THE PHYSIOLOGICAL EFFECT OF NURSERY WATER MANAGEMENT ON THE DROUGHT TOLERANCE OF LOBLOLLY PINE

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CHAPTER I

INTRODUCTION

The southern United States is a major timber-growing region, and many of its rural people are tree farmers. In fact, 70% of the southern forest land consists of small, private non-industrial ownerships. In addition, many southern forest industries, based on a variety of wood products, own vast areas devoted to tree plantations. The rebirth of the southern pine industry, which followed a period of readjustment after removal of the virgin forest, is due to the ability of the southern pines to produce wood in large volume on land unsuited to intensive agriculture. The timber type occupies about 60% of the total area of the southern United States, and 55% of the timber volume is pine (28). Timber is replacing annual crops as a result of land acquisition programs of forest industry.

Loblolly pine (*Pinus taeda* L.) is the most important softwood species in the southern pine region. It occurs throughout the entire southern and southeastern United States, with the exception of the lower part of Florida, and extends from Delaware to Texas (Figure 1). It is now considered to be the leading commercial timber species in the region (133), commonly forming a medium to large-sized tree 34 to 37 m in

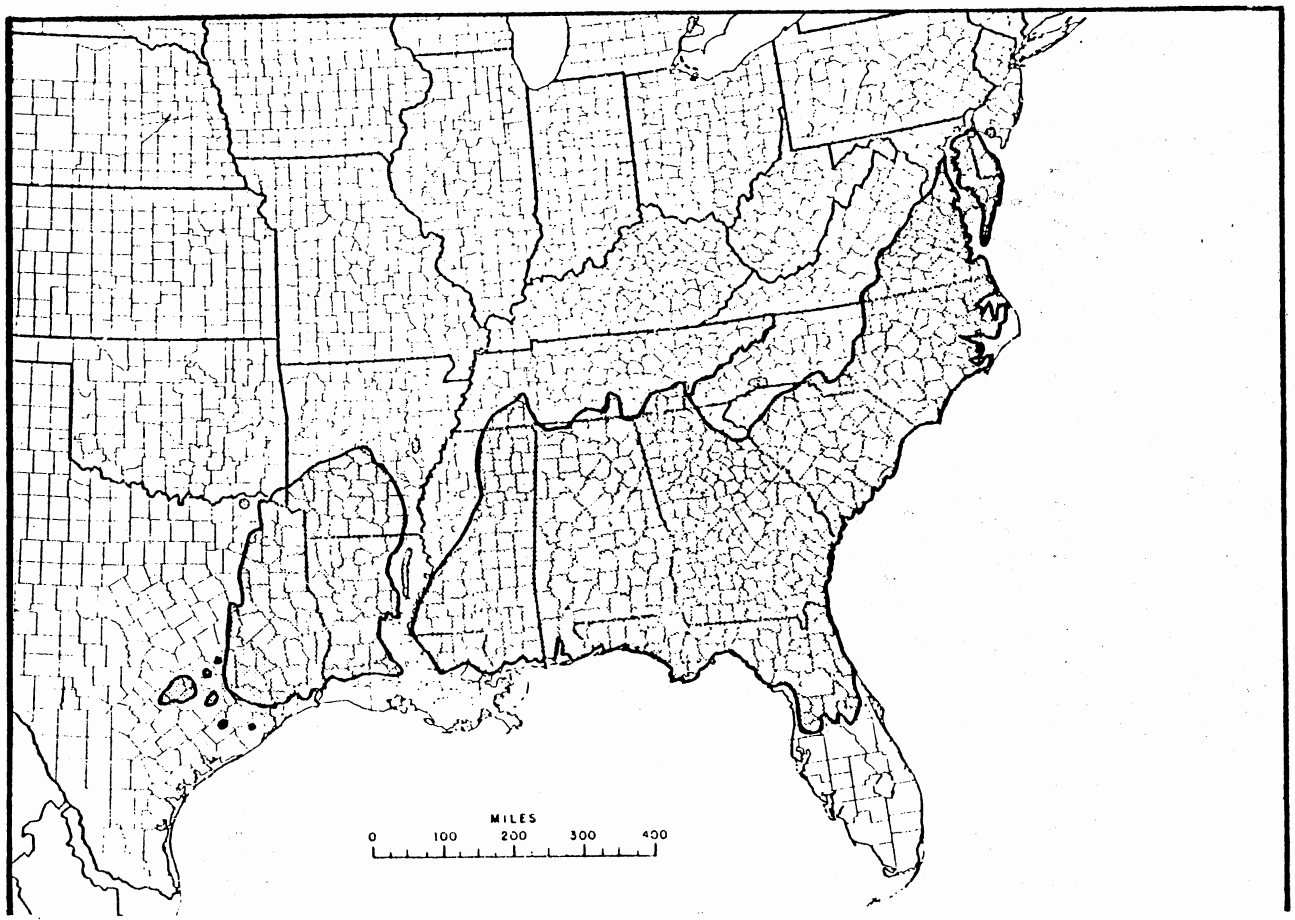

Figure 1. Natural Range of Loblolly Pine, *Pinus taeda* L.

height and 0.6 to 1.2 m in diameter (max 61 x 1.5 m or more). The species makes rapid growth on a variety of soils, especially on old fields, where the growth of young trees frequently averages 1 m in height and 2 cm in diameter per year (43). The wood is valued for pulp and structural materials (22). Loblolly pine, like slash (*Pinus elliottii* Engelm, long-leaf (*Pinus palustris* Mill), and shortleaf (*P. echinata* Mill) pines, occurred in large volume in nearly pure stands over large areas in virgin forests and, as such, were of paramount importance to industry (28). Composing slightly over half the total pine volume, loblolly pine is concentrated in well-defined population centers rather than spread uniformly over areas of similar soil, rainfall, and temperature (Figure 2). In the northern part of the Atlantic coastal plain, an area of large wood volume, high temperatures and rainfall coincide, but in Texas, another center of concentrated wood volume, high temperatures occur during a period of low rainfall. In the East, volume is high along the Atlantic coast in South Carolina, North Carolina, and Virginia (82, 28). In North Carolina, fast-growing tree races evolve in mild climates, while slower-growing but more hardy races evolve in colder or drier climates (135). Thus, climatographs indicate quite strong differences in climate throughout the range of loblolly pine (132).

