "Antonio Narro"
Saltillo Coahuila, Mexico
From 09/1976 to 12/1980
MASTER SCIENCE IN SOILS AND IRRIGATION
Instituto Tecnologico y de Estudios Superiores de Monterrey
Monterrey Nuevo Leon, Mexico
From 01/85 to 12/86
PhD IN PLANT SCIENCE
Utah State University
Logan Utah, USA
Expected 12/97

WORK EXPERIENCE

ASSISTANT RESEARCHER in annual crops, Instituto Nacional de Investigaciones Agricolas Merida, Yucatan Mexico. From 01/81-12/84.
AGRONOMY RESEARCHER in tree fertilization, Instituto nacional de Investigaciones Forestales Agropecuarias, Merida, Yucatan Mexico. From 01/87-09/93
AGRONOMY RESEARCHER, Instituto Nacional de Investigaciones Agricolas y Pecuarias, Culiacan, Sinaloa Mexico.01/98 to the present.

CAREER OBJECTIVE

To do research in soil-plant-microclimate. Special areas of interest: microclimate plant effect and plant-water relationship.