THE WATER RELATIONS AND GROWTH OF *QUERCUS ALBA* L. AND *QUERCUS RUBRA* L. TRANSPLANTED WITH PEAT-AMENDED BACKFILL SOIL

by

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INTRODUCTION

Survival of transplanted nursery stock is one of the most important economic factors in the landscape and nursery industry (Flemer, 1982). Plant replacement costs and customer dissatisfaction arising from plant loss are serious business problems. Materials utilized to aid survival increase landscape installation costs (Hummel and Johnson, 1985) and do not necessarily guarantee success. Researchers have begun to question the validity of some traditional planting practices, often with confusing and conflicting results.

This study was designed to explore how one planting method, the addition of organic matter to planting soil, affects after-transplant establishment by investigating water relations and growth of two species, *Quercus alba* L., white oak, and *Quercus rubra* L., red oak.

CHAPTER I

LITERATURE REVIEW

EFFECTS OF TRANSPLANTING INJURY AND ROOT LOSS

Transplanting severely damages trees. Root system reductions of 95% or more are common when harvesting bare-root and balled and burlapped nursery stock with subsequent impact on physiology and survival (Watson and Himelick, 1982a).

Root and shoot size in intact trees are balanced by the supply of water, nutrients, and photosynthate available from each system (Kramer and Kozlowski, 1960). A large ratio of roots to shoots (root:shoot) is most efficient in water and nutrient uptake (Richards, 1976). Root pruning or harvest alters this balance (Watson, 1985) as root removal stimulates root growth at the expense of shoot growth (Blessing et al., 1987; Geisler and Ferree, 1984; Randolph and Wiest, 1981; Nambiar et al., 1979; Larson 1975). Twig growth may be reduced as much as 22-38% in transplanted trees and three to five years may be required to regain pre-transplant shoot growth rates (Watson et al., 1986). The severity of these reductions depends upon the degree of root loss (Fare, et al., 1985;

Lopushinsky and Beebe, 1976; Larson 1975). Root:shoot ratios of root-pruned trees and shrubs returned to "normal" in one to five years (Pratt and Klett, 1986; Laiche et al., 1983; Randolph and Wiest, 1981).

Many researchers have shown water stress to be a result of transplanting (Grossnickle, 1988; Sands, 1984; Nambiar et al., 1979; Kramer and Kozlowski, 1960) even when trees are planted into wet soils (Sands, 1984). One cause is undoubtedly the actual loss of roots. Malus sp. Mill. 'Golden Delicious' (apple) leaf water potential was reduced 1.5 MPa after root pruning (Geisler and Ferree, 1984). A root system pruned of all unsuberized roots to forty percent of its original size absorbed only eighty percent as much water as an intact system (Kramer, 1983). Another study indicated that water stress was a result of inadequate root-soil contact (Sands, 1984).

Species undergo varying periods of transplant water stress. Stress persisted for 150 days with Pinus radiata D. Don (radiata pine) (Sands, 1981), but Pinus ponderosa Laws. (ponderosa pine) seedlings required two years to regain leaf water potentials equal to those of non-transplanted seedlings (Baldwin and Barney, 1976).

A pruned or reduced root system restricts soil water availability (Barnett, 1986; Kramer and Coile, 1940). It was once thought that water absorbed by plants was immediately replaced by capillary water (Kramer and Coile, 1940). However, soil physical properties (Baver et al., 1972) and the quantity of water in the soil (Gardner, 1979) govern direction and rate of capillary water movement. Movement is often too slow to meet a plant's needs (Kramer and Coile, 1940). Thus, as roots rapidly regenerate after transplant, the area of exploitation expands; and water deficits are eliminated (Sutton, 1980).

EFFECTS OF WATER DEFICITS ON TREE GROWTH AND DEVELOPMENT

Of the influences that root loss has on tree physiology, water deficits are the most serious. Water is a reactor and a mediator for all physiological processes (Kramer, 1983; Hsaio, 1973), and physiological damage can occur before any outward signs of stress appear (Kozlowski, 1985; Legge, 1985; Hsaio, 1973).

Transpiration is slowed by water deficit because the controls which govern stomatal resistance, growth regulators and guard cell turgidity, are changed (Salisbury and Ross, 1985; Hsaio, 1973; Livne and Vaadia, 1972; Leopold and Kriedemann, 1964). Guard cell turgidity is reduced by the lack of water and by increases in abscisic acid and decreases in cytokinin. Low plant water potentials decrease photosynthesis directly and indirectly (Bahari et al., 1985; Kramer, 1983). The amount of reduction is species dependent (Bahari et al., 1985). Photoinhibition is likely in water stressed plants growing in full sunlight (Bjorkman and Powles, 1984).

Growth is reduced by even moderate water deficits (Hsaio, 1973). Leaf size and number are diminished (Larson, 1974; Hsaio and Acevedo, 1974; Hsaio, 1973). Helianthus annuus L. (sunflower) leaf growth was possible only when leaf water potentials were above -0.35 MPa (Boyer, 1968). Cell division is slowed by water deficit due to reduced photosynthate (Kozlowski, 1985) and to a number of indirect causes (Hsaio, 1973).

Water deficits postpone onset of spring growth. Red oak budbreak was delayed at -0.6 MPa soil water potential (Larson, 1974) with buds dying at more negative potentials (Larson and Whitmore, 1970). Stem length and diameter are sensitive to water deficit (Kozlowski, 1975). Red oak shoot growth was reduced at -0.2 MPa soil water potential, and ceased at -0.6 MPa (Larson and Whitmore, 1970). Pseudotsuga menziesii (Mirb. Franco) (Douglas fir) circumference growth stopped at -0.3 MPa leaf water potential and shrank at -1.2 MPa (Aussenac et al., 1984). Drought affects bud development, and diminished shoot growth is seen the following year (Williams et al., 1987; Hinckley et al., 1979; Kozlowski, 1975; Zahner, 1968).

Root elongation and branching are also decreased by water deficit (Becker et al., 1987; Kozlowski, 1985). Regeneration slows between -0.6 and -0.8 MPa soil water potential (Bartsch, 1987; Kuhns et al., 1985; Larson, 1974; Larson and Whitmore, 1970) and is negligible at -1.5 MPa (Bartsch, 1987). The influence of water availability on root growth is highly species dependent, most likely as an ecological adaptation. Picea glauca (Moench) Voss. (white spruce) root regeneration and elongation were slowed by high potentials, -0.06 to -0.15 MPa (Day and MacGillivray, 1975), while Atriplex confertifolia (Torr. & Frém) S. Wats. (shadscale) continued root growth to -7.1 MPa (Fernandez and Caldwell, 1975). Some woody species, such as white oak, generate comparatively more roots in dry soil than do other species (Osumbi et al., 1985; Larson, 1974; Cripps, 1971).

RECOVERY FROM WATER DEFICIT

Recovery from water stress is a two-phase process. First, water is absorbed rapidly to eliminate the deficit; then turgidity becomes sufficient for growth to resume (Boyer, 1968). After water deficits are removed, growth is rapid, but does not return to pre-stress levels (Williams et al., 1987). Recovery is slowed by the duration (Williams et al., 1987) and severity of stress (Boyer, 1971). Roots become more resistant to water uptake during severe drought (Kramer, 1983; Coutts, 1982; Boyer, 1971; Slatyer, 1960) as a possible result of root tip suberization (Levitt, 1980) or cavitation within the xylem (Boyer, 1971).

FACTORS NECESSARY FOR ROOT GROWTH AND REGENERATION

Rapid root regeneration is necessary to restore the water status of transplants (Burdett, 1987; Day and MacGillivray, 1975; Kramer and Kozlowski, 1960). Root regeneration depends upon a variety of environmental and physiological conditions including an internal supply of carbohydrates (Watson and Himelick, 1982b; Lee and Hackett, 1976; Farmer, 1975) and the presence of physiologically non-dormant buds (Lee and Hackett, 1976). Soil aeration (Gilman et al., 1987; Watson, 1986; Alberty et al., 1984; Kozlowski, 1975) and water- and nutrient-holding capacity are important for regeneration and long-term survival (Pirone, 1988). Timing of harvest and planting should exploit natural periods of cyclical root growth (Watson and Himelick, 1982b; Lee and Hackett, 1976).

Species have differing optimum soil temperatures and water potentials for root growth (Kramer, 1983; Lyr and Hoffman, 1967). These interact to control root growth (Teskey and Hinckley, 1981; Stone, 1967). Seventeen degrees C, was the controlling temperature affecting white oak root growth rate. Above that temperature, even small reductions in soil moisture decreased root elongation (Teskey and Hinckley, 1981). Juglans nigra L. (black walnut) root growth rates peaked at a lower soil temperature (17° C) in dry (<-0.1 MPa) soils than in wet (>-1.0 MPa) soils (19° C) (Kuhns et al., 1985).

ROOT SYSTEM MORPHOLOGY

High density root systems are more likely to survive transplanting (Fare et al., 1985; Struve and Moser, 1984; Struve et al., 1984). Coarse-rooted trees have a proportionally greater loss of roots at harvest (Fare et al., 1985; Struve et al., 1984). Absorption capacity is correspondingly reduced, and water stress is apt to occur (Fare et al., 1985; Struve and Moser, 1984). Some coarse-rooted species, e.g. Gleditsia triacanthos L. (honeylocust), transplant easily possibly because these species can quickly regenerate and elongate new roots (Struve et al., 1984).

Root system morphology also affects water absorption (Chaney, 1981). There are three general types of root systems in trees -- taproot, heartroot and plateroot (Chaney, 1981). Taproots have few branches, but extend deeply through the soil to tap subsurface water.

Heartroots are well-branched, moderately deep rooting, and are able to use available water from a wide area. Plateroot systems spread widely, but remain near the soil surface. Available water is limited to that shallow area. Atmospheric and soil environmental conditions can alter basic root structure (Chaney, 1981).

TRADITIONAL PLANTING METHODS

Several transplanting methods have historically been employed to increase root regeneration and/or to restrict water loss. Most methods take advantage of efficient water absorption by high root:shoot ratios while others alter the tree's environment to slow water loss or improve water delivery to the tree.

Shoot Pruning

Shoot pruning after transplanting has been recommended to return root:shoot ratios to a level similar to that before harvest (Flemer, 1982; Shoup, et al., 1981; Pirone, 1988; Kozlowski and Davis, 1975; Cripps, 1971; Harris, 1983). An arbitrary 30% reduction in crown area is usually suggested (Evans and Klett, 1984). Theoretically, transpiration area is reduced to a size that the remaining root system can supply with water. This improves water status as demonstrated by shoot-pruned, transplanted *Ilex crenata* Thunb. (Japanese holly) (Randolph and Wiest, 1981).

However, root:shoot ratios are not always improved. Unless more than 30% was removed (Hummel and Johnson, 1986), shoot pruning stimulated shoot growth -- length and number (Gilliam et al., 1986; Evans and Klett, 1984; Randolph and Wiest, 1981). This shoot growth was at the expense of root growth. Japanese holly pruned 50% had a 93% reduction in number of roots (Gilliam et al., 1986), and a 36% reduction in root dry weight (Randolph and Wiest, 1981). Thinning and heading caused variable root development in Prunus cerasifera J. F. Ehrh 'Newportii' (Newport plum) and Malus sargentii Rehd. (Sargent crab-apple) (Evans and Klett, 1985).

Wrenching

A less frequently practiced management technique is the undercutting of roots while in the nursery bed -- sometimes referred to as wrenching. This is done to increase fine root production in the root ball and to slow shoot growth. Wrenching improved root:shoot ratios for transplanted Pinus taeda L. (loblolly pine) and Douglas fir either by increasing root dry weight with no change in shoot growth (Douglas fir) or by reducing shoot growth with no change in root dry weight (pine) (Tanaka et al., 1976). Wrenched Pinus caribaea Mor. var. hondurensis B. & G. (caribbean pine) had higher water potentials than did unwrenched controls after transplanting into containers (Bacon and Bachelard, 1978).

This practice may not increase the root:shoot ratio after transplant in all species. *Acer platanoides* L. (Norway maple), *Ginkgo biloba* L. (ginkgo), and *Fraxinus pennsylvanica* Marsh. (green ash) developed new roots only at the calloused ends of severed roots smaller than 4 cm in diameter. This distributed the new root systems to the outside of the root ball rather than increased densities in the ball (Watson and Himelick, 1982b). These new roots were removed at harvest, and root densities of transplanted trees were less than those of controls.

Anti-desiccants

The use of anti-desiccants is reportedly effective in reducing transpiration after transplanting and is often considered a supplement to after-harvest management (Lumis and Johnson, 1980; Davenport et al., 1972). Species respond differently to treatment and damage can occur (Lumis and Johnson, 1980). Action of anti-desiccants, however, is short-lived fading before root regeneration fully occurs.

Plant Growth Regulators

Auxins stimulate rooting in cuttings. Pre-plant sprays or auxin-impregnated toothpicks inserted into tree roots have resulted in improved re-establishment of landscape trees (Capiello and Kling, 1987; Struve et al., 1984; Magley and Struve, 1983; Lee and Hackett, 1976). IAA applied directly to buds significantly increased root growth especially on root-pruned red oaks (Farmer, 1975). At the same time, shoot development was slowed.

Amended Backfill

The addition of organic matter to backfill soil (the soil taken from the planting hole, then returned to the hole to cover the transplant's roots) has long been recommended to increase water-holding capacity and loosen the soil allowing better oxygen infiltration (Koller, 1987; Pirone, 1988). Recent studies have questioned the value of this practice (Hummel and Johnson, 1985; Corley, 1984; Whitcomb, 1985 and 1979ab; Schulte and Whitcomb, 1975; Pellett, 1971). Researchers noted that root and shoot growth was often not significantly different from controls, (Corley, 1984; Whitcomb, 1979b; Schulte and Whitcomb, 1975; Townsend, 1973; Pellett, 1971), that response varied between species (Corley, 1984; Ingram et al., 1981), and that there was no difference in water status between amended and unamended trees (Hummel and Johnson, 1985).

CHAPTER II

GROWTH AND WATER RELATIONS OF WHITE OAK SEEDLINGS TRANSPLANTED INTO 121 L CONTAINERS GREENHOUSE STUDY

INTRODUCTION

Conclusions regarding the use of amended backfill in transplanting are difficult to make (Ingram et al., 1981) because species show wide variation in response to amendment type on different soils and planting sites (Haynes and Swift, 1986; Corley, 1984; Ingram et al., 1981; Schulte and Whitcomb, 1975; Townsend, 1973; Pellett, 1971).

Cornus florida L. (dogwood) and Japanese holly (Corley, 1984) showed improved shoot growth in peat-amended soils as did *Forsythia* x *intermedia* Zab. (border forsythia), *Ribes sanguineum* Pursh., and *Deutzia gracilis* Siebold and Zucc. (slender deutzia) when a heavy soil was amended with peat (Becker, 1981; Skirde, 1979). *Quercus robur* J. F. Ehrh. (English oak), *Carpinus betulus* L. (European hornbeam) (Sonsky, 1984) and *Pittosporum tobira* Thunb. (Japanese pittosporum) (Ingram, et al., 1981) also increased shoot height in peat-amended soils on irrigated and fertilized sites. Twelve months after transplanting, there was no further shoot growth advantage from peat-amendment for Japanese pittosporum.

Peat-amended *Lonicera korolkowii zabeli* Rehd. (blueleaf honeysuckle) shoot growth was reduced if grown on peat-amended, unfertilized, coarse sandy loam (Pellett, 1971). On other sites, response to peat amendment by blueleaf honeysuckle, *Juniperus conferta* Parl. (shore juniper), *Rhododendron obtusum* (Lindl.) Planch. 'Hindodegiri' (azalea) and *Liquidambar styraciflua* L. (sweet gum) was unchanged from controls (Hummel and Johnson, 1985; Corley, 1984; Pellett, 1971). Shoot growth of *Juniperus chinensis* L. 'Hetzii' (Hetzii Chinese juniper) was unchanged after six months, but was significantly greater than controls a year after transplanting (Ingram et al., 1981). Shoot growth of *Vaccinium corymbosum* L. (blueberry) in peat-amended soils was either improved (Haynes and Swift, 1986) or reduced (Townsend, 1973), depending on the pH of the site.