The wide range in temperature, length of growing season, and variation in the pattern of seasonal rainfall may exert quite strong influences in the development of racial strains

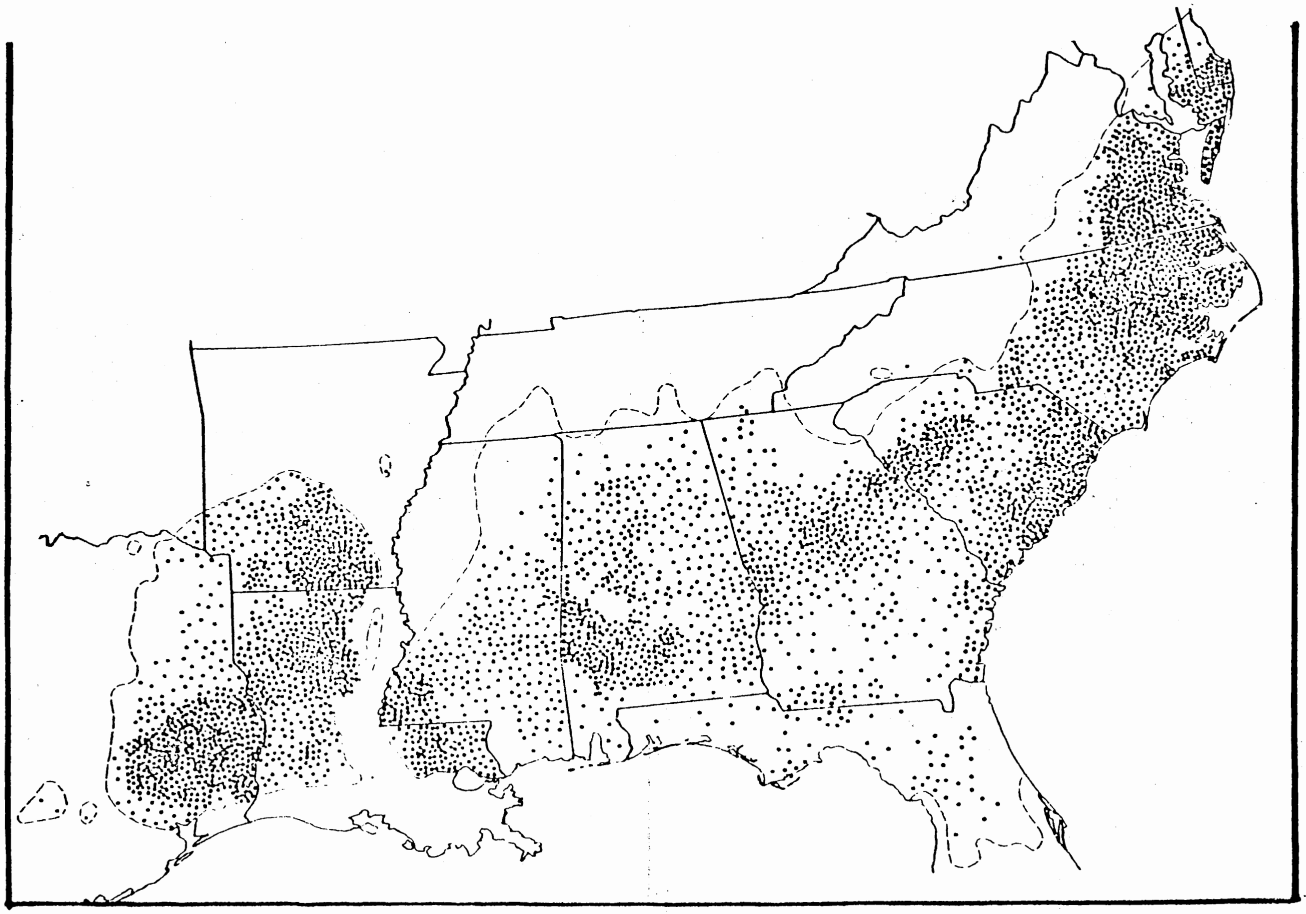

Figure 2. Wood Volume for Loblolly Pine, *Pinus taeda L.* Each dot represents an average of 5,000,000 cubic feet.

over the entire range of loblolly pine (19). For example, a range-wide system of loblolly pine seed source plantings has shown inherent variations in growth rate (135). The western population is slower-growing, more rust-resistant, and more drought-resistant than the eastern loblolly population, whereas Coastal Plain populations are faster growing. The differences in growth rate associated with these major physiographic and climatic effects are persisting as the test nears timber-rotation age but the smaller growth-rate differences within physiographic regions are less stable.

Loblolly pine grows on a very wide variety of soils, but does best in wet clays, swampy soils, and in moist depressions, locally called "loblollies," hence the name of the species (22). It will tolerate droughty soils only moderately well (139). However, even on the relatively drier soils of the Piedmont and inland areas, pure stands develop. Because it occurs on sites which are often moderately dry, the species is more tolerant of moisture-stress than longleaf and slash pines (43).

In Oklahoma, with a land area of over 17.6 million hectares, the variance in precipitation and elevation results in a diverse set of conditions to those interested in her forests (30). Half of the forest, which represents 24% of the state's area, is considered "commercial" forest land, capable of producing sustained yields of wood products. The majority of this production is concentrated in the southern pine area in the eastern one-half of Oklahoma (30). Loblolly pine represents only 7% of the forest land (Figure 3), which is dominant in pine-oak and loblolly pine-sweet gum forests in the Coastal Plain area of southeastern Oklahoma, McCurtain County. It is also becoming common in plantations northward on various soils from flood plains to upland slopes (30).

In Oklahoma, as well as the surrounding "Sun Belt" states, the population is growing, and consumption and demand for wood products is increasing rapidly. In fact, over 20,000 hectares of woodland are being converted to other uses each year in Oklahoma. This had led to greater interest in establishing, caring for, and managing trees and shrubs to produce goods, services, and benefits for the people.

Two long-range solutions for producing more loblolly pine are: 1) to extend its original range toward the west, and 2) to control the proportion of shade-tolerant hardwoods which continually invade the pine stands (133). Another more immediate alternative is to introduce fast-growing seed sources of loblolly pine such as that found in the coastal area of North Carolina into Oklahoma. Because of its extensive natural range, studies in racial variation of loblolly have been attempted since 1928 (19). For instance, Wells (136) reported on a 25-year study of loblolly pine from different provenances tested in southern Arkansas. Most seed sources throughout the range appeared well adapted to the climate; only trees from near the Gulf Coast were obviously poorly adapted. Trees from Western seed sources were an average of 1.5 m shorter than the Eastern trees, and the