Root growth in peat-amended soils does not follow the same pattern. Dogwood and shore juniper had greater root dry weight; Japanese holly, Hetzii Chinese holly, and sweet gum were unchanged, while azalea made significantly less root growth (Hummel and Johnson, 1985; Corley, 1984; Ingram et al., 1981). Japanese pittosporum root growth remained significantly higher if the site was also fertilized (Ingram et al., 1981). *Acer saccharinum* L. (silver maple) grown in a 40% peat backfill developed a densely fibrous root system which did not extend from the planting hole after the first season (Schulte and Whitcomb, 1975).

Pine bark amendment has also resulted in variable reactions. Schulte and Whitcomb (1975) found it "detrimental" to silver maple on all sites; however, statistical interpretations of results were not presented. Shore juniper, Japanese holly, azalea, and dogwood shoot dry weights were not significantly different from unamended controls, but growth of Japanese holly and dogwood in pine bark amendment was less than when planted in peat-amended soils (Corley, 1984). Shoot growth of blueberries was comparable to that in a peat amendment (Haynes and Swift, 1986) and greater than controls. Sawdust amendment of backfill caused no change in height of blueleaf honeysuckle (Pellett, 1971) or blueberry (Townsend, 1973).

Container-grown plant survival was enhanced when backfill was amended with the same materials used in the container soil, but this did not apply to all mixes. Holly grown in a peat/perlite medium transplanted better when peat and perlite were added to the backfill (Ingram and Van de Werken, 1978).

Soil amendment had no effect on water status of transplanted, containerized sweet gum, as plant water potentials were not altered for any amendment treatment in irrigated, sandy soil (Hummel and Johnson, 1985).

Textural differences between the root ball, amended soil, and native soil may cause some of the problems noted with the use of amended backfill. Amended soils appeared to dry faster than the surrounding soil (Whitcomb, 1979b). The interface between undisturbed and amended soil may be a "barrier" to root growth and soil water movement (Corley, 1984). Problems from these differences are short-lived as second-year growth was the same as controls (Skirde, 1979; Pellett, 1971).

Any beneficial effects of organic amendment may be due to secondary effects on the soil itself. The addition of organic matter lowers soil pH which is beneficial to plants adapted to acidic sites (Haynes and Swift, 1986; Whitcomb, 1985). Blueberry growth, stunted by iron and manganese deficiencies, was improved because increased aeration, water-holding capacity, and decreased pH from the addition of peat allowed the utilization of these nutrients (Haynes and Swift, 1986).

Variations in results are seen between amendment types, plant species, soil types, and measurement methods. The use of relatively easy-to-transplant, quickly-rooting species may obscure amendment benefits in transplant survival for slow-to-root species. The lack of information regarding amendment effects on water-holding capacity and plant physiological responses provides an inadequate basis on which to make decisions regarding use of organic amendments. The purpose of this study was to investigate the effects of organic matter (peat moss) on the water relations of transplanted trees and on the survivability of a hard-to-transplant species.

METHODS AND MATERIALS

Sixteen, 1.22 m (4'), bare-root white oak whips (Bailey Nurseries, Inc., St. Paul, MN) were planted in either a shredded, unmapped, "old buried" soil or a three soil : one sphagnum peat (by volume) mix in 121 liter plastic containers (Gott, Winfield, KS). White oak was chosen as the test plant because root morphology affects transplanting success. Establishment is related to root system density with high density systems more likely to survive (Fare et al., 1985; Struve and Moser, 1984; Sonsky, 1984; Struve et al., 1984; Pirone, 1988). White oak is coarsely rooted and considered hard-to-transplant.

Containers had drainage holes drilled in the bottom. Both soil mixes were amended with iron sulfate (160.6 g/m^3) to lower soil pH. Soils were processed for ten minutes in a Dixon Precision Horizontal Batch Mixer (H. C. Davis Sons Mfg. Co., Inc., Bonner Springs, Ks.) to thoroughly incorporate amendments.

Containers were filled to a uniform 46 cm depth. The trees were centered in the pots, and their roots covered with media to the depth at which they had been planted in the nursery as judged by soil marks at the crown. Most of the root systems were within the 15 to 30 cm layer of soil. Three pieces of cotton rope "wicks" were added at planting to aid soil drying. Each piece extended from the soil surface, down through the container soil, and out the drainage holes.

The potted trees were arranged in a completely randomized block design in the greenhouse. The pots were elevated with short lengths of lumber to allow free drainage.

The trees were watered daily for three days after planting to ensure wetting of the entire container soil profile. Then four trees from each soil treatment received irrigation on eleven or twenty-two day schedules. The trees were given 8.7 liters of water to simulate a 2.5 cm irrigation. Soil surfaces were cultivated as the soil dried to prevent crusting which would slow evaporation.

Greenhouse temperatures over the study period varied from 18.3^{o} C to 41.7^{o} C with the mean daytime maximum temperature 36.5^{o} C. Relative humidity averaged 49%. Temperature and humidity measurements were made with a hygrothermograph (Belfort Instrument Co., Baltimore, MD).

Light intensities at the top of the canopy at solar noon were 120 $\mu mol \cdot s^{-1} m^{-2}$ on a cloudy day (7/2/88) and 740 $\mu mol \cdot s^{-1} m^{-2}$ photosynthetic active radiation on a sunny day (7/3/88)(LiCor 185B Quantum/Radiometer/Photometer, LiCor, Inc., Lincoln, NE). The summer of 1988 was particularly hot and dry with 126 days of sunshine between April 1 and August 8. Pan evaporation rate averaged 171.8 ml per day over the study. Complete environmental data are presented in Appendix IV.

On August 11 and 13, the trees were harvested. Predawn leaf water potential, osmotic potential, total height, length of shoot growth, leaf area, caliper (1 m above crown), number of leaves, length of new roots, fresh and dry weights of both roots and shoots, and soil water content and potential were determined.

Predawn leaf water potential readings were made using screen cage psychrometers with chambers (741VC, J.R.D. Merrill Specialty Equip. Co., Logan, UT) and an HR33T Microvoltmeter (Wescor, Inc., Logan, UT) in the dewpoint mode. The psychrometers had been previously calibrated; regression equations were calculated for each psychrometer to convert microvolt output to water potential measurements.

Sample leaf disks were punched with a #5 cork bore in the first lobe below the apex of the highest leaf and were immediately sealed in psychrometers. Mature leaves were used in sampling, but priority in leaf choice was position before maturity. The psychrometers were moved to the laboratory, then placed in a styrofoam cooler to moderate temperature changes, and allowed to equilibrated for six hours. Room and cooler temperature were approximately 25.5^{o} C.

After leaf water potential had been determined, osmotic potential was measured cryogenically. Leaf disks were placed in liquid nitrogen for thirty seconds, re-sealed in the psychrometer chambers, and equilibrated for five hours before taking potential readings with the microvoltmeter.

Roots were washed, mat dried, and allowed to air dry for five minutes. White, unsuberized roots were removed and length was measured using the Newman line intersection method (Marsh, 1971) in which each root/grid intersection is counted as one centimeter of root length. The unsuberized roots, the remaining roots, leaves, and stems were placed in separate paper bags, weighed, dried at 60^{o} C to constant weight (48 hours to one week depending on the size of the sample), and then re-weighed.

Soil samples were weighed before drying at 60^{o} C (Gardner, 1965) for forty-eight hours to determine water content. A soil water release curve presenting amended and unamended soil water contents at differenct pressures was prepared before this study began (see Appendix III). Soil water potentials were determined by comparing soil water contents of the dried samples to this curve.

Analysis of variance results were calculated using SAS General Linear Model (Statistical Analysis System, 1988), a procedure designed to correct for uneven sample size. Regression analysis was made with Number Cruncher Statistical System (Hintze, 1987). There was a total of fourteen observations.

RESULTS

Amending soils with peat moss had little effect on water relations or survival of transplanted white oak trees in the greenhouse. The only variables showing significance less than 10% were leaf water potential, osmotic potential, soil water potential, caliper, and leaf area. There was considerable within-sample variation in the raw data which may have led to the nonsignificant results and complicated discussion of the study. Small sample size also influenced nonsignificance. Leaf area variation from the mean was the result of block effect.

Trees in both soil treatments on the 11-day schedule evinced poor vigor as indicated by very small leaves, chlorosis, and poor root growth. Trees irrigated on the

22-day schedule seemed in better general health and appearance than those on the 11-day schedule.

Soil Water Availability

Mean soil water potential was significantly higher in unamended than in peat-amended soil (Pr>F 0.087, Table II-1); watering day had no significant effect on soil water potential. There were no interactions between the main effects. Soil, 11-day irrigation treatment, had the highest mean soil water potential, -0.14 MPa and peat, 22-day, the lowest, -0.66 MPa. However, these amounts were not significantly different due to variation among replicates.

Soil water contents were measured at three levels within containers: 0-15 cm, 16-30 cm, and 31-45 cm; and there were no significant differences or interactions between treatments (Pr>F 0.455) at any level (Table II-1). Soil water contents ranged from 0.180 g/g in peat, 11-day irrigation treatment, to 0.120 g/g in soil, 22-day irrigation treatment. While soils with peat amendment had significantly lower soil water potential, soil water content was increased but not significantly. Mean soil water content in the 16-30 cm level (the depth where root growth appeared to be the greatest) was 0.020 g/g greater in peat-amended soil; on day twenty-two of the irrigation

TABLE II-1. Mean soil water relations measurements at harvest of unamended and peat-amended white oak trees. Trees had been irrigated either eleven or twenty-two days previously.[z]

Soil Treatment	Irrigation Treatment	Soil Water Potential, MPa 30 cm	Soil Water Content, g/g 15 cm	Soil Water Content, g/g 30 cm	Soil Water Content, g/g 45 cm
Peat		-0.52*	0.19	0.17	0.19
Soil		-0.24	0.18	0.15	0.16
	11-day	-0.26	0.22	0.18	0.21
	22-day	-0.50	0.15	0.14	0.14

[z]Means are calculated on a per tree basis; n = 3 peat, 11-day and soil, 22-day; n = 4 peat, 22-day and soil, 11-day.

*Indicates significant difference between mean pairs (F-test, P = .10).

schedule, peat-amended soils held 0.040 g/g more water than unamended soil (not significant).

Predawn Leaf Water and Osmotic Potentials

Predawn leaf water potential was significantly lower in peat-amended trees (Pr>F 0.096, Table II-2) and significantly higher in trees irrigated on the 11-day schedule (Pr>F 0.019), Table II-2). There were no significant interactions. Osmotic potentials varied between soil and irrigation day treatments (Pr>F 0.017, Table II-2), and there was a significant interaction. Irrigation day had more influence over osmotic potential (Pr>F 0.003) than did soil treatment (Pr>F 0.418.)

Top Growth

Although all stem growth parameters were greater in peat-amended treatments, only stem caliper was statistically significant (Pr>F 0.07, Table II-3). There were no patterns in irrigation treatment, and there were no significant interactions between main effects.

Leaf dry weight and area were significantly less in the 11-day irrigation treatment (Table II-4), though these amounts were not significant overall (Pr>F 0.088, and Pr>F 0.428, respectively). Leaf area analysis indicated that variation from the mean was a result of block effect (see ANOVA Tables, Appendix V). Leaf number was slightly reduced on the 11-day irrigation schedule.

TABLE II-2. Mean predawn leaf water potential and osmotic potential measurements at harvest of unamended and peat-amended white oak trees. Trees had been irrigated either eleven or twenty-two days previously.[z]

Soil Treatment	Irrigation Treatment	Predawn Leaf Water Potential (MPa)	Osmotic Potential (MPa)
Peat		-3.09*	
Soil		-2.62	
	11-day	-2.48**	
	22-day	-3.22	
Peat	11-day		-3.07ab[y]
	22-day		-3.54b
Soil	11-day		-2.30a
	22-day		-3.90b

[z]Means are calculated on a per tree basis; n = 3 peat, 11-day and soil, 22-day; n = 4 peat, 22-day and soil, 11-day.

[y]Mean separation utilizing Tuckey's W procedure, 1% level. Means within each column followed by the same letter are not significantly different.

**Indicates significant difference between mean pairs (F-test, P = .05).

*Indicates significant difference between mean pairs (F-test, P = .10).

TABLE II-3. Mean stem growth measurements at harvest of white oak planted in unamended or in 25% sphagnum peat-amended (v:v) soil and irrigated on either an eleven or a twenty-two day schedule. Trees were planted in 121 liter containers and grown in the greenhouse for 130 days.[z]

Soil Treatment	Irrigation Treatment	Caliper (cm)	Stem Dry Weight (g)	Total Stem Dry Weight[y] (g)	Shoot Growth (cm)	Total Height[x] (cm)
Peat		12.59**	100.40	110.97	15.05	159.14
Soil		10.40	84.22	102.91	13.87	146.37
	11-day	11.75	93.58	103.12	9.90	141.54
	22-day	11.34	91.06	110.76	19.02	163.97

[z]Means are calculated on a per tree basis; n = 3 peat, 11-day and soil, 22-day; n = 4 peat, 22-day and soil, 11-day.

[y]Stem dry weight + leaf dry weight

[x]New and original growth combined

**Indicates significant difference between mean pairs (F-test, P = .05).

TABLE II-4. Mean leaf growth measured on harvest day in unamended and peat-amended white oak trees irrigated on an eleven or a twenty-two day schedule.[z] These means are not significantly different in the overall test.

Soil Treatment	Irrigation Treatment	Leaf Dry Weight (g)	Leaf Area cm^2	Leaf Number
Peat		7.43	1671.49	159.66
Soil		17.94	2522.87	123.54
	11-day	6.38*	1515.62*	136.54
	22-day	18.99	2678.74	146.66

[z]Means are calculated on a per tree basis; n = 3 peat, 11-day and soil, 22-day; n = 4 peat, 22-day and soil, 11-day.

*Indicates significant difference between mean pairs (F-test, P = .10).

Soil treatment did not affect leaf growth. Measurements were not statistically significant even though unamended trees had greater leaf area and dry weight and a wide spread in means existed. Peat-amended trees had slightly more leaves.

Root Growth

New root growth, identified as any white growth at root terminals, varied greatly within treatments, and thus, affected significance between treatments. There was less new root growth with peat amendment and with more frequent irrigation, but there was no interaction. New root length (Pr>F 0.092) and dry weight (Pr>F 0.014) were reduced on the 11-day irrigation schedule (Table II-5). New root dry weight was also significantly reduced by peat amendment (Pr>F 0.077, Table II-5). These variables were not significantly different overall (Pr>F 0.559, new root length; Pr>F 0.137 new root dry weight). Despite the great difference in new root length between peat and soil treatments, this variable was not significantly different.

Total root dry weight (initial root dry weight plus new root dry weight) was not significantly different between all treatments due to the large initial root system; however, it was larger when planted in peat backfill and when irrigated on the 11-day schedule.

TABLE II-5. Mean harvest day root growth measurements of white oak trees planted in soil or peat-amended soil and irrigated on either an eleven or a twenty-two day schedule.[z] Trees were harvest 130 days after planting. In the overall test, there are no significant differences.

Soil Treatment	Irrigation Treatment	New Root Length (cm)	New Root Dry Weight (g)	Total Root Dry Weight[y] (g)
Peat		43.68	0.063*	151.81
Soil		128.37	0.211	108.18
	11-day	31.81*	0.022***	142.30
	22-day	140.24	0.253	117.70

[z]Means are calculated on a per tree basis; n = 3 peat, 11-day and soil, 22-day; n = 4 peat, 22-day and soil, 11-day.

[y]Original root plus diameter increase

*Indicates significant difference between mean pairs (F-test, P = .10).

***Indicates significant difference between mean pairs (F-test, P = .01).

DISCUSSION

Soil Water Relations

Peat-amended soils had higher water content than did unamended soils. This was especially apparent when comparing soil water contents of the 22-day irrigation treatment for each soil. But differences in soil water content were not statistically significant because of large within-treatment variability -- as much as 20% in soil, 22-day irrigation treatments. This indicated that each pot was not uniformly affected by water treatment. The trees may have used soil water at differing rates, but there was no evidence of a relationship between soil water content, tree size, or appearance.

Factors other than irrigation timing or tree water usage may account for much of this within-sample variation. In order to maintain a similarity between field and container soils, no extra coarse aggregate amendment (e.g., perlite) was included in the potting mix. The greenhouse soil was a relatively heavy, fine-textured soil which had been shredded prior to sterilization. Over time, pore space probably decreased because bulk density increases when soil particles wash down with irrigation water (Mastalerz, 1977). This combination probably created a container soil with numerous micropores, slow infiltration and percolation, possible uneven horizontal water distribution, and impeded evaporation. Water infiltration after irrigation was visibly slower in some containers. Oxygen diffusion measurements were not made but would have confirmed a lack of oxygen in the containers.