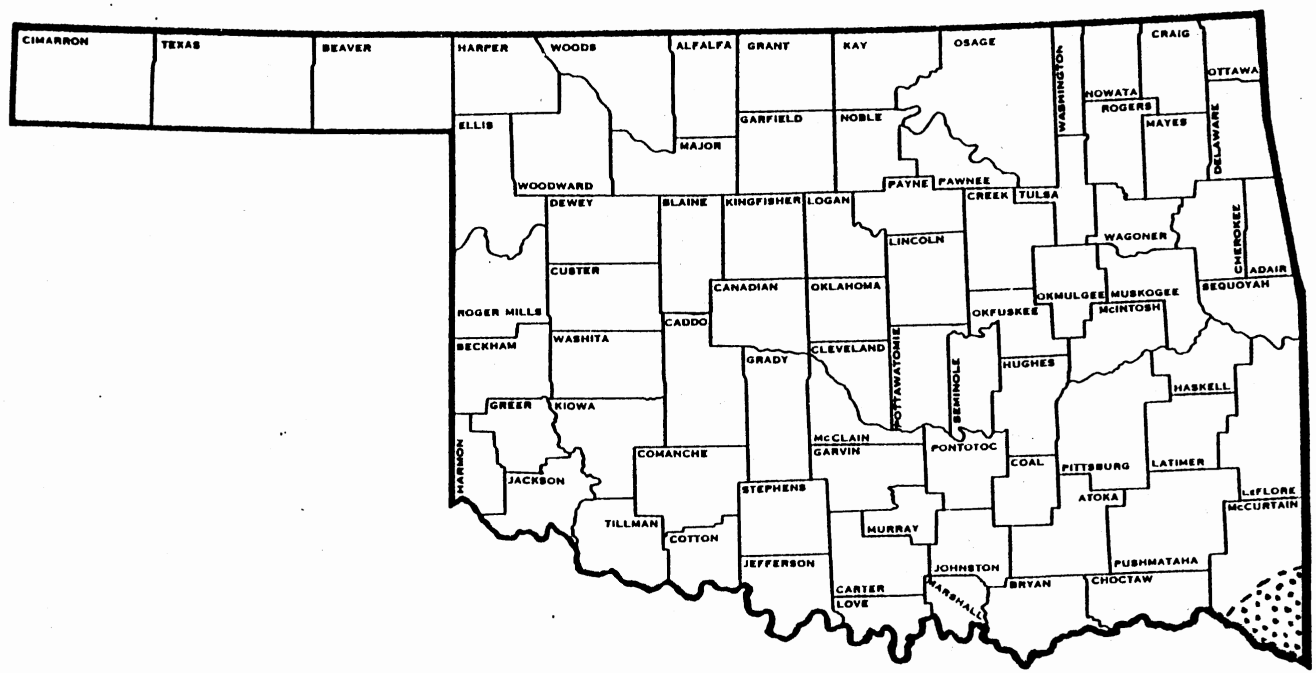

Figure 3. Natural Range of Loblolly Pine in Oklahoma

Oklahoma trees were the shortest, averaging 0.9 m shorter than the Arkansas trees. Trees from the Coastal Plain of South Carolina were the tallest after 25 years averaging about 3 m taller than those from Oklahoma. Nance et al. (87) estimated that Arkansas trees were about six years behind the fastest-growing Eastern trees in height growth when both were 25 years old, indicating the advantage of planting Eastern sources of loblolly pine in southern Arkansas. A potential gain of 1.6 m to 2.5 m in dominant-codominant height with consequent increases in volume and product value at age 25 are too attractive to be ignored. Similar results were reported by Cech et al. (19) from study of the plantings in Arkansas of seed from 36 geographic locations throughout the loblolly pine range. When evaluated after 10 years, both height and diameter were greater for trees from the southeastern Atlantic Coast; trees from South Carolina produced 30% more volume than local trees.

While it would appear that there are large potential growth gains to be realized by transferring seed sources of Loblolly pine which grow rapidly in the eastern United States into areas such as Oklahoma and Arkansas, the principal limitation is the degree of drought adaptation required for survival in the more dessicating environment found in the western range of the species. Because of the difference in the pattern of seasonal rainfall across the range of Loblolly pine, it is likely that different races have evolved with different physiological and morphological characteristics, particularly with respect to factors influencing their water relations.

The purpose of this study was to characterize the physiological response of two wide-ranging families of loblolly pine (coastal North Carolina vs. McCurtain County, Oklahoma) when grown under different moisture environments in the nursery. It is known that numerous opportunities exist within nursery management to tailor seedling morphology and physiology to provide for greater reforestation success on target sites. One important physiological characteristic which may be influenced by the irrigation regime involves induced changes in seedling turgor maintenance capacity, or the ability to maintain adequate turgor as plant water potential drops. Selection for this characteristic may be particularly valuable when wide-ranging seed sources are to be planted on soils subjected to seasonal moisture deficits.

In this study, loblolly pine seedlings native to coastal North Carolina and southeastern Oklahoma were selectively irrigated in the nursery, and the in-plant response to the water treatments were monitored periodically over one growing season using the pressure-volume method. Following lifting, seedlings were grown in soil at two temperatures ($10^{o}C$ and $25^{o}C$) in growth chambers, and root numbers were sampled at 15, 25 and 35 days to observe the relationship between induced osmotic adjustment in the nursery and subsequent root regeneration potential.

CHAPTER II

LITERATURE REVIEW

Global Perspective

Human distribution and the rapid expansion of the global population has taken place primarily in the more moist lands of the world. For example, only 14% of the world's population live in the dry lands, and of this group of about 630 million people, approximately 72% live in the semiarid zone, 27% in the arid zone, and only 1% in the extremely arid zone (112). However, more and more forest land is being converted either for construction or for agricultural purposes. Consequently, the improvement of the semiarid zone by introducing trees and the developing of forest stands is a major objective of researchers. For example, Garduno (35) stated that the problem of desertification is mainly caused by humanity through the faulty application of technology. He pointed out that control of desertification must give high priority to preventive techniques, and that afforestation, revegetation, pasture and crop rotation, and the use of drought-resistant plants are significant factors in increasing productivity.

With the increase in the world population, the need to develop and manage wisely the semiarid and arid zones of the globe for increased food and wood fiber production demands better knowledge about the nature of water stress and of ways of changing its harmful effects on production (114). The worldwide interest in water relations of plants is accentuated by increasing sensitivity to the seriousness of dwindling water supplies in many regions.

Plant-Water Relations

All forms of terrestrial life are dependent upon their ability to extract water from their environment and to hold it above certain free energy levels within the cells in order that life processes be sustained at rates proportional with survival. Plants are immobile and unable to escape the demands of their immediate environment (131).

About one-third of the world's potentially arable land suffers from an inadequate supply of water, and for the remainder, crop yields are periodically reduced by drought (128). Plant water deficits affect every aspect of plant growth (55) and the worldwide losses in yield from water stress probably exceed the losses from all other causes combined (128).

Over 50% of the total fresh weight of a tree consists of water, but the water concentration varies widely in different parts of a tree and with species, age, site, and season (70).

Plant water status is determined by the rate of exchange of water between soil and atmosphere through plants. The effects of water deficits produced by drought or other causes are just as important to the growth of forest, fruit, and ornamental trees as for annual herbaceous crop plants. However, the capacity to survive drought depends on a variety of phenological, morphological, and physiological factors. Farmers and foresters as well as ecologists and physiologists know that trees of some species survive drought with less injury than those of other species (93). In fact, under some conditions, moderate water stress can improve the quality of plant products even though it reduces vegetative growth (99). Furthermore, the quality of apples, pears, peaches, and plums is improved by water stress, and the oil content of olives is said to be increased, although it is probable that the total yield is decreased (32). It is also claimed that the alkaloid content for several drug plants is increased by water stress. In turn, growth may be limited by the water stress occurring every day during summer (98). The dependence of growth on turgor suggests that the optimum water potential (ψw) for growth and the maximum ψw are identical at 0 bars. This expectation is supported by direct measurements of the growth of buds of sugar cane (115) and by the increased growth of peas when field capacity is maintained daily (96). The importance of recognizing and accounting for phenological development in plants in relation to ecological studies has been emphasized by Lieth (77). Phenological studies delimit periods of the year and developmental stages of plants during which environmental stresses such as water deficits are most or least critical. Kramer (69) stated that it is impossible to predict what level of soil-moisture stress will limit plant growth unless atmospheric conditions, the kind of plant, and its stage of growth are known. Theoretically, any change in soil moisture tension of one or two bars should inhibit plant growth, as postulated by Kramer and Kozlowski (67). The effect of drought on plant growth and yield results from the closure of stomata and a reduction in cell enlargement. These physiological processes can reduce the leaf area and limit photosynthesis (128) particularly during seedling establishment (1, 8). Kramer (68) stated that internal water deficits can be the result of excessive transpiration or slow absorption from dry, cold, or poorly aerated soil or, more commonly, a combination of these factors.

However, plants have three basic means for controlling internal water deficits: absorption, transpiration, and internal redistribution of water. Plants control water loss primarily by stomatal regulation (73) and according to Evenari et al. (31), in dry environmental conditions plants must have certain adaptive features or be able to acclimatize to water stress. The main adaptive features of plants which maintain metabolic activity through drought are: a tendency to develop xeromorphic structures, a high root-to-shoot ratio, a reduction of metabolically active surface, the capacity to tolerate high soil water stress, the reduction of the transpiration rate through morphological and anatomical changes, sensitive stomatal regulations as a function of ambient conditions, and adaption of gas exchange mechanisms to high temperatures. It has been documented that the quality and the quantity of growth made by plants depends on interactions between their hereditary potential and the environment in which they are growing. Many problems facing foresters require evaluation of the relative importance of various factors of the environment and identification of the physiological processes through which they affect growth (71). Furthermore, the ability to adjust to the environment is one of the most important but perplexing attributes of plant behavior. It is important because this adjustment permits plants to colonize diverse environments, which has immense practical significance. It is perplexing because of the plasticity and variability of plant response (128). Cultural practices generally attempt to improve the environment for tree growth, and they are effective only if they increase the overall efficiency of the physiological processes that control vegetative and reproductive growth (71). Physiologists interested in control mechanisms have been the first to run into the problem of developing useful concepts that integrate the various constituent levels of understanding into a hierarchical systems model that accurately portrays the functional system comprising a plant in its environment (114). The understanding of the general response of crop plants to stress from the environment becomes more and more a subject of interest in the concept of stress physiology (123).

Plant-Water Stress

The importance and possible ecological significance of plant water potential (ψw) was recognized early, notably by Hofler (53) who hypothesized the relationship between water availability in different habitats and the response of the turgor (ψp) and osmotic ($\psi \pi$) component potentials to changes in tissue water content in plants occupying such habitats. With most crop plants, the maintenance of function, and ultimately of survival, depends upon the maintenance of a relatively high water content of the protoplasm. During periods of water deficit the amount of water lost depends on the way in which the cells respond to a reduction in the water potential (85).

Plants require high tissue water potentials for rapid growth. In soybeans, leaf enlargement was reduced to 25% of the controls when leaf water potential declined 2 bars (8). Similar responses have been found in corn and sunflower leaves. A mild degree of water stress affects many plant constituents and processes. Cell enlargement is one of the most important of these processes and is also one of the most sensitive to a change in plant water status (55). A reduction in cell water potential of only three to four bars can completely stop cell expansion (8). Despite this, cell expansion must occur in leaves at the tops of tall trees and in plants growing in saline conditions, two situations where high water potentials are never recorded. These two observations may be reconciled in the knowledge that it is the level of turgor rather than water potential that is critical for continued cell enlargement, and that the primary effect of mild stress on growth is purely lack of the physical force necessary for cell expansion (9). The ability of a plant to grow satisfactorily when exposed to periods of water stress is called drought resistance (79). Drought resistance can take the form of either avoidance or tolerance (such as an osmotic adjustment) of severe levels of stress. Overall, drought resistance refers to the ability of a plant to complete its life cycle even though its growth is limited by an inadequate supply of water or by an inability to conduct water to its leaves quickly enough to satisfy a high evaporative demand (91). The two critical areas with respect to water flow through the soil-plant-atmosphere continuum are the soil-root and the leaf-air interfaces. It is reasonable to suppose that adaptations to drought have developed in roots, as they have in leaves and stems (76).

Heth (48) found that Pinus taeda L. survived at water potentials of nearly -40 bars, but Hall (39) observed that cowpea (Vigna unguiculata (L) Savi) died at -12 to -13 bars even under field conditions. A soil water potential of -10 bars may be considered a mild drought for woody species but a devastating treatment for herbaceous plants (64).

Plotting the relationship between the inverse of pressure (1/p)or 1/water potential and relative water content (RWC) in examining tissue water relations (7, 100, 129) has provided considerable evidence regarding the relationship between water potential and the relative water content. In studies on *Vicia faba* L (62, 63), the relationship between relative water content and water potential was found to depend upon the osmotic potential and relative water content at zero turgor and a coefficient of enlargement, all of which respond to both age and environmental condition. Numerous studies indicate that species differences exist, both for the RWC - ψw curve and in the RWC at zero turgor. Wilted sorghum plants have been found to have a leaf water potential of -16 bars and RWC of 55%, while values for wilted corn were -13 bars and 71% (108). Many techniques have been tried, ranging from simple pot experiments when water was withheld (92, 95) to extensive irrigation experiments in an arid or semiarid environment when water was applied or withheld at various stages of the life cycle of the plant (6, 61), to solve the aspect of the ever-present problem of fitting different plant species to different sites. This is especially important in the seedling stage, which is the most sensitive to site conditions. Consequently, a knowledge of seedling behavior is an essential part of the information needed to judge the suitability of a site for the species in question (135).

Evolution of Methodology

Plant growth is a turgor-dependent process. Therefore, a plant's ability to maintain positive cell turgor over a wide range of water potentials (turgor maintenance capacity) is a key to adaptation to water-related stresses (102).

According to the theoretical work of Tyree and Hammel (129) and others, the quantification of relationships between the RWC, ψw, $\psi \pi$, and ψp of plant tissues has become possible by using the pressure chamber and an analytical balance. The pressure chamber technique can be used to predict responses of different plant tissues and plant types to drought, transplanting shock, cold dessication, and other water-related stresses (102) and the evaluation of these effects on various species, stock types, clones, etc. as well as their comparative abilities to survive and perform under such stress. Additionally, the chamber can be used to ascertain the impacts of certain cultural practices, e.g., wrenching, transplanting, undercutting, watering, on various key seedling physiological characteristics (101). This greatly expanded use of the pressure chamber to estimate water potential components represents a major development in plant eco-physiological research methodology (45). Scholander, Hammel, and colleagues (101) demonstrated that a pressure chamber could be used to derive a so-called "pressure volume" (P-V) curve. Later verification by Tyree and Hammel (129) provided a theoretical framework for this method and confirmed its validity, subsequently leading to its increased use as a tool for studying plant-water relations of many species (45, 106, 129). The pressure chamber has become the standard technique for assessing plant water status in the field. It is reliable, repeatable, and rapid in measurement (101). For instance, an obvious cultural application of the pressure chamber technique is the development and implementation of effective irrigation programs for agricultural plants and woody seedlings in the nursery. The determination of the timing of irrigation (65, 42, 40, 49) and the effects of irrigation on plant processes (50, 11, 49) are two areas that seem directly susceptible to study.