Undoubtedly, the addition of peat improved infiltration and percolation compared to unamended soil. A seven:three silt loam/sphagnum peat mix has been reported to have 7.9% more total pore space and 10.8% greater air space than unamended soil (White and Mastalerz, 1967). But this was apparently not enough to counteract the differences in water flow and, thus, content measurements between individual pots.

Flow of soil water is at equilibrium when the matric tension between water and soil particles at the top of the water column is equal to the downward pull of gravity (Mastalerz, 1977). When field soil is transferred to a container, the change in depth changes the gravitational potential (tension = density of liquid x acceleration of gravity x height of water column). In addition, a water table develops at the bottom of the container due to the air/soil interface. Both of these factors restrict drainage from the pot and result in a wetter soil than would be found in the field. Although the largest container available was used in this study to overcome these drainage changes, there was little or no drainage from the pots after irrigation. It appears that not enough water was applied with the irrigation treatments to wet the entire soil profile because soil water content was highest in the 15 cm layer of the unamended soil.

The addition of a larger percentage of peat or other coarse aggregates amendment might have improved percolation and infiltration rates and lowered bulk density (White and Mastalerz, 1967). Standard greenhouse soil mixes are usually composed of two-thirds coarse aggregate for that reason (Mastalerz, 1977; Bunt, 1976). This, however, would have eliminated the possibility of comparison with field application because such amendment in the field would have also changed soil drainage physics there.

Plant Water Relations

Reduction of predawn leaf water potential when soil water content and potential are low was confirmed in the 22-day irrigation treatment. However, these results were not supported by soil treatment analysis. While peat-amended trees had significantly lower predawn leaf water potential and soil water potential than unamended trees, soil water contents were as high as those in the 11-day irrigation treatment.

Predawn leaf water potential of trees planted in peat-amendment may be responding to the lower energy status of the water in the soil. But the reasons for this decrease in predawn leaf water potential remains unclear because of the higher soil water content in peat-amended soils and because of white oak's abilities to adapt to drought. Numerous studies have shown white oak to be adapted to xeric sites (Bahari et al., 1985; Hinckley et al., 1979). By making active osmotic adjustments during periods of drought and having a high bulk modulus of elasticity, white oak was able to maintain a high leaf water potential with low soil moisture (Parker and Pallardy, 1988; Bahari et al., 1985; Parker et al., 1982).

This decrease in leaf water potential in this study may indicate a lack of a straight line relationship between soil water content and leaf water potential. As seen in Appendix I and other studies (Gardner and Nieman, 1964), leaf water potential can remain nearly constant while soil dries. Adjustments are made to keep leaf water potential within a narrow range until soil water potential is reduced beyond a critical point (Slatyer, 1957). Once soil has dried to that point, leaf water potential declines rapidly (Gardner and Nieman, 1964). The range of leaf water potentials and the critical soil water potentials vary with species (Levitt, 1980). For some species, eighty percent of available soil water can be removed before leaf water potential is affected (Whitehead and Jarvis, 1981).

Exponential decreases in leaf water potential are usually seen when soil water potential is reduced (Whitehead and Jarvis, 1981). Predawn leaf water potential measurements compared to soil water potential are more linear, but a clear correlation between predawn soil water potential and leaf water potential is difficult to make unless transpiration is zero and soil water potential is uniform throughout the soil profile (Whitehead and Jarvis, 1981)

Total leaf water potential is composed of four parts: osmotic potential, turgor potential, matric potential, and gravity potential. Normally, matric potential and gravity potential are ignored because of the small contribution they play in total plant water potential. The adjustments a plant makes to maintain leaf water potential are often osmotic in nature. In a tree capable of osmotic adjustment, water status cannot be totally understood without knowing the value of that component.

In this study osmotic potential varies in response to soil and irrigation day treatments with irrigation timing having more control over response. Calculating the turgor potential for each treatment by subtracting mean osmotic potential from mean leaf water potential showed that peat 11- and 22-day irrigation treatments and soil 11-day irrigation treatment all had about 0.2 MPa turgor potential while soil 22-day had 0.75 MPa turgor potential. It appears that soil 22-day irrigation treatment is the treatment undergoing osmotic adjustment. If this was the only treatment to undergo osmotic adjustment, it is reasoned that this may be the treatment to be experiencing the most water stress.

After looking at the water parameters of this study in total, what perhaps can be concluded is that peat-amended trees are not necessarily under water stress even though leaf water potential is statistically lower. Further research into what is "normal" for this species would help to clarify what can be considered excess water stress for this species.

Top Growth

Except for stem diameter, which was 2.2 mm larger in the peat-amended treatment, top growth measurements were not significantly different between treatments. Top growth was, however, generally larger in peat-amended trees. Mean leaf dry weight was the only variable to be decreased in peat backfill. Total height and total stem dry weight encompass previous years' growth as well as added new growth, and there was a wide range in initial sizes which led to nonsignificance. Shoot growth was greater in peat-amended soil, but replicate variation prevented significance. Several studies have demonstrated increased shoot growth for different species in peat-amended sites (Corley, 1984; Sonsky, 1984; Becker, 1981; Skirde, 1979).

Other studies have not found significant responses by diameter growth to amended backfill. Calipers of transplanted, containerized sweet gum in one-third peat (Hummel and Johnson, 1985) and Fraxinus profunda (pumpkin ash) in one-third pine bark (Gibson and Granberry, 1984) were slightly larger. Silver maple stem diameter increased when planted in one-third pine bark only if fertilizer was incorporated at the same time (Schulte and Whitcomb, 1975).

It was expected that any amendment effects would be the result of a change in soil water relations. This was especially anticipated for stem diameter growth because caliper is extremely sensitive to fluctuations in soil water availability -- diurnally and seasonally (Aussenac et al., 1984; Hinckley and Bruckerhoff, 1975; Kramer and Kozlowski, 1960). It remains unclear whether this expectation was met. While there was a large nonsignificant difference in soil water contents between the 11- and 22-day irrigation treatments, stem diameters were essentially equal. Peat and soil, 11-day irrigation treatments, had nearly equal mean soil water content, yet peat was 2.2 mm larger in stem diameter.

This increase in caliper and other top growth measurements in peat may also be explained by possible differences in porosity imparted by peat as presented in the soil water relations section. Because of the fine texture, shredded soil and possibly reduced bulk density, the containers were probably lacking in oxygen. If there was a lack of oxygen, the trees would be unable to absorb water after irrigation. Absorption ability would resume as soils dried. Peat amendment increases soil porosity (White and Mastalerz, 1967). As soils dried, this increase probably allowed absorption by peat-amended trees to resume before it resumed in unamended trees.

Not all top growth variables responded positively to peat addition; mean leaf dry weight was greatly decreased in amended trees. It is unclear why only one variable would be affected. Leaf dry weight in 11-day irrigation treatment trees was also significantly reduced, possibly an indication that soils were deficient in oxygen. The extremely wide range of leaf sizes within each treatment made it difficult to judge the effect of peat on leaf growth.

Root Growth

New root length measurements varied widely within treatments and this resulted in nonsignificant differences between treatments. Total root dry weight encompassed previous year's growth, and nonsignificance was reflective of that fact. Total root dry weight was greatest in the peat and the 11-day watering treatments. New root length and dry weight, however, were lower in these treatments either because of a lack of oxygen in the soil, or because new root growth had slowed from a natural stage in root growth periodicity.

Inadequate pore space is not conducive to root growth (Pirone, 1988). Low oxygen concentrations create conditions optimum for disease development, and microorganisms emit substances which may be toxic to roots (Pirone, 1988). Tissues which lack protective coverings are more susceptible to pathogen attack (Agrios, 1978), and new roots may be easily infected.

Because peat-amended trees are larger than unamended trees, it must be assumed that any decrease in new root growth due to low oxygen and high soil water happened after the major growth flush. Leaf water potential could appear unaffected because water uptake is possible even in the absence of unsuberized root since a large percentage of water enters through older, suberized root (Kramer,

1983) and because as soil dries, oxygen replaces water in the micropores and absorption resumes.

End-of-season harvest was not the best time to obtain accurate estimates of new root growth because two-year-old, white oak trees have only one period of rapid root growth in the spring of the first season after transplanting. This period is not affected by current growing conditions (Reich et al., 1980).

Within-Sample Variability

There was a wide spread of measurements within treatments. Genetic variability and differences in previous handling and storage conditions may account for some of this variation affecting not only ability to survive, but also ability to respond to applied treatments (Burdett, 1987; Sutton, 1980; Lopushinsky and Beebe, 1976; Stone, 1967). This genetic variation was demonstrated by the difference in root dry weight and shoot dry weight for two sacrifice trees (151 g and 56 g, respectively) and the fact that trees with extremely small leaf areas were scattered throughout all treatments.

Sample size was too small to separate these effects and made it impossible to clearly establish the effect of peat-amended backfill on white oak transplant survival. Limitations on budget, growing space, equipment, and time prevented using a larger sample.

Conclusions

Because of within sample variation and, thus, lack of significance between most variables, conclusions on the use of organic backfill cannot be made. There is slight evidence that in soils with low porosity, the addition of peat may increase growth. Oxygen diffusion measurements should be made in later studies to determine if this observation is correct. Further studies with larger sample size or clonal plant material are recommended.

CHAPTER III

RESPONSE OF RED AND WHITE OAK TREES TO PEAT-AMENDED BACKFILL WHEN TRANSPLANTED IN THE FIELD

INTRODUCTION

Container studies with amended backfill have an inherent drawback: the change of depth from soil profile to container alters the downward flow of water in the soil because the gravitational potential is changed. When free drainage ceases, container soils have a higher water content and a lower oxygen concentration than would be found in the field (Mastalerz, 1977). Coarse amendments are usually added to greenhouse and nursery container media to augment pore space, decreases the matric tension, and increases oxygen concentration. Creating a mixture that preserves field soil characteristics while allowing adequate water movement may be impossible. Therefore, greenhouse investigations may very well yield results that are different from field research. This study was designed to determine if the effects of peat obtained in the greenhouse study would also occur in field-transplanted trees.

Field study also allowed a broadened scope of inquiry. The survival of high density, fibrous-rooted systems over those with tap roots may be due to better water status. The greater number of root tips enlarges root surface area and absorption capacity within the root ball (Kramer and Kozlowski, 1960). Because root system morphology affects transplanting success, it was desirable to compare how two species with different rooting patterns react to peat backfill. Therefore, a second purpose of this study was to compare after-transplant growth of a coarse-rooted species, white oak, with that of a fibrous-rooted species, red oak, and to determine if organic soil amendment enhanced survival and water relations of either species in the field.

METHODS AND MATERIALS

Thirty red oak, 1.83 m (6’) and thirty 1.22 m (4’) white oak whips (Bailey Nurseries, Inc., St. Paul, MN) were planted by hand at Ashland Horticulture Farm on April 8, 1988. The soil was a Haynie fine sandy loam underlain with a heavier silt loam. Elemental sulfur (220 g/m^2) was incorporated into the plot to lower pH on April 7. One half of each species was amended with 25% sphagnum peat moss (three:one by volume) mixed into the native soil backfill. Each treatment was replicated three times with five trees per replicate. Planting holes were uniform and just large enough to accommodate the root systems. Backfill was firmed around the roots as it was added.

Trees were not graded as to size of root system nor pruned to uniformity.

Trees received 1.27 cm of rain the day following planting. Supplemental irrigation was applied at irregular intervals from a water truck; each tree received an estimated 20 liters per application.

Seasonal environmental conditions were measured at the Agronomy Research Farm approximately one mile from the study site and are presented in Appendix IV. The experimental plots received 1 cm of rain two days before harvest.

On August 14 examination of the plots revealed that only six of each white oak treatment, six unamended red oak, and four amended red oak had comparable growth patterns. Many trees had died, others had root suckers replacing dead stems while some did not break dormancy until the first of August. These remaining twenty-two plants were harvested over three days. Roots were excavated at the same time. Total tree height, new growth, stem diameter (1 m from the crown), leaf area, dry weight and number, new root length, fresh and dry weight of roots and shoots, predawn leaf water potential, osmotic potential, and soil water content and potential were measured on August 15-17 as described earlier (see page 20-22).

RESULTS

Each species exhibited distinct qualitative characteristics. Red oak leaves were somewhat ragged, but size, color, and turgidity were "normal" to good. White oak tended to have numerous, small leaves with little branch extension. Three were "wilty" (soft), slightly chlorotic and scorched. The soil pH of the site is alkaline, and sulfur amendment may not have been adequate to eliminate chlorosis.

Root spread outside the original planting hole varied between trees and treatments. Some, including those with good visual characteristics, seemed to have had little growth while others had deep sinker roots. Both species tended to send their roots down rather than laterally from the original roots. No correlations were made to confirm these observations.

Soil Water Relations

There was no statistical difference in soil water content between soil treatments for white oak, but red oak in peat-amended soils had significantly greater soil water content (Pr>F 0.019, Table III-1). Peat-amended soils had significantly lower soil water potential for both white and red oak (Pr>F 0.0002, 0.076 respectively).

TABLE III-1. Mean harvest day soil water relations measurements of field-grown white and red oak whips transplanted into either unamended or 25% peat-amended (v:v) fine Haynie silt loam. Measurements were made on August 15-17, 130 days after transplanting.[z] Species have been analyzed separately.

Soil Treatment	Soil Water Content (g/g)	Soil Water Potential (MPa)
	White Oak	
Peat	0.12	-0.24***
Soil	0.11	-0.04
	Red Oak	
Peat	0.15**	-0.12*
Soil	0.10	-0.04

[z]Means are calculated on a per tree basis; n = 6 white-peat, white-soil, and red-soil; n = 4 red-peat

*Indicates significant difference between mean pairs (F-test, P = .10).

**Indicates significant difference between mean pairs (F-test, P = .05).

***Indicates significant difference between mean pairs (F-test, P = .01).

Plant Water Relations

Predawn leaf water potential and osmotic potential did not vary between treatments for white oak (Table III-2). Red oak planted in peat-amended backfill had significantly higher leaf water potential than unamended red oak (Pr>F 0.08). Osmotic potential was not significantly different between treatments.

Stem and Leaf Growth

Red oak and white oak top growth responded in radically different ways to peat amendment (Table III-3). White oak total height (Pr>F 0.019) and shoot growth (Pr>F 0.09) were significantly greater with the addition of peat. Other stem growth measures were not significantly different, though total stem dry weight was larger in peat-amended soil. Total height (Pr>F 0.07), shoot growth (Pr>F 0.013), and total stem dry weight (Pr>F 0.057) in red oak were significantly decreased by peat amendment. Caliper was unchanged by soil treatment for both species.

No leaf growth parameters were significantly different for white oak trees though peat amendment resulted in greater leaf number, dry weight and area (Table III-4). Red oak leaf number (Pr>F 0.081), dry weight and area was less in peat-amended soil.

Root Growth

New root length and new root dry weight were larger

TABLE III-2. Mean predawn leaf water potential and osmotic potential on harvest day of white and red oak whips transplanted into peat-amended or unamended soil.[z] Species have been analyzed separately.

Soil Treatment	Leaf Water Potential (MPa)	Osmotic Potential (MPa)
	White Oak	
Peat	-1.51	-1.93
Soil	-1.54	-2.18
	Red Oak	
Peat	-1.54*	-2.01
Soil	-2.06	-2.26

[z]Means are calculated on a per tree basis; n = 6 white-peat, white-soil, and red-soil; n = 4 red-peat.

*Indicates significant difference between mean pairs (F-test, P = .10).

TABLE III-3. Mean top growth measurements at harvest of field-grown red and white oak whips transplanted into unamended or peat-amended soil.[z] Species have been analyzed separately.

Soil Treatment	Total Height[y] (cm)	Shoot Growth (cm)	Caliper (mm)	Total Stem Dry Weight[x] (g)
		White Oak		
Peat	159.73**	18.00*	11.45	124.84
Soil	148.52	8.72	11.43	96.25
		Red Oak		
Peat	212.63*	2.63***	14.52	179.51*
Soil	229.65	16.77	14.34	231.19

[z]Means are calculated on a per tree basis; n = 6 for white-peat, white-soil and red-soil; n = 4 for red-peat.

[y]Original height and new shoot growth combined.

[x]Stem dry weight plus leaf dry weight.

*Indicates significant difference between mean pairs (F-test, P = .10).