The pressure-volume curve is the graphical representation of the results of a series of equilibrium pressure measurements performed on a sample of leaves within a pressure chamber (Figure 4). The P-V curve exhibits the characteristics of a two-phase relationship: an initial non-linear portion at low values of V_e (defined below), and a linear relationship at higher values of V_e. Tyree and Hammel (129) have proposed that the pressure volume curve can be described as: $1/P = (V_o - V_e)/[RTN - f(V)]$ (1) where P is the equilibrium bomb pressure, V_e is the associated volume of water expressed from the tissue, V_o is the turgid water volume for cells in the tissue, $V = V_o - V_e$ is the water-volume remaining in the cells, N is the total number of osmoles in all cells, T is the absolute temperature, and R is the gas constant. The term f(V) is an unspecified function of V representing the dependency of turgor pressure on cell volume, cell wall elasticity, and, additionally, on mechanical interactions between expanding or contracting neighboring cells (17, 16).

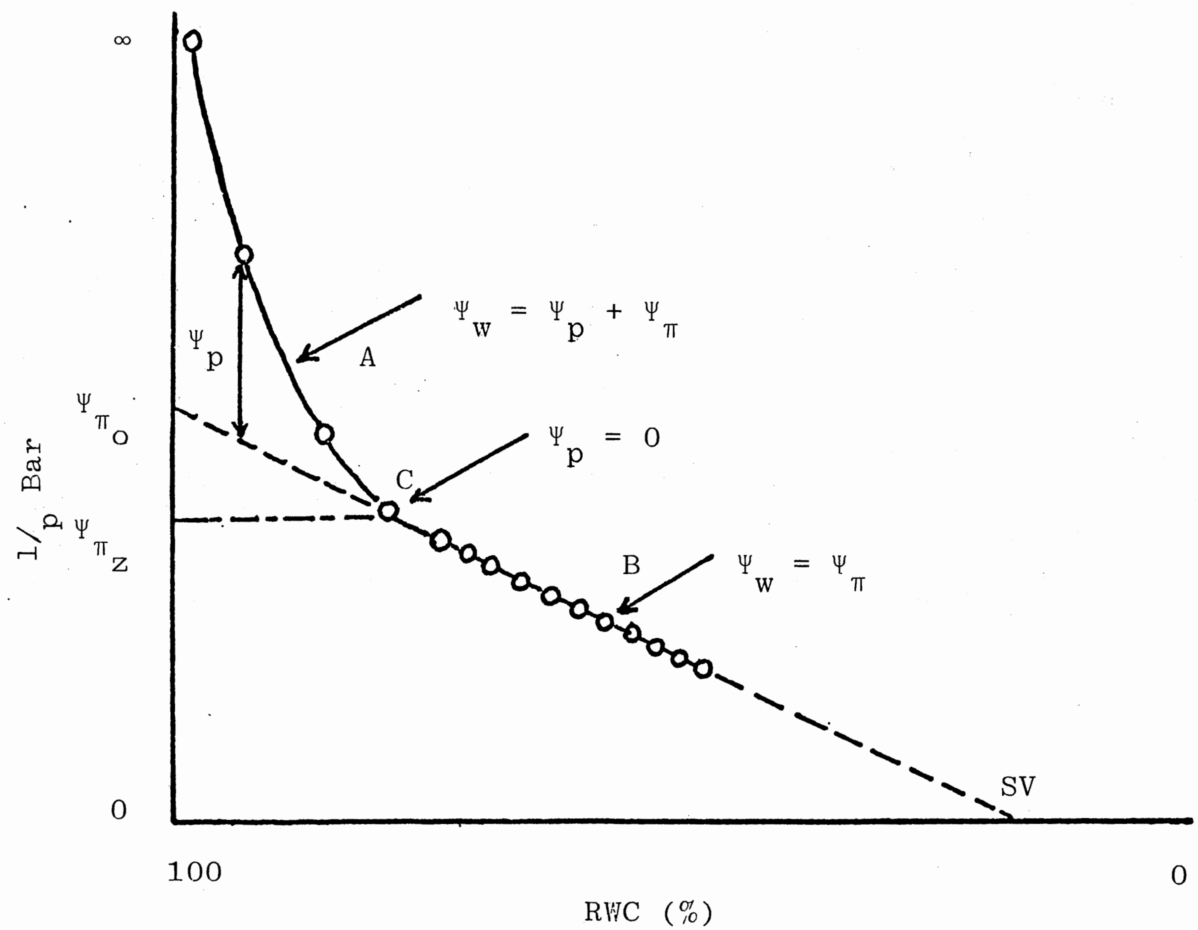

Figure 4. A Typical Pressure-Volume (P-V) Curve

According to the theory presented by Tyree and Hammel (129). the point "C" at which the P-V curve just becomes linear corresponds to the point of incipient plasmolysis when f(V) = 0. At larger volumes of V_e, therefore, the relationship between 1/P and V_e is a straight line with slope equal to -1/RTN and intercept V_o/RTN. The slope and intercept can be calculated by a least-squares fit to the points on the linear part of the curve. The relationship then gives the inverse of the osmotic potential and holds for any V_e over the interval $0 \leq V_e \leq V_o$. For low values of V_e when f(V) > 0, the difference between calculated osmotic potential and the equilibrium bomb-pressure can be taken as the turgor potential (129). V_o in equation (1), which represents the volume of tissue water available for exchange across membranes to affect osmotic potential, is commonly less than the total tissue water content. V_o may be thought of as the osmotically-operative water content. An assumption of the P-V method is that the volume of non-cellular water in the sample is small and remains relatively constant throughout the analysis (45).

Generation of P-V curves had been restricted to theoretical rather than eco-physiological studies because of the long sampling times involved and the lack of a coherent theoretical examination, until the work of Tyree and Hammel (129, 41). A pressure-volume curve contains all the information needed for estimates of solute potentials, mean water potential at incipient plasmolysis, bound water content, and relative osmotic adjustments as well as the xylem pressure potential of a plant (101).

The Osmotic Adjustment

The need for quantitative measurements of water stress was appreciated by ecologists and physiologists early in this century, but the only method available was to measure the osmotic potential of expressed sap (88, 141). However, by 1940 fewer measurements of osmotic potential were being made. One reason for this was the uncertainty about whether expressed sap provided a reliable sample. In addition, it was increasingly appreciated that water movement was controlled by differences in water potential rather than by differences in osmotic potential. In 1960, the thermocouple psychrometer became available, and shortly afterwards, the pressure chamber was introduced. The availability of equipment for measuring water potential may have led to overemphasis on this variable $\psi w = \psi\pi + \psi p$.

Water movement is controlled by the water potential and cell enlargement by the turgor pressure potential (128). Currently, there is increasing interest in the possibility that reduced turgor is the factor directly affecting metabolic processes in stressed plants (55, 128). Furthermore, there is strong interest in the importance of a decrease in the osmotic potential or "osmotic adjustment" as an adaptive mechanism to water stress. An osmotic adjustment in higher plants refers to the lowering of the osmotic potential arising from the net active accumulation of solutes in response to water deficits (128). The measure of the degree of osmotic adjustment is made at either full turgor ($\psi_{\pi o}$, when $\psi w = 0$, and $\psi p = \psi\pi$) or at zero turgor ($\psi_{\pi z}$, when $\psi p = 0$, and $\psi w = \psi\pi$). At full turgor the value is somewhat smaller than that at zero turgor (57). The osmotic adjustment takes place in the leaves (2, 24, 33, 58, 59), hypocotyls, stems (82, 81), roots (38, 111), and reproductive organs of several plant species resulting in full or partial turgor maintenance (82, 83). The adjustment comes from the effects of water deficits on the concentration of solutes, particularly sugars and free amino acids (44, 56). Potassium, sugars, and amino acids accounted for 60 to 100% of the osmotic adjustment observed in the apex and expanding leaves of wheat (86), whereas increases in chloride and carboxylic acids, in addition to potassium, sugars, and free amino acids, were needed to account for the osmotic adjustment in fully expanded sorghum leaves (60).

Many factors contribute to effect an osmotic adjustment, such as the rate of development of water stress (which has the major effect on the degree of osmotic adjustment), the degree of stress, the environmental conditions, and differences in species (128).

Osmotic adjustment is an important mechanism in the drought tolerance of plants (60) because the effect of stress on growth is a lack of the physical force necessary for cell expansion (9). It appears that even in mesophytes, osmotic adjustment may be an important mechanism for adaptation to water-limiting conditions (58, 84, 90). Its benefits allow the maintenance of cell elongation (80), maintenance of stomatal opening (5, 37), maintenance of photosynthesis, the survival of dehydration, and exploration of greater soil volume for water. However, the osmotic adjustment is limiting by its transcience; it doesn't fully maintain physiological and morphological processes, and it is finite.

Not all species or cultivars show evidence of osmotic adjustment. In many instances, the lack of osmotic adjustment is attributable to too rapid a rate of drying of the plant (128). A recent field study reported that for each 1-bar decrease in leaf water potential there is a change of 0.64 and 0.54 bar in osmotic potential when the midday leaf water potential decreased over a range of -12 to -22 bars in Sorghum bicolor L and sunflower (Helianthus annus L), respectively (126). Turner and Long (3) found that when the quantum flux density at the leaf level was 650 $uE/m^2/s$ the osmotic adjustment was only 3 bars, but it was 6 bars at a higher light level of 1300 $uE/m^2/s$. As water stress developed there was a decrease in the water potential at which a stomatal conductance of 0.17 cm/s was reached, as sorghum and sunflower plants adjusted osmotically (126). A similar result was obtained in Sitka spruce (Picea ritcheusis (Bong) carr) grown under different environmental conditions and with different osmotic potentials (3). Jones and Rauson (60) showed that sorghum plants allowed to dry slowly and adjust osmotically maintained a higher rate of photosynthesis at low leaf water potentials than sorghum plants in which little adjustment occurred.

The osmotic adjustment also allows root growth to continue in drying soils, as reported for wheat and maize (*Zea mays* L) (60). This enables a greater volume of soil to be explored or leads to a greater density of roots in a fixed volume of soil. However, studies by Wilson et al. (140) and Turner (126) showed that an osmotic adjustment of from 4 to 7 bars, measured at zero turgor, had disappeared within 10 days of stress in sunflower and sorghum. Furthermore, the degree of osmotic adjustment must be limited where plants are grown in restricted soil volume and when there is a limit to the available soil water (84, 85).

The ability of a plant to maintain adequate osmotic water content even at low water potentials would seemingly have adaptive value to a plant species which undergoes high water stress during its life cycle (20). However, under field conditions a plant may often experience a series of drying cycles, and it has been proposed that shoots will show an increased capacity for turgor maintenance as the water potential declines if they have previously been subjected to low water potentials (13, 23). This was reported, for instance, in Xerophytic *Acacia harpophyller* (mill) F, which has a naturally low sap osmotic potential. In addition, Tunstall (124) found that at the onset of the drying cycle, an elevated solute concentration in previously-stressed *Acacia phyllodes* (Mill) F resulted in turgor pressures up to 10 bars higher than in previously-unstressed *A. phyllodes*, over a 35-bar range of water potential.

Hellkuist et al. (45) examined pressure-volume curves from several Sitka spruce twigs at various times of the year. They found that the solute potential (osmotic potential) decreased with height, and from early to late summer. In addition, the mean water potential at incipient plasmolysis (the point at which turgor pressure becomes zero) was -21 bars in early summer and -33.7 bars in late summer. Sharp's (111) work indicated that in water-stressed plants older leaves may be acting as sources of solutes so that turgor may be maintained in the younger-growing parts of the plant.

Two aspects of solute accummulation should be distinguished. First, many species such as summer ephemerals, xeromorphic shrubs, and halophytes accumulate high concentrations of solute whether or not they are subject to stress, and they should be able to maintain turgor and normal cellular function at low tissue water potential. Second, other species with naturally low solute concentrations have the capacity to accumulate additional solutes in response to water stress and to achieve some measure of "osmotic adjustment" (60). On the other hand, conifers such as Douglas-fir seedlings photosynthesize actively during the winter while growth is negligible and respiration is very low, resulting in foliar sugar accumulation (47). Low temperature may prevent phloem transport of photoassimilates from the foliage, as observed by Watson (134) in _Picea sitchensis_ and _Abies procera_ Rehd. Low temperature may also promote hydrolysis of foliar starch to sugar. Therefore, the mid-winter osmotic adjustments in seedlings of Douglas fir would not appear to be a drought-tolerance strategy. Krueger (74) reported that low winter osmotic potentials may reflect the high foliage of sugar concentration that was implicated in the development of cold hardiness (78).

There are additional features involved in active solute accumulation, as seen in the osmoregulation by the elongating region of Soybean hypocotyls. Soybean (_Glycine max_ (L) Merr) seedlings osmoregulate when the supply of water is limited around the roots. Osmotic adjustment was reported to occur in the elongating region of the hypocotyls because solute utilization for growth decreased while solute uptake continued (81). Therefore, the factor controlling the osmotic adjustment was the balance between the rate of solute utilization and the rate of solute uptake.

Turgor Potential

Plant growth is a turgor-dependent process. Therefore, a plant's ability to maintain positive cell turgor over a wide range of water potentials (turgor maintenance capacity) is a key adaptation to water-related stress (102). Turgor pressure (ψp) is a very meaningful water-relations parameter, and it is improved by the lowering of the osmotic potential due to the interaction of the components as follows: $\psi w = \psi p + \psi\pi$. A tissue having low $\psi\pi$ will have high ψp at any value of ψw, so the $\psi_{\pi o}$ sets the upper limit to the turgor which can be developed (105). It is generally recognized that osmotic regulation is an effective means of turgor maintenance in plants subjected to water stress (90, 38). Furthermore, the ability to maintain adequate turgor as ψw decreases is an important adaptation to water deficits (57). And its maintenance during a change in plant water status should maintain the metabolic processes of the plant and aid in its growth and survival (55, 4). Either full or partial turgor maintenance results from the osmotic adjustment. For example, in a study to examine partial turgor maintenance in sorghum leaves, stressed plants were dried slowly over several weeks, whereas well-watered ones were dried quickly over several hours to minimize the degree of osmotic adjustment. Under water potential below -5 bars, the leaves of the slowly dried plants had higher turgor potentials at similar leaf water potentials compared with the leaves of the rapidly-dried plants (84, 58). This was supported by work reported by Meyer and Boyer (80). Likewise, in a study of wheat leaves, as the water potential decreased from -1 to -13 bars, type *Triticum dicoccum* L. showed full turgor maintenance, whereas type *T. aestrineum* L. showed no osmotic adjustment over the same range (84, 85). Turgor maintenance by osmotic adjustment has also been shown to occur in response to the daily changes in the water status of leaf tissue. Turner (125) observed a daily change in the osmotic potential of 6 bars in maize, and Weukert et al. (138) provided evidence of diurnal changes in the osmotic potential greater than that arising from dehydration alone, thereby at least partially maintaining turgor. The authors attributed the reduction in growth to an increase in the minimum turgor at which growth occurs as a result of dehydration, although this is contrary to experience with leaves that showed a decrease in the minimum turgor for growth and/or increase in the extensibility of the cell as a result of water stress (14). Diurnal curves from arid zone species tend to begin at low ψP values and gradually decrease throughout the day, recovering only slightly at night (101).