**Indicates significant difference between mean pairs (F-test, P = .05).

***Indicates significant difference between mean pairs (F-test, p = .01).

TABLE III-4. Mean leaf growth of field-grown white and red oak whips transplanted into either unamended or 25% peat-amended (v:v) soil.[z] Species have been analyzed separately.

Soil Treatment	Leaf Number	Leaf Dry Weight (g)	Leaf Area (cm^2)
	White Oak		
Peat	202.33	23.84	2133.01
Soil	140.33	14.19	1329.33
	Red Oak		
Peat	141.50*	30.52	2846.79
Soil	173.33	37.48	3566.42

[z]Means are calculated on a per tree basis; n = 6 for white-peat, white-soil, and red-soil; n = 4 for red-peat.

*Indicates significant difference between mean pairs (F-test, p = .10).

when white oak was planted in unamended soil (Table III-5). Total root dry weight, which is reflective of original root size and represents total root growth and diameter increase, was larger in amended soil. All red oak root growth measurements were larger in unamended soils; however, none of these parameters were statistically different within either species.

DISCUSSION

Water Relations

Because of the rain two days prior to harvest, soil water contents were, as expected, similar for all treatments. By the third (last) day of harvest, soil water contents had decreased slightly. This decrease over time was not analyzed. Peat-amended soils held more water then unamended soils, 0.010 g/g for white oak and 0.050 g/g for red oak (see soil water release curves, appendix III). The significantly higher soil water content of peat-amended red oak indicated that this species may have been absorbing water at a slower rate than unamended red oak.

Soil water potential was significantly lower in peat-amended soils for both species. At the same time, soil water content was higher at those potentials as has been confirmed by others (Nus et al., 1987). (See soil water release curve, Appendix III).

TABLE III-5. Mean root growth measurements of red and white oak whips transplanted into either unamended or peat-amended soil. There are no significant differences between treatments (F-test, P = .10).[z] Species have been analyzed separately.

Soil Treatment	New Root Length (cm)	New Root Dry Weight (g)	Total Root Dry Weight[y] (g)
	White Oak		
Peat	25.67	0.020	162.71
Soil	39.60	0.028	131.63
	Red Oak		
Peat	30.00	0.020	205.60
Soil	45.83	0.057	224.94

[z]Means are calculated on a per tree basis; n = 6 white-peat, white-soil, and red-soil; n = 4 red-peat.

[y]Root dry weight plus new root dry weight.

Mean leaf water and osmotic potentials were not significantly different for white oak and were indicative of the lack of variation in mean soil water content. There was a slight decrease in leaf water and osmotic potential that corresponded to the slight decrease in soil water content in unamended soils. Peat-amended red oak's significantly higher mean leaf water potential is reflective of the significantly higher soil water content for this treatment. Hummel and Johnson (1985) also found no significant variation in leaf water potential in previously irrigated sweet gum.

Top Growth

Because stem and leaf growth was greater in peat-amended white oak while it was reduced in red oak, it appears that white oak benefited from peat-amended backfill while red oak may have actually been harmed by it. Why this is so is not readily apparent. The differences may be explained by an examination of soil water availability for each species.

Red and white oak have adapted to different sites based on their abilities to handle water deficits (Parker et al., 1982; Hinckley et al., 1979). White oak has features which classify it as drought tolerant: high bulk modulus of elasticity and active osmotic adjustment (Levitt, 1980; Parker et al., 1982). As compared to red oak, non-transplanted white oak has less elastic leaf tissue, closes stomata at a lower bulk leaf pressure potential, and keeps stomata open to lower total leaf water potentials, even when osmotic potentials were similar (Parker, et al., 1982). Red oak is adapted to mesic sites and closes stomata at "high" soil water potentials (Parker et al., 1982). Cessation of red oak shoot growth has been noted at -0.2 MPa (Larson and Whitmore, 1970). The fact that peat-amended red oak soil water potential was much higher than that of amended white oak (Table III-3) may support the fact that the two species use water at different rates.

If white oak stomata did remain open at low soil water potentials, it might have been able to take advantage of the higher soil water content that peat adds and increased growth resulted. European hornbeam and English oak osmotically adjust (Hinckley et al., 1981), and improved growth in these species has been observed on peat-amended sites (Sonsky, 1984).

In this study, amended red oak had the highest soil water content. Even though the energy status of soil water was reduced to -0.12 MPa, growth comparable to unamended red oak should have occurred. Rather than being an indication of good water status, however, this high soil water content may reflect stress-induced stomatal closure which stopped water uptake and allowed leaf water potential to remain high. Stomatal resistance could have confirmed stomatal closure.

Why or what caused this stress can only be speculated about at this time. Perhaps red oak is sensitive to by-products from peat decomposition or perhaps there are other, unknown, detrimental secondary effects. These topics warrant further study by others.

Root Growth

Root growth measurements followed the same pattern which demonstrated the beneficial effects of peat on white oak and the detrimental ones on red oak. New root length and dry weight were not improved by the addition of peat for white oak; however, total root dry weight, which reflects diameter increase in existing root, was greater. The harmful effect of peat on red oak was borne out in all root growth parameters, with unamended trees having greater root growth. Considerable within-sample variation led to nonsignificance of results, even though a wide variation in means existed.

Both species had few new roots. End-of-season harvest did not adequately measure the extent of new root growth. Transplanted two-year-old white oak seedlings experience one root growth flush extending for only a short period after shoot growth stops in the spring. Root growth slows even when soil water and temperatures are not limiting (Reich et al., 1980). In addition, new roots are continuously sloughed off or suberized (Kramer and Kozlowski, 1960).

Conclusions

The variation in response to amendment treatment by species is consistent with the findings of others (Corley, 1984; Ingram et al., 1981), as is the lack of significance in leaf water potential in recently irrigated trees (Hummel and Johnson, 1985). Whether backfill amendment is beneficial to a species may depend on a plant's particular physiology and habitat adaptation; and, thus, it is impossible to make conclusive statements that cover all species. In this study it appears that white oak transplantability was improved by the addition of sphagnum peat moss to the backfill soil while red oak had much worse survival and growth when amended with peat.

CONCLUSIONS

Peat-amended backfill had little effect on white oak growth, survival, or water relations when transplanted in the greenhouse or in the field. Most top and root growth measurements were not significantly different as has been found in studies of other species (Hummel and Johnson, 1985; Corley, 1984; Townsend, 1973) with the exception of caliper in the greenhouse study and new shoot and total shoot growth in the field study.

Caliper increased when peat was added to container media. It was reasoned that this may be due to improved oxygen concentration within the media or to other secondary effects. The effect did not carry over into field soils, most likely because field soil was light-textured. Improvements arising from secondary effects of organic backfill amendment have been supported by other studies which have measured increased growth in azaleas and blueberries due to a lowering of pH (Whitcomb, 1985) and additional nutrient availability (Haynes and Swift, 1986). The use of peat-amended backfill might be warranted, therefore, when soils are heavy or when trees are sensitive to compacted soil conditions and would benefit from an increase in oxygen supply. Oxygen diffusion measurements are necessary to confirm this conclusion.

Addition of peat increased water content in field soil. Because white oak is a drought-tolerant species, and keeps its stomata open to low leaf water potentials, the tree could avail itself of the greater water content and increased growth resulted.

The field study illustrated differences between species. Red oak top growth was significantly reduced by peat amendment, and root growth was lowered, although not significantly. Soil water was apparently not a factor in this reduced top growth. Peat-amended red oak had the highest soil water content of all treatments, indicating that possibility some other stress had induced stomatal closure. Further study is required to determine what property of peat deters red oak growth. No firm answers arose from this study.

These experiments had great within-sample variability. Because of the broad range in initial size, unknown previous handling, and genetic variability, non-significance was the result. Sample size was not adequate to eliminate the effect of these factors on the outcome of the treatments. Yet sample sizes appear to also be small in other studies (Hummel and Johnson, 1985; Corley, 1984; Schulte and Whitcomb, 1975; Pellett, 1971). Whether these researchers made conclusions of nonsignificance with within-sample variability is not known.

Results from this study imply that a slow-to-root species with "drought tolerance" adaptation would benefit from the addition of peat to the backfill, while one which has adapted to drought by stomatal closing would not show any improvement. Soil texture alteration, which increases oxygen content, would favor growth in some species in some situations. This study reinforces that all species do not respond the same (Corley, 1984; Ingram et al., 1981) and that the same conclusions about one species cannot be made for other species. Some species may be harmed by the addition of peat due to secondary effects on the soil environment. There may be a need for testing on a species-by-species basis.

If more studies were to be done, testing should be more detailed. Species should be examined in terms of what is known about their physiology, drought adaptation, and rooting habits. The soil needs to be analyzed for nutrients, pH, texture, bulk density, oxygen diffusion rate, water-holding capacity, and soil water potential. Amendment properties, after addition to the soil and during decomposition, must be researched, as well as the species' reaction to decomposition products and root-environment alterations. Clones or a large sample size should be used.

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APPENDIX I

PRELIMINARY STUDY
TO DETERMINE IRRIGATION SCHEDULES
FOR GREENHOUSE STUDIES

METHODS AND MATERIALS

Preliminary studies were conducted to determine the irrigation schedule for subsequent greenhouse studies and were expected to indicate: 1) the lowest soil water potential that could be considered well-watered; 2) the lowest soil water potential to which a plant could be subjected without dying; and 3) the time necessary for soils to dry to these water potentials.

Sixteen, one-year-old, 15 cm (6"), bare-root white oak seedlings (Forrest Keeling Nursery, Elsberry, MO) were planted in 3.7 liter containers on March 17, 1988. Seedlings were root pruned as necessary for uniformity. Two 1.2 m (4'), bare-root white oak whips (Bailey Nurseries, Inc., St. Paul, MN) were transplanted into 121 liter containers (Gott, Winfield, KS) on April 11 as described in Chapter II. Media were either a shredded, unmapped, soil or a three soil : one sphagnum peat moss (by volume) mix amended with iron sulfate (160.6 g per m^3) to lower soil pH and processed as described in Chapter II.

All trees were well-watered until they leafed out, then groups of the 15.2 cm seedlings were allowed to dry for 5, 7, 8 or 9 days before re-watering. Leaf water potential and soil water content for each plant were measured daily or every other day depending upon the regime. At the end of each drying period, trees were irrigated, then measured the day afterwards to determine the extent of water stress achieved and whether a tree was able to recover. The white oak whips in the 121 liter containers were measured for 39 days before irrigation. Predawn leaf water potential, soil water content and potential, and sample disks were measured as described in Chapter II.

RESULTS AND DISCUSSION

Predawn leaf water potential of the 3.8 container liter plants remained relatively constant until day 6 (soil) or day 7 (peat/soil), then markedly decreased (Fig. AI-1 and AI-2). Soil water contents steadily declined from day 1 to day 9 for both soil treatments (Fig. AI-3 and AI-4). Analysis showed no correlation (r^2 = 0.04 peat; .31 soil) between leaf water potential and days since irrigation. There was better correlation between soil water content and time (r^2 = .78 peat; .73 soil).

Figure AI-1. Mean predawn leaf water potential of four trees measured over eight days as soil dried after irrigation, unamended soil. Leaf water potential remains almost steady until the eighth day of measurement.

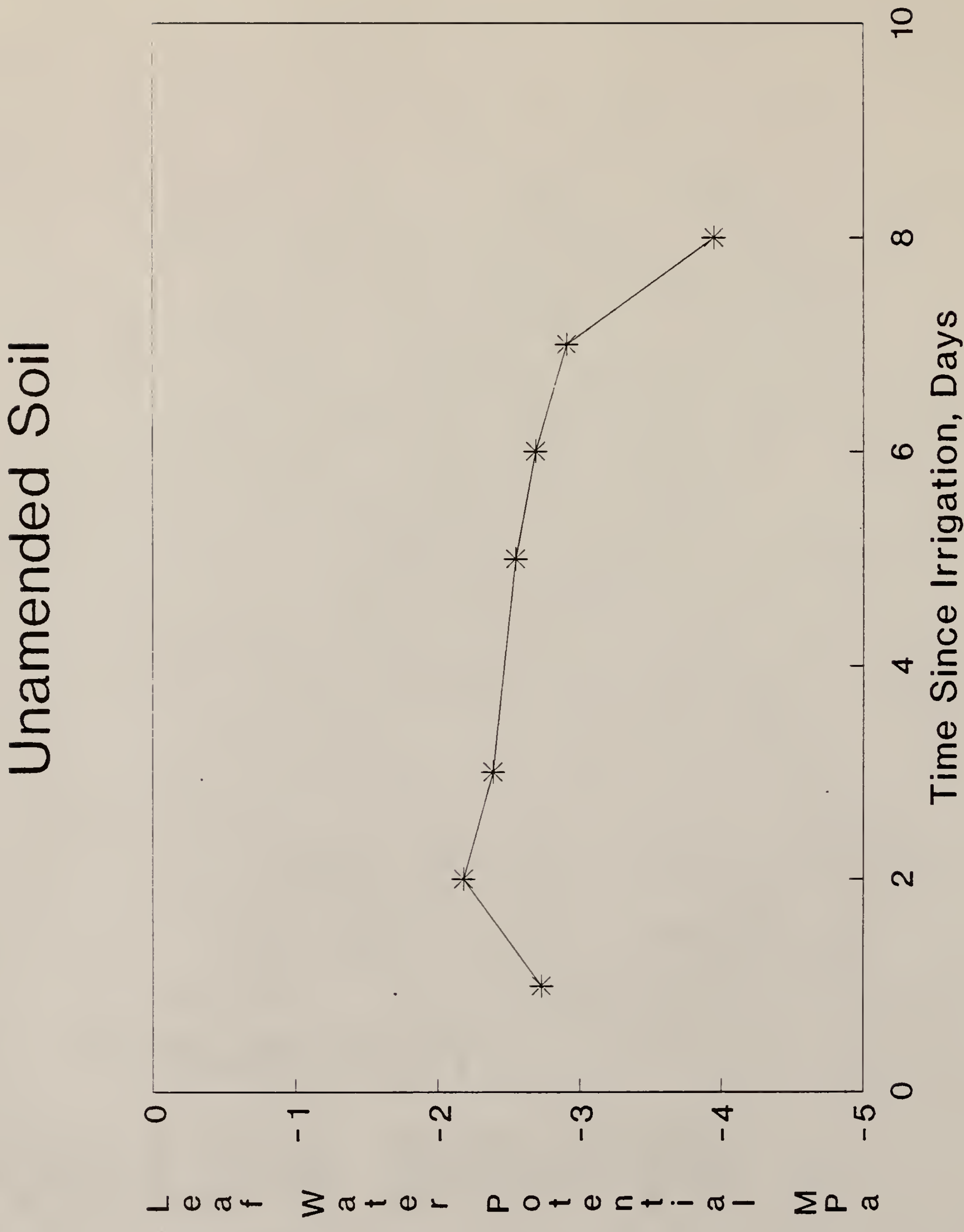

Unamended Soil
Leaf Water Potential MPa
0
-1
-2
-3
-4
-5
0
2
4
6
8
10
Time Since Irrigation, Days

Figure AI-2. Mean predawn leaf water potential of four trees measured for eight days as soils dried after irrigation, peat-amended soil. Leaf water potential remains fairly constant until day eight.

Peat-Amended Soil

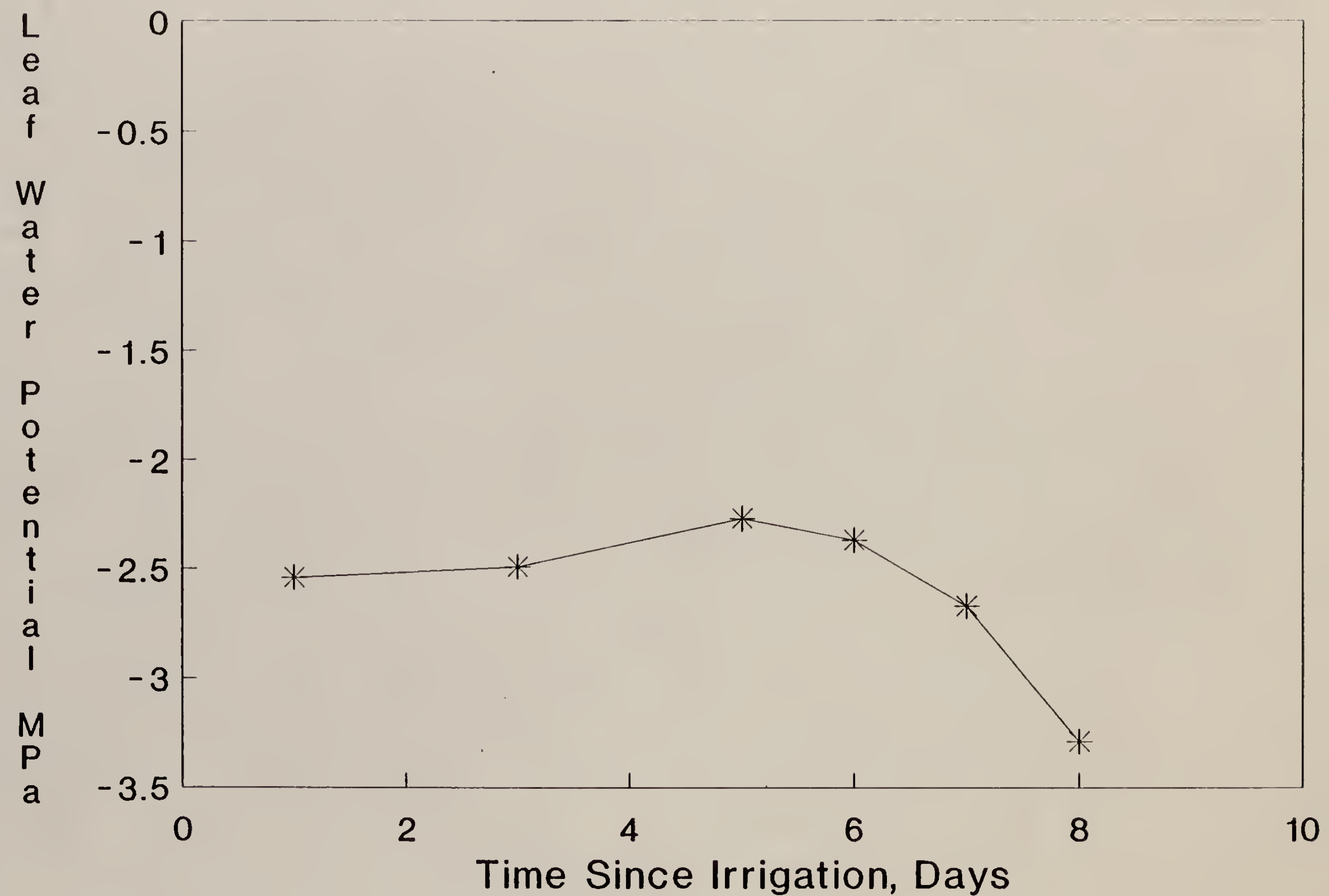


Figure AI-3. Mean soil water contents from the containers of four trees measured for eight days after irrigation, unamended soil.

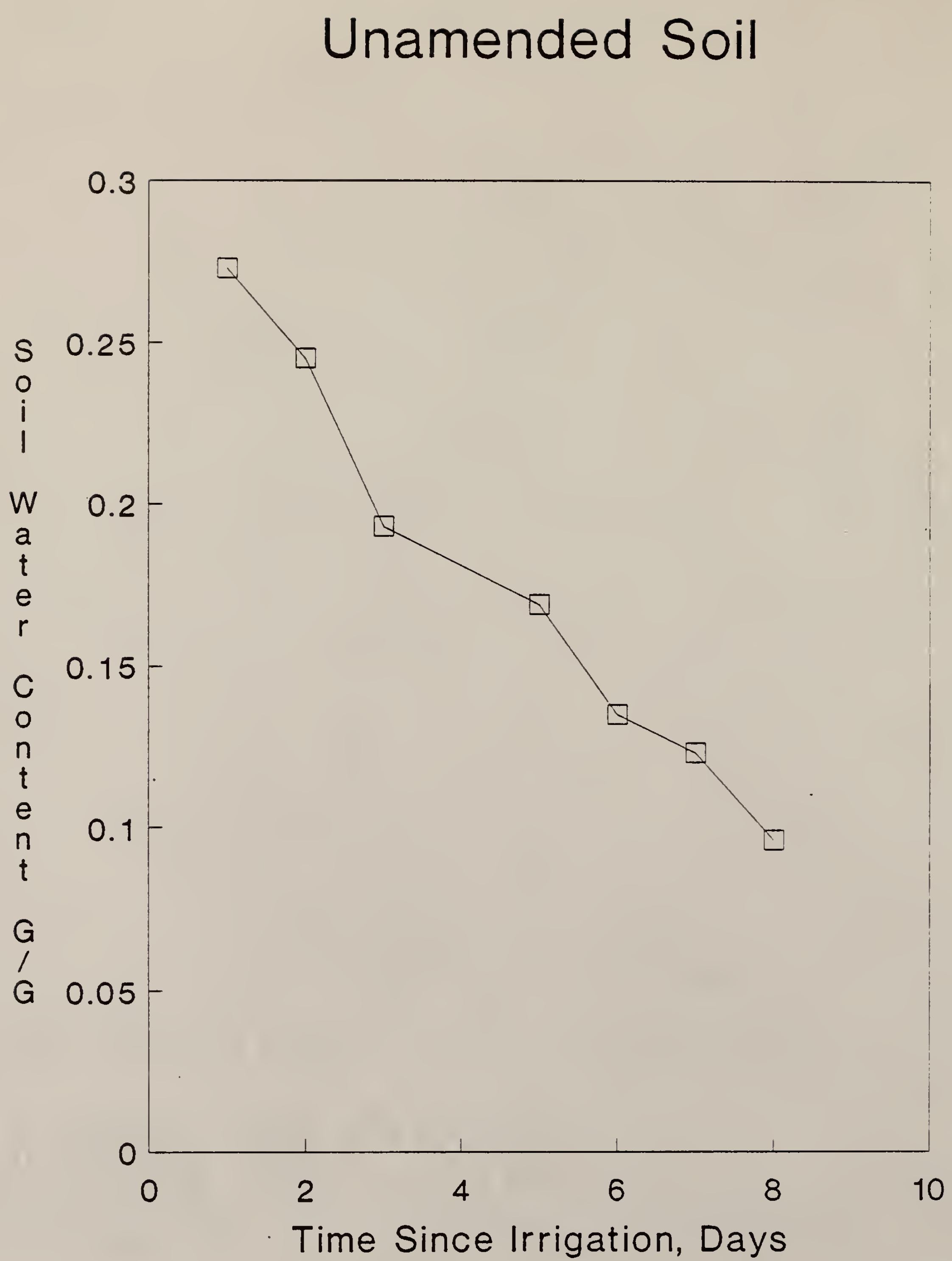
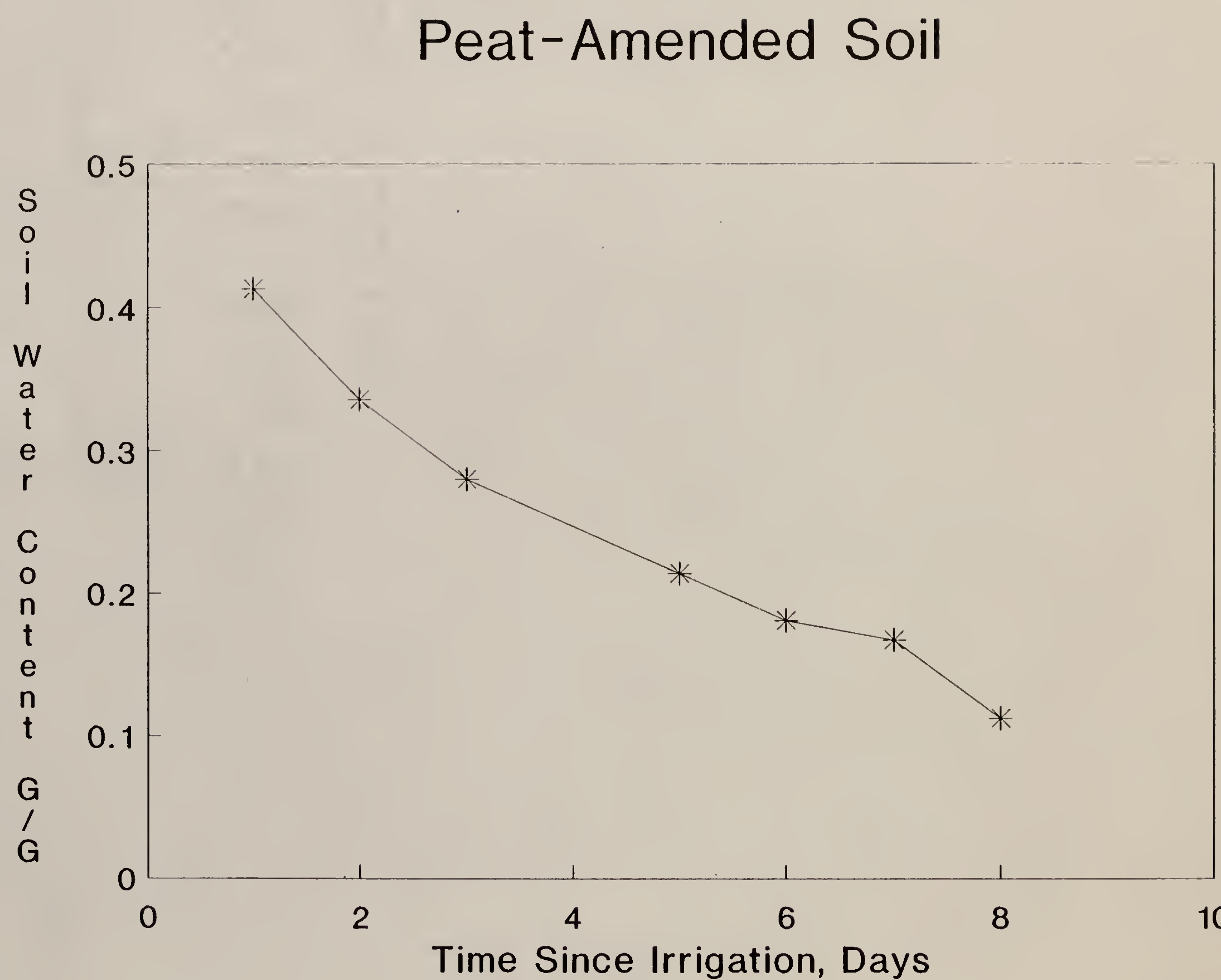

Unamended Soil
Soil Water Content G/G
0.3
0.25
0.2
0.15
0.1
0.05
0
0
2
4
6
8
10
Time Since Irrigation, Days

Figure AI-4. Mean soil water contents from container soils of four trees measured for eight days after irrigation, peat-amended trees.

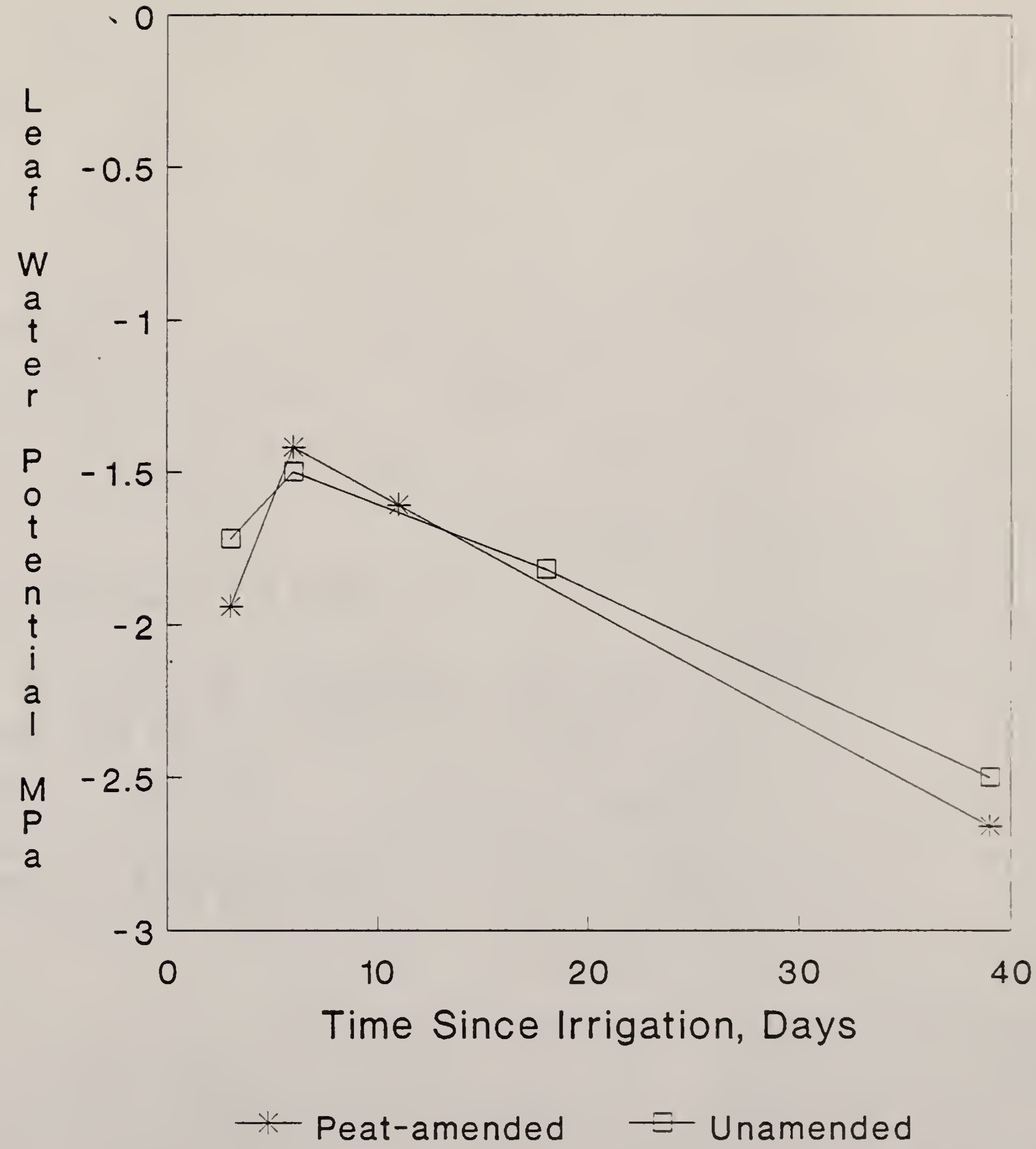

Peat-Amended Soil
Soil Water Content G/G
0.5
0.4
0.3
0.2
0.1
0
0
2
4
6
8
10
Time Since Irrigation, Days

Both treatments in the 121 liter study had a "plateau stage" before predawn leaf water potentials decreased (Fig. AI-5), while soil water content decreased steadily over time (Fig. AI-6 and 7). Because data was not taken daily, the actual degree of change in predawn leaf water potential was not apparent. There was little variation in predawn leaf water potential between treatments. Regression analysis showed little correlation between predawn leaf water potential (r^2 = 0.18), soil water content (r^2 = -0.01) and days since irrigation.

Selection of treatment watering periods was a qualitative decision. At the end of the 3.8 liter container study, many of the seedlings were scorched, wilted and dying. After working with the plants in the study, it was thought that these symptoms would be avoided if the stress period lasted no longer than six days.

The 1.2 m seedlings presented another problem. Injury was not visible after 39 days; there was no time to do a second dry-down to test the response to repeated stress because study trees had already broken dormany. A rough estimate made before statistical analysis was completed indicated that soil water content for unamended soil might be maintained between 15 and 20% if trees were irrigated no less than every twenty-two days, thus an eleven and a twenty-two day schedule was chosen.

Figure AI-5. Predawn leaf water potential measurements of two 1.22 meter white oak trees measured for 39 days after irrigation, unamended and peat-amended treatments.



0
-0.5
-1
-1.5
-2
-2.5
-3
Leaf Water Potential MPa
0
10
20
30
40
Time Since Irrigation, Days
Peat-amended
Unamended

Figure AI-6. Soil water content of unamended 121 liter container soil measured for 39 days after irrigation. Water content was measured at three levels: 15 cm, 30 cm, and 45 cm.