Root Regeneration Potential

Root systems show a high degree of morphological plasticity that enables them to cope with highly variable soil and root moisture conditions (76), and since water is the major limiting factor for plant growth in arid zones, it can be expected that root systems develop a way that tends to optimize absorption.

The root regeneration potential (RRP) is the potential of root systems of transplanted or outplanted nursery stock to initiate or elongate new roots (white) shortly after transplanting or outplanting (27). This ability to initiate or elongate white roots soon after transplanting is one of the most important attribute of seedling quality. The key to survival and establishment is the rapid resumption of water and mineral uptake. This depends on the rate of renewal of intimate soil-root contact by initiation and elongation of roots into the soil matrix. It was first reported by Stone (117) that tree seedlings vary widely in their ability to regenerate new roots after planting into an optimum environment and this ability depended upon their physiological status. This ability, called the root regeneration potential (104), is a key indicator that all systems in the seedling are functioning properly. High RRP is often correlated with high survival. Caldwell (18) has shown that the growth of roots in drying soil is important if the rate of uptake of water by plants is to be maintained. There is evidence to suggest that the ability of forest nursery stock to survive when planted is affected by its root growth capacity (26, 119, 107). Plantation failure immediately after planting is often attributed to low root regeneration, soil drought, or to a combination of these factors when the seedlings lack functional roots (21, 122). Stone and Jenkinson (122) showed that the root regenerating potential of ponderosa pine (*Pinus ponderosa* Laws) was very low in soils with moisture tensions of approximately 15 bars (the wilting coefficient), but was adequate in soils with moisture tensions of 2.5 bars or less. There is a relationship between the limitation of plant moisture stress and the root regenerating potential in the post-planting period. Thus, if roots are regenerated, water is absorbed and turgor remains high enough for further root regeneration and seedling establishment. If roots are not regenerated and intimate contact with soil is not achieved, the plant moisture stress rises and root initiation and extension becomes impossible (26). For example, the higher the root growth capacity of lodge pole pine nursery stock the higher will be its survival (15). But it should be noted that this conclusion does not imply that the survival of field-planted stock could not be predicted separately from its root growth capacity, because there are a number of factors such as weather, soil conditions, the method of planting, and the physiological condition of the stock that affect survival (15). The physiological behavior of Ponderosa pine seedlings when transplanted suggest that spring planting is more favorable than fall planting because the seedling can regenerate a new root system at a lower soil temperature in the spring than in the fall (119). Ponderosa pine is a relatively drought-tolerant conifer; perhaps this capacity for root growth in relatively dry soil is a contributing factor (118). For example, when the soil moisture was about 45 to 60% of capacity, the root growth for seedlings transplanted in December, January, and April was the same or greater than in soil with 100% available water (122).

The capacity for root growth on any particular planting date depends on the physiological condition of the seedling. A number of factors affect this physiological condition, e.g., nursery cultural practices, nursery climate, lifting date, and cold storage (121). Root growth capacity can be predicted once nursery cultural practices are standardized and the nursery climate is characterized. The system involves: monthly tests of root growth capacity of seedlings lifted prior to and during the lifting and shipping season, and a cumulative record of the number of hours that air temperatures in the nursery are below 10^{O} C. Stone and Jenkinson (122) reported on seedlings lifted in the nursery in October, December, and January that had been exposed to temperatures of 10^{O} C or less for 190, 850, 1570 hours and transplanted into soils varying in moisture, content from 10 to 100 percent. The root growth capacity had a marked seasonal periodicity: it was low in October and increased through December to a peak at the end of January, then dropped sharply to reach in April the same level as October. Meanwhile, the top growth began. Nursery stock of a superior morphological grade may have a very low capacity to grow new roots when lifted at one time of the year, even when planted in an optimum environment, and a very high capacity when lifted and planted a month or two earlier or later (122, 119). Stone et al. (119) showed that the RRP of ponderosa pine varied greatly with the time of year in which the seedlings were lifted and outplanted. This was supported later with work on douglas-fir (Pseudotsuga menziesii (Mirb) Franco) RRP (120). In a ponderosa pine plantation, Dunning et al. (29) found considerable mortality early in the summer (in California) when soil moisture was still readily available. From this, they concluded that the physiological condition of the seedlings, not the environment, was limiting. With the douglas fir seedlings at a constant root temperature of 20° C, the RRP was low during the summer months, rose abruptly during September, was high during the winter months and dropped off sharply during April when the terminal buds broke and new top growth began (120).

In addition, the seasonal increase in the translocation of food reserves and current photosynthate from the shoot to the roots could also help to explain the buildup in root growth capacity. In three-year-old eastern white pine, the capacity to translocate sucrose and raffinose from the shoot to the roots increased four fold from mid-April to mid-May. Since root respiration increased in this period and there was no shoot growth, it was suggested that peak root growth capacity occurred in their seedlings in May (113). Gordon et al. (36) found in five-year-old red pine, translocation to the roots was high when bud break occurred, then decreased rapidly as the new shoot expanded.

In most seasons, soil moisture tension greater than 0.5 to 1.0 bar appeared to limit the RRP. However, in January when the RRP is highest in California, roots were regenerated in soils with tensions up to 7 bars (27). This was supported by a study with white spruce (Picea glauca (moench) Voss), black spruce (Picea mariana (Mill) B.S.P.), and jack pine (Pinus banksiana Lamb), where the RRP was high in the spring, low during the summer, and moderate in the fall. It was also shown that the RRP tended to be very low in soils at more than 0.5 bars of tension (135, 136, 87).

Kummerow (76) concluded that it appears that roots and root systems have relatively few adaptive structures when compared with leaves. Roots appear to be much more plastic than shoots adapting to environmental stress. Many studies done by Kummerow et al. (75) and Hellmers et al. (46) showed that shallow or deep-rooting habits are expressions of morphological plasticity rather than adaptations to water stress. Compared with the true desert, mediterranean regions have deeper soils, favoring deeper penetration of root systems (76). A generally accepted view is that desert plants frequently have more shallow and widespread root systems, although this is not an exclusive feature.

Foresters are generally aware of the importance of deep rooting and have given considerable attention to differences in the initial root habitat of tree seedlings as a cause of differences in survival (54). An increase in the root/shoot ratio played in some cases negative roles as found by Passioura (91), who showed that the performance of modern cultivars under drought might be better if their ratio of root-to-shoot growth was lower. However, he suggested that the growth of the root, by using assimilate which could be better used to increase the size of the shoot, reduced the potential of the plant for future photosynthesis. He emphasized that crop plants don't need a large ratio of root-to-shoot growth, but it is appropriate for drought-affected plants growing among competitors.