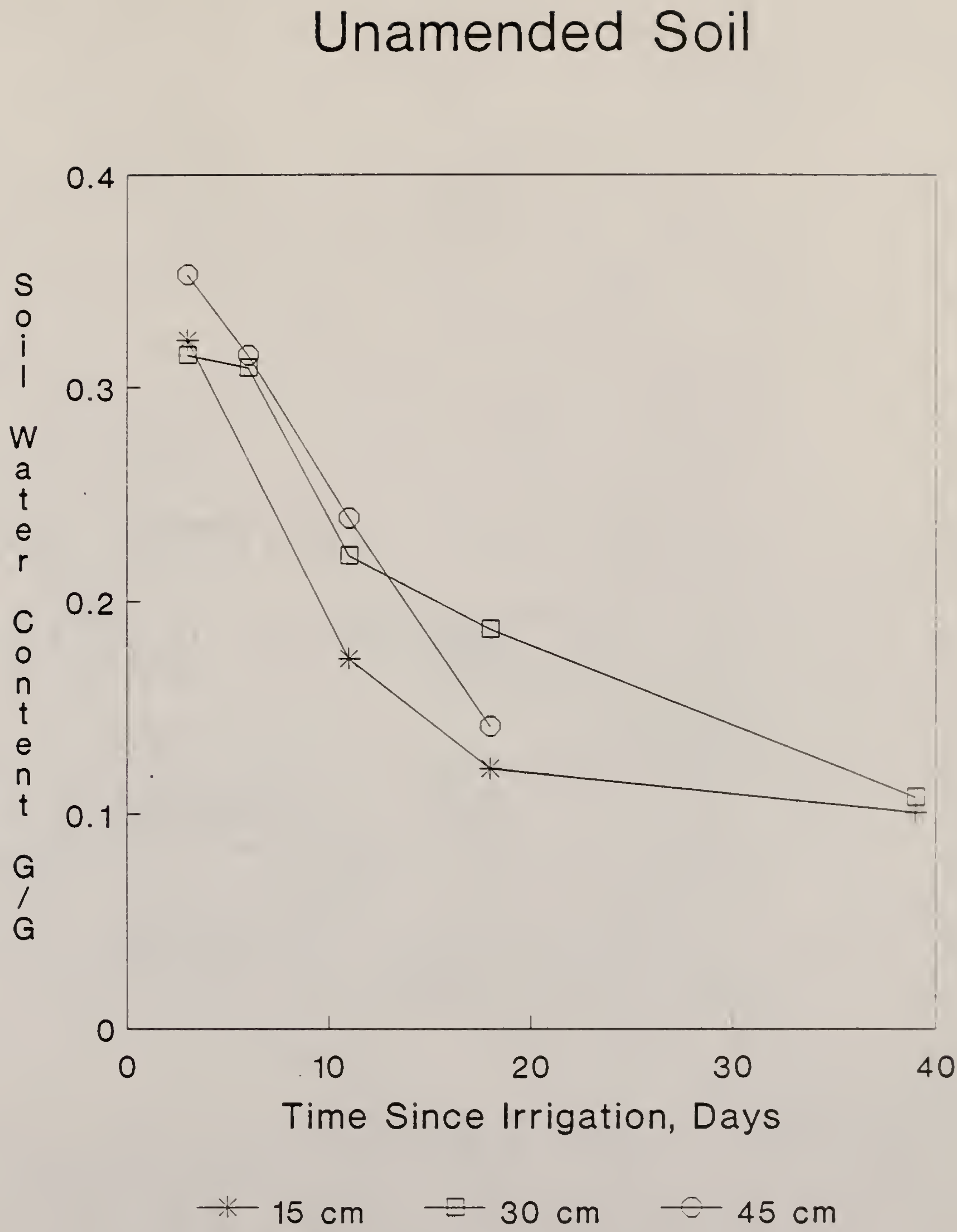
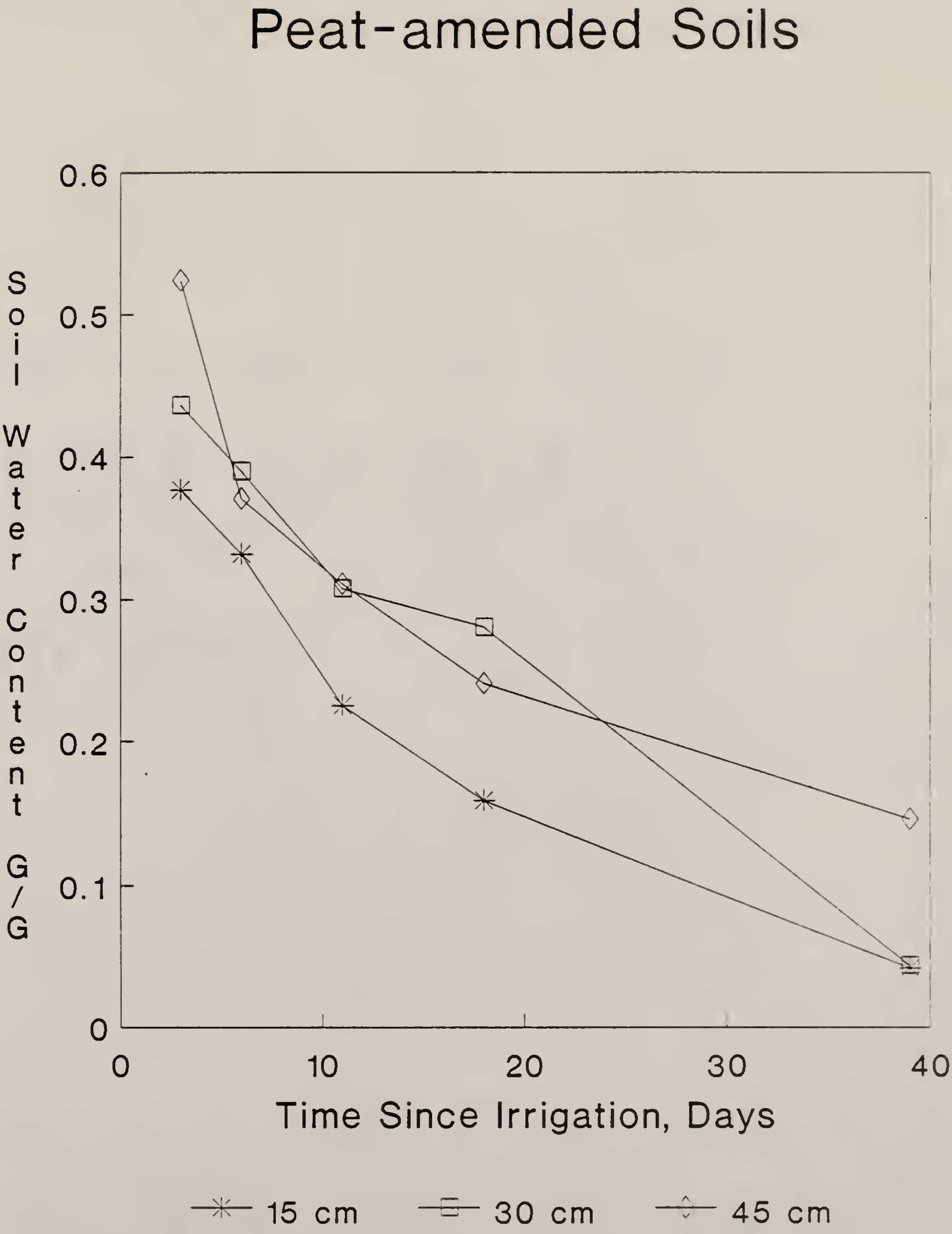

Unamended Soil
Soil Water Content G/G
0.4
0.3
0.2
0.1
0
0
10
20
30
40
Time Since Irrigation, Days
15 cm
30 cm
45 cm

Figure AI-7. Soil water contents of peat-amended 121 liter containers measured for 39 days after irrigation. Water contents were determined at three levels in the containers: 15 cm, 30 cm, 45 cm.


Peat-amended Soils
Soil Water Content G/G
0.6
0.5
0.4
0.3
0.2
0.1
0
0
10
20
30
40
Time Since Irrigation, Days
15 cm
30 cm
45 cm

It became apparent during the study that there are several problems inherent in interpreting data from a drying schedule treatment on trees. Two water potential gradients exist -- one from the leaf base to the leaf apex (Wiebe and Prosser, 1977), and one from the lower branches to the upper ones (Wiebe et al., 1970; Scholander et al., 1965). A standardized reference point is necessary for uniformity between samples, but this is not possible when taking numerous samples from the same tree. Not only must samples come from different sides and levels of the tree, but the limited number of leaves may entail using the same leaf twice. The injury from the first sample most likely changes the water status of the leaf.

Another problem occurred when the soil volume was reduced by repeated removal soil cores. After so many soil cores had been removed, root growth was restricted to a smaller area. The soil did not re-wet thoroughly at irrigation. Much of the plant mortality seen in this preliminary study may be a consequence of soil disturbance.

APPENDIX II

GROWTH AND WATER RELATIONS OF CONTAINERIZED 15 CM WHITE OAK SEEDLINGS TRANSPLANTED INTO PEAT-AMENDED BACKFILL -- GREENHOUSE STUDY

METHODS AND MATERIALS

One-year-old, 15.2 cm (6"), bare root white oak seedlings (Forrest Keeling Nursery, Elsberry, MO) were potted into 3.78 liter plastic containers in a shredded, unmapped, "old buried" soil or a 3:1 mixture of shredded soil and sphagnum peat moss (by volume) on April 1 and 4, 1988. All soils were amended with iron sulfate (160.6 g per m^3) to lower soil pH. Soil and amendments were thoroughly mixed in a Dixon Batch Mixer as described earlier. Seedlings were root-pruned for uniformity.

Potted trees were arranged pot-to-pot in a randomized block design on two greenhouse benchs and watered-in after planting. Seedlings were periodically irrigated until all seedlings had broken dormancy, seven weeks later. On May 19, three and six day irrigation treatments were initiated.

Greenhouse environmental conditions were the same as in Chapter II. Light intensity over the tree canopy was 145 $\mu mol \cdot s^{-1} m^{-2}$ on a cloudy day (7/2/88) and 740 $\mu mol \cdot s^{-1} m^{-2}$ on a sunny day (7/3/88).

Beginning June 9, predawn leaf water potential, osmotic potential, soil water content and potential, and growth measurements were taken every three days on a randomly selected group of eight plants representing all treatments. Sample leaf disks, soil water, predawn leaf water potential and osmotic potential measurements were made as described in Chapter II. Total shoot height, new growth, caliper (5 cm from the crown), fresh and dry weight, and root growth measurements were also made as described earlier.

RESULTS AND DISCUSSION

Timing of dormancy release was erratic; some trees were in full leaf within three weeks while others had not broken bud by June 1. Stems of most of those in the peat/soil mix died without leafing out but suckers arose from the roots. There was no apparent reason for this death.

Statistical analysis reflects the fact that there was little comparable plant material. Trees grown in soil were significantly larger because they were not root suckers. Significant block effects obscure the variables of leaf water potential, osmotic potential and soil water content. Analysis of variance results are presented in Appendix V.

APPENDIX III

SOIL WATER RELEASE CURVE

A STUDY RELATING THE WATER CONTENT OF A SOIL SAMPLE TO ITS SOIL WATER POTENTIAL

Soil was collected from the field study area at Ashland Research Farm and from the greenhouse study source (Chapter II, Appendix I). Half of each sample was mixed with sphagnum peat moss, 25% by volume, while the other half was unamended. After all media were passed through a #10 sieve (2 mm mesh), duplicate samples of amended and unamended portions were placed in three-inch rubber rings in a pressure plate apparatus. Distilled water was added to the plates, and samples were covered for 24-36 hours until they appeared totally saturated.

The pressure plates were sealed, and pressures (0.014, 0.021, 0.030, 0.050, 0.10, 0.50, 1.0 MPa) were applied until water potential of the soil equilibrated with the applied pressure. At this point there was no further drainage from the apparatus.

After equilibration, samples were weighed, dried at 60° C (Gardner, 1965) until weight was constant (24 hours), and then weighed again.

The negative value of the pressures applied are equal to the soil water potential. A plot of the water content of the soil at each pressure represents the soil water release curve from which soil water potentials in the studies were found (Fig. AIV-1 and AIV-2).

RESULTS AND DISCUSSION

Soils with added organic matter had a lower soil water potential at equal soil water content. Amended greenhouse soil held 0.2179 g/g more water than unamended soil at -0.14 MPa, while amended field soils held 0.2086 g/g more. Total water availability was improved by the addition of peat. Between -0.1 and -1.0 MPa soil water potential, field soil plus peat held 0.1695 g/g more water. Greenhouse soil plus peat contained 0.1623 g/g more water between those potentials. This is consistent with results presented by others who found peat mixes to be superior in water retention (Nus et al., 1987).

Figure AIV-1. Soil water release curves of unamended and 25% (v:v) peat-amended Haynie fine sandy loam. Soil water potential is the negative value of pressure applied.

SOIL WATER RELEASE CURVE
FIELD SOIL

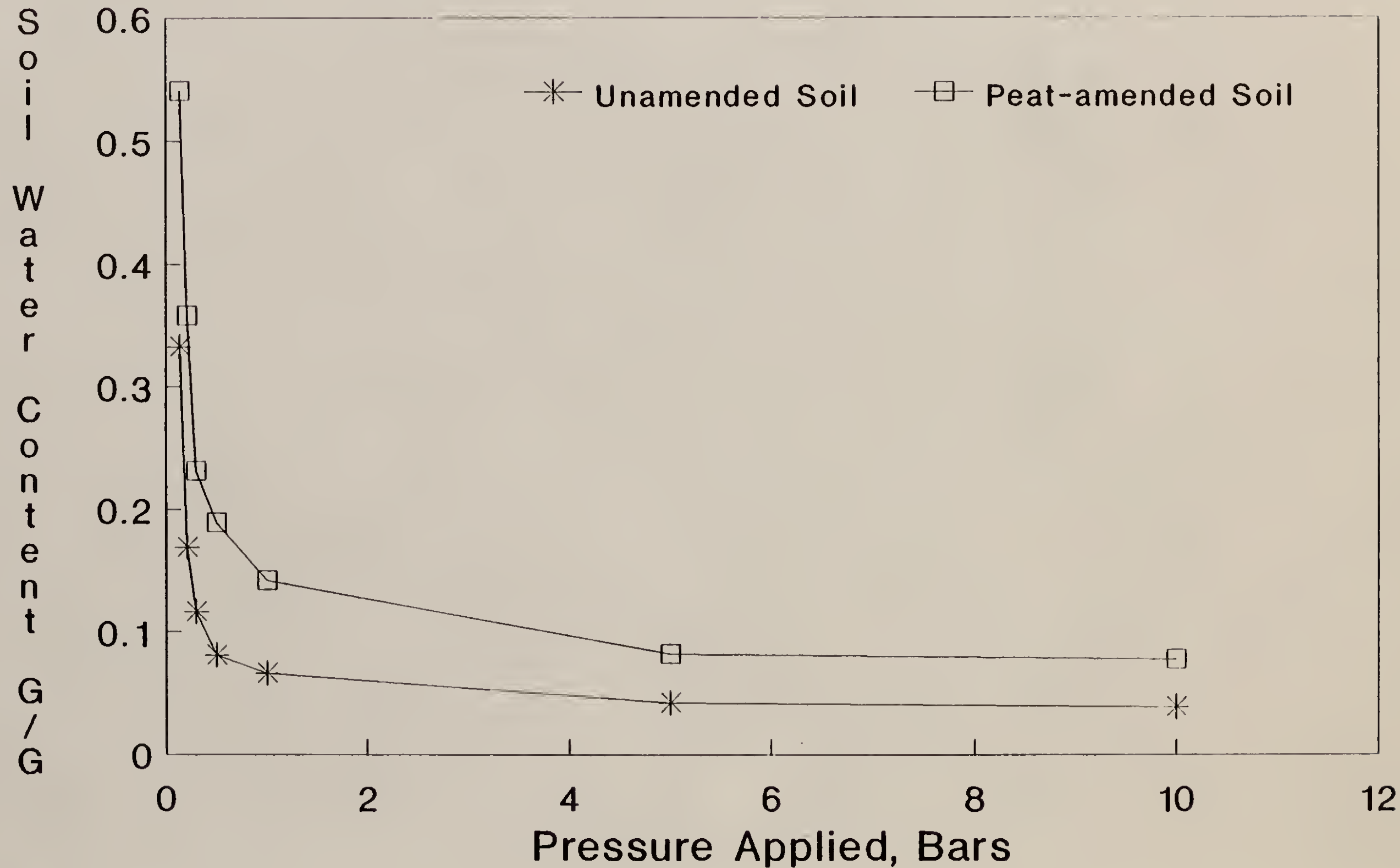
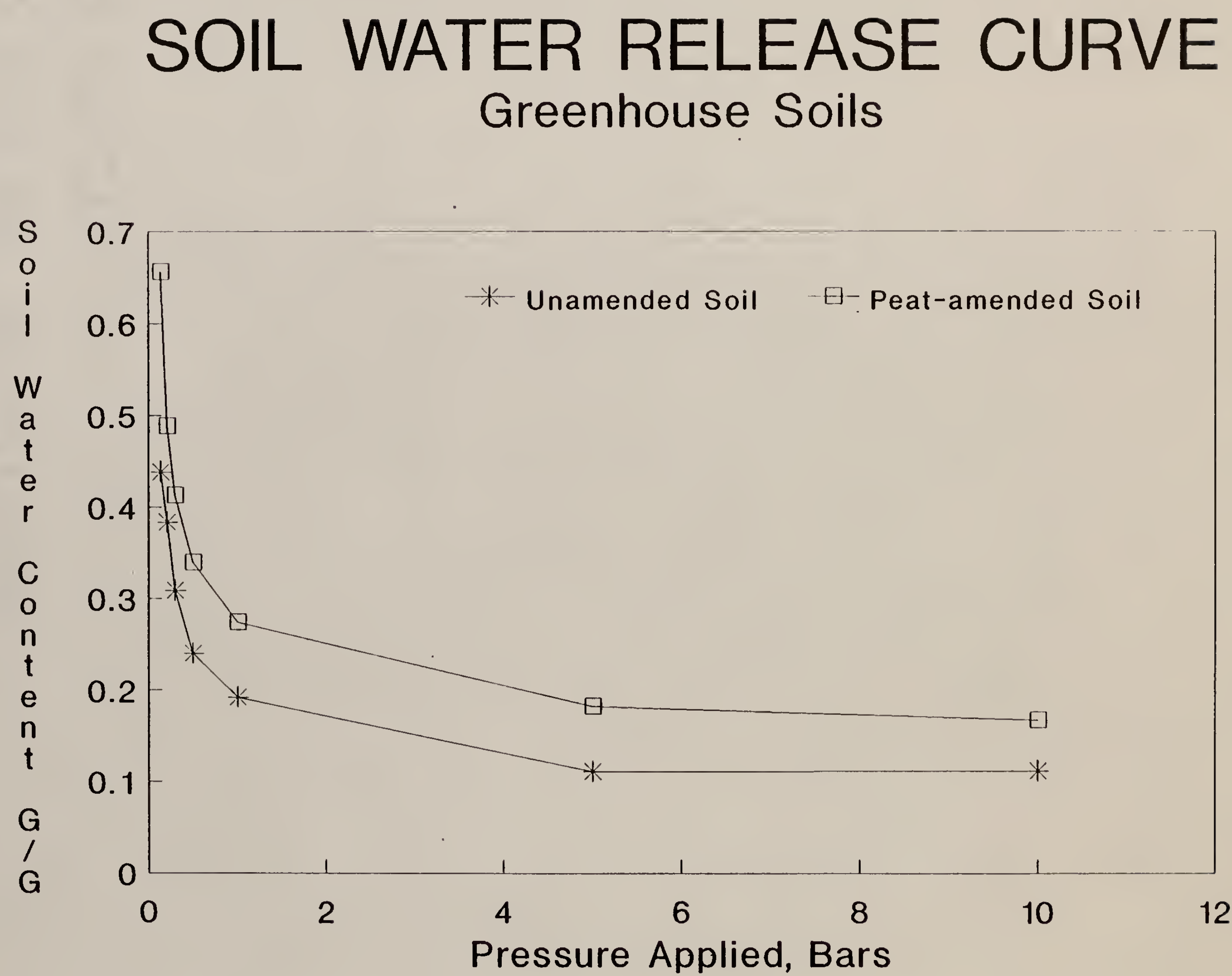


Figure AIV-2. Soil water release curves of unamended and 25% (v:v) peat-amended, unmapped, "old buried" soil from the greenhouse. Soil water potential is the negative value of pressure applied.


SOIL WATER RELEASE CURVE
Greenhouse Soils
Unamended Soil
Peat-amended Soil
Soil Water Content G/G
0.7
0.6
0.5
0.4
0.3
0.2
0.1
0
0
2
4
6
8
10
12
Pressure Applied, Bars

APPENDIX IV

GREENHOUSE ENVIRONMENTAL CONDITIONS
DURING STUDIES OF THE WATER RELATIONS
AND GROWTH OF WHITE OAK SEEDLINGS
FROM MAY 19, 1988 TO AUGUST 14, 1988

Date	Temperature Max (°C)	Temperature Min (°C)	Relative Humidity Max (%)	Relative Humidity Min (%)	Date	Temperature Max (°C)	Temperature Min (°C)	Relative Humidity Max (%)	Relative Humidity Min (%)	Pan Evap (mm)
5/19	36.0	27.0	66	8	5/20	37.0	27.0	66	27	160
5/21	37.0	25.0	50	18	5/22	37.0	28.0	58	16	420
5/23	36.0	27.0	58	16	5/24	37.0	27.0	66	30	325
5/25	32.0	27.0	66	54	5/26	36.0	28.5	64	24	--
5/27	37.5	27.0	64	24	5/28	35.5	28.0	60	22	470
5/29	37.0	28.0	52	10	5/30	38.0	28.0	46	14	430
5/31	37.0	28.0	64	21	6/ 1	37.0	28.0	64	22	340
6/ 2	37.5	27.8	68	6	6/ 3	36.1	26.7	68	20	210
6/ 4	36.1	25.6	50	2	6/ 5	37.8	26.7	46	6	600
6/ 6	40.0	27.8	56	4	6/ 7	40.6	28.3	68	16	400
6/ 8	40.6	28.3	66	16	6/ 9	33.9	27.2	50	18	490
6/10	36.1	27.8	44	2	6/11	39.4	28.9	44	6	380
6/12	36.7	28.3	62	16	6/13	38.3	28.3	60	8	570
6/14	35.6	28.3	66	26	6/15	34.4	27.8	66	32	330
6/16	36.7	28.9	66	18	6/17	36.7	27.8	65	18	425
6/18	35.6	27.2	66	14	6/19	40.0	28.9	60	20	450
6/20	35.0	23.0	78	38	6/21	40.0	27.0	78	26	340
6/22	40.0	27.0	74	36	6/23	41.0	25.5	78	29	410
6/24	41.0	25.5	76	30	6/25	41.0	26.0	78	36	460

Date	Temperature Max (°C)	Temperature Min (°C)	Relative Humidity Max (%)	Relative Humidity Min (%)	Date	Temperature Max (°C)	Temperature Min (°C)	Relative Humidity Max (%)	Relative Humidity Min (%)	Pan Evap (mm)
6/26	39.5	26.0	78	32	6/27	--	24.0	78	--	400
6/28	40.0	30.0	76	38	6/29	38.9	25.6	78	46	420
6/30	35.6	22.8	78	56	7/ 1	23.9	20.6	78	78	260
7/ 2	27.2	18.9	78	70	7/ 3	35.6	21.1	78	34	55
7/ 4	40.0	28.0	76	26	7/ 5	41.0	25.0	76	28	370
7/ 6	39.0	25.5	76	26	7/ 7	34.0	24.0	76	48	290
7/ 8	33.0	24.0	76	50	7/ 9	32.0	22.0	76	50	380
7/10	33.0	21.0	76	36	7/11	32.2	23.3	70	28	80
7/12	34.4	21.1	76	46	7/13	36.7	24.4	76	50	390
7/14	37.8	27.8	76	50	7/15	35.6	23.9	76	50	180
7/16	35.6	23.3	76	46	7/17	31.7	24.4	76	52	70
7/18	35.0	25.6	78	50	7/19	31.1	22.2	77	61	240
7/20	35.0	20.0	77	22	7/21	34.4	17.8	77	20	340
7/22	33.3	18.9	77	26	7/23	35.6	21.1	77	36	300
7/24	40.0	22.2	77	28	7/25	41.1	24.4	74	18	280
7/26	37.2	20.6	78	22	7/27	40.0	20.0	76	24	370
7/28	37.8	22.2	76	30	7/29	37.8	23.3	77	36	350
7/30	40.6	25.6	77	26	7/31	37.2	25.0	78	24	300
8/ 1	41.7	28.9	62	24	8/ 2	40.0	26.7	78	28	360
8/ 3	37.2	26.7	76	30	8/ 4	37.8	26.7	76	42	620
8/ 5	37.2	23.3	76	14	8/ 6	40.6	24.4	76	24	360
8/ 7	40.0	26.7	77	38	8/ 8	38.9	26.7	80	36	550
8/ 9	37.2	24.4	77	28	8/10	40.6	22.2	76	18	430
8/11	40.0	25.6	77	20	8/12	37.2	24.4	77	30	
8/13	37.8	23.3	76	30	8/14	32.2	23.9	76	42	

ENVIRONMENTAL CONDITIONS DURING
FIELD STUDIES ON THE GROWTH AND WATER RELATIONS
OF RED AND WHITE OAK

April 4, 1988 to August 18, 1988

Date	Air Temperature Max. (°C)	Air Temperature Min. (°C)	Solar Radiation (Langeleys)	Soil Temperature Max. (°C)	Soil Temperature Min. (°C)	Relative Humidity (%)	Precip. (cm)
4/ 4	27.5	10.9	500.6	17.6	8.5	59.9	
4/ 5	18.9	4.9	243.1	13.3	8.7	78.8	
4/ 6	19.8	2.9	606.6	14.5	6.1	48.9	
4/ 7	29.2	5.6	583.9	18.8	8.2	46.8	
4/ 8	29.7	13.3	575.2	20.1	11.3	39.3	1.27
4/ 9	18.4	4.1	120.7	16.2	8.6	86.3	
4/10	12.6	2.2	609.6	12.2	6.9	65.5	
4/11	15.7	.6	610.6	13.4	5.8	57.6	
4/12	21.5	.6	621.5	17.2	6.3	49.8	
4/13	27.1	2.7	623.8	19.7	8.3	51.2	
4/14	15.7	6.4	481.6	16.9	11.3	48.1	
4/15	17.4	3.6	627.4	18.3	10.3	41.7	
4/16	21.8	-1.2	621.7	18.9	8.5	45.2	
4/17	17.1	8.4	112.4	14.2	11.6	79.9	
4/18	13.7	1.4	624.5	14.8	7.2	45.9	
4/19	19.6	- .9	585.5	17.9	7.1	53.7	
4/20	25.7	8.5	592.9	19.8	10.1	51.9	
4/21	26.0	9.2	527.0	20.8	12.3	57.7	
4/22	16.5	4.1	499.1	18.4	12.6	63.6	
4/23	14.8	1.7	510.5	16.7	10.1	62.2	
4/24	23.6	1.6	574.9	19.5	9.2	58.3	
4/25	21.2	7.7	460.9	19.2	12.9	73.4	
4/26	12.5	2.6	523.1	15.9	11.8	71.4	

Date	Air Temperature Max. (°C)	Air Temperature Min. (°C)	Solar Radiation (Langeleys)	Soil Temperature Max. (°C)	Soil Temperature Min. (°C)	Relative Humidity (%)	Precip. (cm)
4/27	18.5	- .4	617.3	17.6	8.6	51.5	
4/28	25.3	2.4	658.7	21.4	10.3	50.2	
4/29	20.8	8.4	426.6	20.1	13.2	63.7	
4/30	25.4	11.6	487.2	21.8	14.3	64.4	
5/ 1	25.6	12.2	466.4	20.8	14.6	57.8	
5/ 2	24.1	13.3	297.7	19.1	14.5	59.8	
5/ 3	17.8	11.1	414.6	18.4	13.4	86.9	
5/ 4	20.9	8.9	535.0	20.9	12.5	80.4	
5/ 5	26.4	6.8	670.5	24.3	12.4	68.1	
5/ 6	28.9	11.9	513.1	24.3	15.3	55.9	
5/ 7	28.6	17.5	648.1	26.0	16.9	63.6	
5/ 8	24.1	12.5	606.3	24.4	18.1	55.8	
5/ 9	23.8	9.9	708.0	23.7	15.4	45.7	
5/10	29.9	6.5	642.4	24.4	14.6	46.9	
5/11	29.6	9.8	650.8	25.6	15.8	48.9	
5/12	32.3	11.3	709.0	27.2	16.8	45.2	
5/13	30.2	17.0	686.9	27.7	18.9	50.3	
5/14	32.7	16.9	636.3	27.3	19.4	47.1	
5/15	29.9	14.8	660.2	27.6	20.3	44.8	
5/16	29.3	8.7	706.0	27.8	17.7	38.9	
5/17	30.5	11.1	686.0	29.1	18.3	44.7	
5/18	35.3	15.9	691.7	30.6	20.3	48.9	
5/19	33.7	16.2	616.2	30.2	21.4	59.5	
5/20	32.7	16.5	402.7	27.7	21.7	74.3	
5/21	23.5	15.9	216.0	23.4	19.5	90.1	3.2
5/22	23.7	16.9	59.5	22.8	19.3	88.4	.
5/23	21.3	16.2	230.8	19.9	18.1	90.3	
5/24	27.5	14.4	698.6	24.1	16.5	69.0	1.3
5/25	26.6	14.0	668.9	28.2	17.3	73.5	
5/26	29.3	13.7	671.5	28.3	18.3	52.8	

Date	Air Temperature Max. (°C)	Air Temperature Min. (°C)	Solar Radiation (Langeleys)	Soil Temperature Max. (°C)	Soil Temperature Min. (°C)	Relative Humidity (%)	Precip. (cm)
5/27	30.8	17.2	661.9	28.9	19.3	50.9	
5/28	31.5	17.4	527.1	27.9	20.5	54.8	
5/29	30.2	18.2	466.6	27.6	20.9	65.8	
5/30	30.3	19.1	576.1	28.8	20.9	63.7	
5/31	31.9	17.3	379.4	27.9	21.8	72.6	
6/ 1	26.9	16.5	347.0	24.6	20.1	81.2	1.2
6/ 2	27.3	16.4	510.8	25.1	19.5	76.4	
6/ 3	30.3	20.1	422.7	26.8	21.5	65.8	
6/ 4	28.6	15.4	649.1	29.4	20.5	57.9	
6/ 5	30.2	12.2	738.0	30.3	19.6	50.6	
6/ 6	32.1	11.1	729.0	31.0	20.1	52.0	
6/ 7	34.9	18.5	681.4	31.8	22.2	54.3	
6/ 8	35.1	20.7	708.0	32.5	24.1	59.0	
6/ 9	26.9	12.2	676.6	30.3	23.6	57.4	
6/10	30.9	7.8	750.0	31.3	20.0	44.9	
6/11	32.8	11.8	714.0	31.1	20.9	36.0	
6/12	34.9	17.4	668.4	31.9	22.5	36.8	
6/13	36.7	22.2	692.2	33.2	24.2	36.7	
6/14	34.2	19.9	477.6	30.1	24.4	64.9	
6/15	26.5	16.7	409.6	25.5	21.9	78.1	0.8
6/16	33.1	14.1	729.0	30.4	19.6	64.0	
6/17	33.9	18.4	590.0	31.1	22.0	59.4	
6/18	37.6	21.6	654.5	33.4	23.4	53.7	
6/19	41.4	25.3	672.2	34.4	25.4	41.7	
6/20	41.1	24.7	695.0	36.1	26.0	41.3	
6/21	41.1	24.9	698.1	35.6	26.9	34.5	
6/22	40.8	25.9	491.0	33.8	27.6	41.5	
6/23	41.1	23.3	694.4	36.1	26.6	36.4	
6/24	40.7	22.9	683.2	35.9	27.3	37.8	
6/25	42.1	24.2	645.2	35.9	27.7	41.9	

Date	Air Temperature Max. (°C)	Air Temperature Min. (°C)	Solar Radiation (Langeleys)	Soil Temperature Max. (°C)	Soil Temperature Min. (°C)	Relative Humidity (%)	Precip. (cm)
6/26	34.3	22.0	668.1	34.6	27.9	42.3	
6/27	34.1	18.9	719.0	34.9	26.4	39.7	
6/28	40.8	18.5	661.3	35.6	26.1	40.2	
6/29	37.7	21.9	431.2	33.1	26.9	72.1	5.6
6/30	25.5	16.7	227.3	26.8	22.9	89.4	
7/ 1	17.7	15.4	79.7	22.9	20.3	91.1	
7/ 2	19.7	15.0	143.8	21.9	19.7	89.5	
7/ 3	32.3	17.4	586.3	28.8	20.3	77.7	
7/ 4	36.4	19.7	637.7	30.7	22.4	67.6	
7/ 5	36.9	23.5	668.4	34.1	24.7	65.4	
7/ 6	37.2	23.8	583.4	34.2	26.2	62.4	
7/ 7	35.6	22.7	619.5	34.7	26.3	63.9	
7/ 8	35.3	21.9	352.5	31.2	26.6	75.2	
7/ 9	33.9	19.9	315.7	29.7	23.9	83.6	
7/10	29.3	19.2	489.1	28.7	22.9	82.4	
7/11	31.8	18.3	695.7	31.4	22.8	73.5	
7/12	34.4	19.5	673.5	33.1	23.9	73.2	12.0
7/13	39.1	23.6	675.6	35.2	25.3	61.6	
7/14	38.8	26.8	668.1	36.5	27.4	62.3	
7/15	38.9	20.6	604.6	36.6	27.8	64.9	3.0
7/16	35.9	21.4	593.1	32.8	25.6	75.6	
7/17	29.7	22.2	274.1	29.0	26.4	84.9	1.5
7/18	32.5	20.5	622.0	32.2	24.6	79.7	
7/19	26.0	18.4	254.5	27.7	23.6	86.8	
7/20	29.4	16.9	704.0	27.9	21.6	71.3	
7/21	29.7	13.1	706.0	29.9	20.7	63.9	
7/22	30.7	15.1	659.0	30.6	21.9	63.2	
7/23	33.8	18.3	670.8	32.2	23.2	65.1	
7/24	35.5	19.2	628.6	32.7	24.7	68.7	
7/25	32.4	18.1	643.6	32.4	26.1	65.3	

Date	Air Temperature Max. (°C)	Air Temperature Min. (°C)	Solar Radiation (Langeleys)	Soil Temperature Max. (°C)	Soil Temperature Min. (°C)	Relative Humidity (%)	Precip. (cm)
7/26	31.9	15.6	529.3	30.2	23.9	63.1	
7/27	35.6	14.6	679.0	32.4	23.1	64.5	
7/28	32.9	18.2	510.7	30.9	24.6	74.1	
7/29	34.6	20.9	427.3	29.5	25.1	71.8	
7/30	40.2	23.3	625.8	33.5	25.3	56.6	
7/31	39.7	24.1	626.4	33.5	26.1	50.9	
8/ 1	37.5	24.2	633.5	33.7	26.7	50.4	
8/ 2	36.7	24.5	631.7	34.2	27.1	57.3	
8/ 3	38.4	24.4	588.3	34.2	27.4	55.3	
8/ 4	33.3	22.2	387.9	31.6	27.9	69.1	
8/ 5	33.9	18.9	672.0	33.3	26.0	59.4	
8/ 6	37.6	16.4	583.7	33.9	25.2	63.6	
8/ 7	40.5	24.2	601.2	34.9	27.5	54.1	
8/ 8	37.7	22.4	456.9	32.9	28.4	59.0	1.0
8/ 9	31.7	21.7	357.6	30.5	27.0	80.9	
8/10	38.3	19.3	561.4	33.3	24.9	67.1	
8/11	38.5	24.0	617.0	34.9	26.8	60.8	
8/12	32.8	21.6	394.7	32.2	27.4	74.0	
8/13	34.4	19.5	330.4	29.9	24.9	79.2	1.0
8/14	38.9	23.4	636.8	32.9	25.6	67.9	
8/15	39.6	25.5	613.4	34.2	26.4	59.2	
8/16	38.3	23.9	609.1	34.6	26.8	55.1	
8/17	39.3	23.5	585.3	34.5	26.8	52.6	
8/18	36.4	23.7	422.6	32.2	27.3	64.3	

SOIL TEST RESULTS

Soil	pH	Phosphorus lb/A	Potassium lb/A	Organic Matter %	Soluble Salts mmhos/cm
Field					
Amended	7.9	58	440	1.2	0.80
Unamended	7.9	53	440	0.8	0.83
Greenhouse, 121 Liter Containers					
11-day Schedule					
Amended	7.9	49	680	3.6	1.5
Unamended	7.9	63	740	2.0	1.6
22-day Schedule					
Amended	.	.	.	.	.
Unamended	7.9	59	700	2.0	1.4
Greenhouse, 3.78 Liter Containers					
3-day Schedule					
Amended	7.8	51	720	4.2	1.0
Unamended	8.2	50	700	1.8	0.61
6-day Schedule					
Amended	7.8	67	860	4.4	3.1
Unamended	8.1	51	700	1.6	0.83

APPENDIX V

ANALYSIS OF VARIANCE TABLES

FOR CHAPTER II

GROWTH AND WATER RELATIONS OF WHITE OAK SEEDLINGS
TRANSPLANTED INTO 121 L CONTAINERS --
GREENHOUSE STUDY

Table No.	Variable	Source	DF	Mean Square	PR>F	PR>F*
II-1	Soil	Block	3	0.2350	0.0714	0.0650
	Water	Soil	1	0.2531	0.0873	
	Potential	Irrigation	1	0.1824	0.1356	
	30 cm	Interaction	1	0.0048	0.7920	
II-1	Soil	Block	3	0.0073	0.2479	0.1835
	Water	Soil	1	0.0008	0.6857	
	Content	Irrigation	1	0.0184	0.0723	
	15 cm	Interation	1	0.0099	0.1698	
II-1	Soil	Block	2	0.0127	0.2950	0.4553
	Water	Soil	1	0.0006	0.6972	
	Content	Irrigation	1	0.0009	0.6479	
	30 cm	Interation	1	0.0006	0.7091	
II-1	Soil	Block	2	0.0045	0.2130	0.2677
	Water	Soil	1	0.0013	0.3276	
	Content	Irrigation	1	0.0025	0.2502	
	45 cm	Interation	1	0.0000	0.8710	

*Overall test of significance for all 4 treatments, using SAS GLM, Version 5.

Table No.	Variable	Source	DF	Mean Square	PR>F	PR>F*
II-2	Leaf Water	Block	3	27.65	0.3146	0.0479
	Potential	Soil	1	71.61	0.0964	
		Irrigation	1	177.58	0.0193	
		Interaction	1	36.51	0.2198	
II-2	Osmotic	Block	3	37.93	0.1917	0.0168
	Potential	Soil	1	13.52	0.4179	
		Irrigation	1	343.08	0.0034	
		Interaction	1	104.22	0.0482	
II-3	Caliper	Block	3	5.10	0.1038	0.0696
		Soil	1	14.03	0.0237	
		Irrigation	1	0.54	0.5893	
		Interation	1	0.04	0.8822	
II-3	Shoot	Block	3	166.39	0.3566	0.4518
	Growth	Soil	1	4.47	0.8588	
		Irrigation	1	266.09	0.1974	
		Interaction	1	87.21	0.4417	
II-3	Total	Block	3	543.05	0.6567	0.5342
	Height	Soil	1	521.22	0.4864	
		Irrigation	1	1611.01	0.2375	
		Interaction	1	776.23	0.3997	
II-3	Stem	Block	3	684.51	0.4249	0.3672
	Dry Weight	Soil	1	838.97	0.2920	
		Irrigation	1	20.31	0.8643	
		Interaction	1	1119.11	0.2296	

*Overall test of significance for all 4 treatments using SAS GLM, Version 5.

Table No.	Variable	Source	DF	Mean Square	PR>F	PR>F*
II-3	Total Stem Dry Weight	Block	3	1412.89	0.3446	0.4555
		Soil	1	207.75	0.6739	
		Irrigation	1	186.66	0.6898	
		Interaction	1	1870.25	0.2293	
II-4	Leaf Dry Weight	Block	3	117.62	0.4831	0.4276
		Soil	1	353.51	0.1421	
		Irrigation	1	508.69	0.0876	
		Interaction	1	8.13	0.8091	
II-4	Leaf Area	Block	3	5871232.70	0.0416	0.0881
		Soil	1	2319496.27	0.2140	
		Irrigation	1	4329146.60	0.1041	
		Interaction	1	4209957.09	0.1081	
II-4	Leaf Number	Block	3	1873.71	0.5785	0.4415
		Soil	1	4176.05	0.2501	
		Irrigation	1	328.05	0.7356	
		Interaction	1	4551.01	0.2319	
II-5	New Root Length	Block	3	2268.51	0.8725	0.5591
		Soil	1	22950.31	0.1708	
		Irrigation	1	37627.81	0.0916	
		Interaction	1	17.63	0.9674	
II-5	New Root Dry Weight	Block	3	0.01	0.7694	0.1366
		Soil	1	0.07	0.0759	
		Irrigation	1	0.17	0.0142	
		Interaction	1	0.02	0.3060	

*Overall test of significance for all 4 treatments, using SAS GLM, Version 5.

Table No.	Variable	Source	DF	Mean Square	PR>F	PR>F*
II-5	Root Dry Weight	Block	3	219.04	0.9153	0.7730
		Soil	1	2820.79	0.1860	
		Irrigation	1	361.59	0.6158	
		Interaction	1	610.11	0.5172	
II-5	Total Root Dry Weight	Block	3	499.66	0.9358	0.7630
		Soil	1	6093.37	0.2396	
		Irrigation	1	1936.41	0.4922	
		Interaction	1	1454.64	0.5499	

*Overall test of significance for all 4 treatments, using SAS GLM, Version 5.

ANALYSIS OF VARIANCE RESULTS

FOR CHAPTER III

RESPONSE OF RED AND WHITE OAK TREES TO PEAT-AMENDED BACKFILL WHEN PLANTED IN THE FIELD

White Oak Trees

Table No.	Variable	DF	Mean Square	Pr>F
III-1	Soil Water Content	1	0.000	0.5626
	Soil Water Potential	1	0.120	0.0002
III-2	Leaf Water Potential	1	0.282	0.9123
	Osmotic Potential	1	16.340	0.3426
III-3	Total Height	1	377.440	0.0186
	Shoot Growth	1	258.540	0.0900
	Stem Dry Weight	1	1075.410	0.2372
	Total Stem Dry Weight	1	2450.740	0.2180
	Caliper	1	0.001	0.9841
	Leaf Number	1	11532.000	0.1532

Table No.	Variable	DF	Mean Square	Pr>F
	Leaf Dry Weight	1	279.27	0.2366
	Leaf Area	1	1937712.66	0.2471
	New Root Length	1	529.47	0.5843
	New Root Dry Weight	1	0.000	0.7200
	Root Dry Weight	1	2891.38	0.2686
	Total Root Dry Weight	1	2896.35	0.2685

Red Oak Trees

Table No.	Variable	DF	Mean Square	Pr>F
III-1	Soil Water Content	1	0.006	0.0193
	Soil Water Potential	1	0.015	0.0755
III-2	Leaf Water Potential	1	66.02	0.0800
	Osmotic Potential	1	14.29	0.1231
III-3	Total Height	1	695.64	0.0703
	Shoot Growth	1	479.97	0.0125
	Stem Dry Weight	1	4799.35	0.0599
	Total Stem Dry Weight	1	6410.39	0.0566

Table No.	Variable	DF	Mean Square	Pr>F
III-3	Caliper	1	0.082	0.9232
III-4	Leaf Number	1	2432.07	0.0813
	Leaf Dry Weight	1	116.37	0.4143
	Leaf Area	1	1242887.37	0.3724
III-5	New Root Length	1	601.67	0.6515
	New Root Dry Weight	1	0.003	0.2925
	Root Dry Weight	1	889.27	0.5411
	Total Root Dry Weight	1	897.45	0.5391

ANALYSIS OF VARIANCE RESULTS

FOR APPENDIX II

GROWTH AND WATER RELATIONS
OF CONTAINERIZED 15 CM WHITE OAK
SEEDLINGS TRANSPLANTED INTO PEAT BACKFILL --
GREENHOUSE STUDY

Variable	Source	DF	Mean Square	PR>F	Overall PR>F*
Soil	Block	19	0.025	0.0091	0.0001
Water	Soil	1	0.821	0.0001	
Content	Water	1	0.318	0.0001	
	Interaction	1	0.034	0.0915	
Leaf Water	Block	19	181.24	0.0221	0.0329
Potential	Soil	1	32.50	0.5617	
	Water	1	187.37	0.1651	
	Interaction	1	50.31	0.4705	
Osmotic	Block	19	745.57	0.0001	0.0001
Potential	Soil	1	65.02	0.4693	
	Water	1	224.57	0.1800	
	Interaction	1	5.54	0.8326	
Total	Block	19	76.33	0.3855	0.0001
Height	Soil	1	3981.27	0.0001	
	Water	1	121.11	0.1941	
	Interaction	1	0.38	0.9417	

*Overall test of significance for all 4 treatments using SAS GLM, Version 5.

Variable	Source	DF	Mean Square	PR>F	PR>F*
Shoot Growth	Block	19	40.20	0.1684	0.1718
	Soil	1	94.81	0.0773	
	Water	1	0.004	0.9903	
	Interaction	1	0.415	0.9063	
Shoot Dry Weight	Block	19	6.98	0.0996	0.0001
	Soil	1	217.27	0.0001	
	Water	1	29.87	0.0127	
	Interaction	1	0.99	0.6463	
Caliper	Block	19	3.12	0.2027	0.0001
	Soil	1	128.55	0.0001	
	Water	1	6.99	0.0919	
	Interaction	1	0.37	0.6962	
New Root Length	Block	19	21631.87	0.0597	0.0038
	Soil	1	2848.82	0.6437	
	Water	1	217061.74	0.0001	
	Interaction	1	12.13	0.9759	
New Root Dry Weight	Block	19	0.097	0.0001	0.0001
	Soil	1	0.011	0.4014	
	Water	1	0.139	0.0036	
	Interaction	1	0.017	0.3027	
Root Dry Weight	Block	19	48.13	0.0732	0.0006
	Soil	1	374.07	0.0007	
	Water	1	271.94	0.0034	
	Interaction	1	143.78	0.0319	

*Overall test of significance for all 4 treatments using SAS GLM, Version 5.

Variable	Source	DF	Mean Square	PR>F	PR>F*
Total Root	Block	19	47.84	0.0846	0.0007
Dry Weight	Soil	1	376.34	0.0007	
	Water	1	280.65	0.0032	
	Interaction	1	144.63	0.0329	

*Overall test of significance for all 4 treatments using SAS GLM, Version 5.

WATER RELATIONS AND GROWTH OF *QUERCUS ALBA* L. AND *QUERCUS RUBRA* L. TRANSPLANTED WITH A PEAT-AMENDED BACKFILL

by

Marilyn K. Rogers

B. S., Kansas State University, 1980

AN ABSTRACT OF A THESIS

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1989

These studies were designed to explore how one planting method, the use of organic matter in backfill soil, alters growth and water relations of two species, *Quercus alba* L., white oak, and *Quercus rubra* L., red oak.

White oak whips were planted in the greenhouse in 121 liter containers and grown in either a soil or a three : one soil/sphagnum peat (v:v) mix and were irrigated on either an eleven or a twenty-two day schedule. Trees were harvested after four months. Leaf water potential, osmotic potential, total height, shoot growth, caliper, leaf area, length of new roots, root and shoot dry weights, and soil water content and potential were measured.

Peat amendment produced little change in white oak growth. Caliper was the only variable significantly increased by the addition of peat. The addition of peat reduced soil water potential. Leaf water potential was slightly decreased in peat-amended trees. Osmotic potential was lower in trees watered every twenty-two days. Considerable variation in raw data, obscured significance of results and meaningful interpretation.

A concurrent field study monitored 1.8 m red oak and 1.2 m white oak whips transplanted with either a loam or a soil : 25% sphagnum peat (v:v) backfill. Trees were harvested after 130 days, and growth and water status readings, as above, were measured.

There was little difference in soil water content between soil treatments for white oak. Soil water potential was significantly lower in peat-amended soils. Leaf water potential and osmotic potential were not significantly different. Peat-amended white oak had significantly increased shoot growth, total height and larger total stem dry weight, leaf number, leaf dry weight, leaf area, and total root dry weight. There was no difference in caliper between treatments. New root length and new root dry weight were the only variables reduced by peat amendment for white oak, though these were not significantly different.

Soil water content of peat-amended soils was significantly greater for red oak. Soil water potentials were also lowered. Leaf water potentials were significantly higher in peat-amended red oak. All red oak growth parameters were reduced in peat-amended soil; total height, shoot growth, total stem dry weight and leaf number were significantly decreased.

Rather than being an indication of good water status, peat-amended red oak's high soil water content may reflect stress-induced stomatal closure which stopped water uptake but allowed leaf water potential to remain high. Reasons for this stress were not explored in this study.