The effect of stock preconditioning was reported by Deging (25), where light and moisture treatments were compared using seedlings of _Scaphium sp._ and _Deyera costula_. Preconditioned seedlings tended to have a higher root-to-shoot ratio, better field performance, better moisture status, and higher starch content than those unconditioned plants. Sharp (111) showed that water-stressed plants exhibited a net increase in root growth compared with well-watered plants.

Temperature has also been shown to have an effect on root growth. For instance, the maximum amount of root growth for fraser fir (_Abies fraseri_ (Pursh) Pois) seedlings occurred between 10^{o} to 14^{o} C of night temperature and 24^{o} to 27^{o}C day temperature. The root/shoot ratio decreased rapidly at night temperatures below 14^{o} C and were highest for 30^{o} C days in combination with 18^{o} to 22^{o} C nights. The heaviest root systems occurred at day/night temperatures of $26/10^{o}$ C and decreased rapidly with day temperature above 26^{o} C as well as temperature combination cooler than $22^{o}/14^{o}$ C (52).

Studies on Loblolly Pine

The relative adaptation of loblolly pine seedlings to drought conditions was shown by Noy-Meir (89), who presented loblolly pine "water potential isotherms," curves which depict the magnitude of the drop in ψw associated with the loss of a given amount of water, or relative water content (RWC). As a property of drought-resistant species, the tissue (or species) which undergoes a relatively larger ψw drop per unit water loss would establish a steeper ψw gradient between plant and soil and improve the plant's ability to extract moisture. Thus, the loblolly pine shoots examined underwent a far steeper ψw depression with water loss than did the root systems (127).

The osmotic potential at full turgor ($\psi_{\pi o}$) is very important because it establishes the maximum turgor pressure which can exist in the tissue. According to a study by Ritchie et al. (103), loblolly pine shoots showed an osmotic potential at full turgor of -16.3 bars, while the osmotic potential at zero turgor ($\psi_{\pi z}$) was -25 bars. These values gave an estimate of the incipient plasmolysis which is in good agreement with other studies with conifers (51). In general, lower (more negative) values of $\psi_{\pi z}$ in both roots and shoots and the higher symplastic volume (SV) in roots of loblolly pine could hint that this species might be better adapted to droughty conditions than are Douglas fir or western hemlock. This may be because more negative values of $\psi_{\pi z}$ in the shoots enable leaf conductance to remain relatively high at relatively low leaf water potentials (103). Even the difference between $\psi_{\pi o} - \psi_{\pi z}$ would indicate that the tissue elastic properties were effectively buffering cell volume changes enabling ψp to remain positive over a broad range of water deficits. For instance, loblolly pine shoots and roots showed larger $\psi_{\pi o} - \psi_{\pi z}$ gradients than the other conifers examined (103).

Brix (12) found leaf moisture content to be a reliable indicator of the water regime of loblolly pine seedlings. When leaf moisture content dropped from an initial 200% to 110% (expressed on dry weight basis), seedling mortality could be expected (lethal threshold). But Stransky (116) found that leaf moisture contents of 105 to 65% represented the range within which a loblolly and shortleaf pine seedling might either live or die; 85% was the midpoint of an even chance of survival for the seedlings. Brix (12), in his experiment to determine the viability of loblolly pine seedlings after wilting, found that a leaf water content of 110% was a critical plant water balance, below which the plants did not recover after rewatering.

Different seasons, temperatures, and light affect the shoot and root growth of oblolly pine. Reed (97) measured shoot growth of oblolly pine in the field and concluded that the seasonal course of growth was controlled by air temperature. Also, oblolly pine seedlings resumed growth sooner and made more growth in the season at high temperatures than did those grown with lower temperatures, but the latter made more growth late in the season (66). The best growth of oblolly pine seedlings was made with the widest spread (12° or 13° C) between day and night temperatures, and poorest growth with nights as warm as days. Therefore, a differential between day and night temperatures is required for optimum growth (66). For instance, when the night temperature was maintained at 17° C, the amount of shoot growth tripled as the day temperature was increased from 17° C to 30° C, but when the day temperature was maintained at 23° C the amount of shoot growth was reduced about 50% by increasing the night temperature from 11° to 23° C (66). There is evidence the threshold temperature for shoot growth was about 4.4° C at night and averaged 10° C during the day (10). For this reason, oblolly pine may thrive better in the northern part of its range than in the southern because there is a greater difference between day and night temperatures in the northern part (66). Friesner (34) reported that the effect of temperature on the root growth of loblolly pine from North Carolina may be considered as a continuous series from 5° C to 35° C. As the temperature increased, there was a fairly steady increase in growth from .17 mm per day at 5° C until it reached a maximum of 5.33 mm per day at 25° C, and then rapidly decreased. The rate at 35° C was .23 mm.

Kozlowski (72) showed that the ratio of weight of roots to tops in loblolly pine increased with increased light intensity. A study by Shirley (112) found a similar response in root growth for loblolly pine with increasing light intensity. The average daily growth rate increased gradually at 25° C and 12 hours photoperiod. In general, studies of periodicity have shown that the maximum growth of the roots occurs during evening or night, and the minimum growth occurs during early morning or forenoon (34).

CHAPTER III

OBJECTIVES

The major objectives of this study are as follows:

1. To evaluate the usefulness of P-V analysis as a method of screening wide-ranging seed sources of loblolly pine to evaluate their capacity to tolerate water stress both in the nursery and after outplanting or to determine the limits to cultural stressing in the nursery.

2. To investigate the relationship between nursery cultural practice (i.e., different irrigation regimes), and growth response by loblolly pine.

3. To determine whether the physiological changes induced by moisture stress in the nursery are permanent or transient in nature.

4. To develop an improved understanding regarding seasonal response by loblolly pine seedlings to water stress, with special attention to osmotic properties.

Through these objectives, it was expected that information would be generated to aid in efforts to improve the ability of loblolly pine native to North Carolina to endure periods of seasonal drought commonly encountered in Oklahoma. In addition, it was felt that a better understanding of seedling water relations might provide a basis for the expanded use of culturally-induced water stress techniques to manipulate other physiological processes, including dormancy, frost hardiness, and root regeneration potential.

Lastly, it was expected that empirical information would be gathered concerning the role of nursery water management in controlling seedling morphology (i.e., height and diameter growth). This information is valuable in achieving a better understanding of the interrelationships between nursery practices such as irrigation and undercutting/wrenching in the culture of seedlings designed to perform on sites subject to seasonal moisture stress.

CHAPTER IV

METHODS

The experimental site was located in southeastern Oklahoma at the Weyerhauser Company nursery near Fort Towson. Two seed sources of loblolly pine (Pinus taeda L.) were used in the experiments: North Carolina coastal open-pollinated (OP) family 8-44, and open-pollinated seed from McCurtain County, Oklahoma.

The seed was precision sown at a density of 295 seeds/m^2 from March 31 to April 6, 1982. All nursery beds prior to seeding had been fertilized with N, P, and K. Separate seeding blocks were utilized for each seed source. Within a block, nine beds, each 185 m in length, were seeded to a uniform depth of 6 mm in the sandy soil. Throughout the early portion of the growing season, the seedlings were fertilized every two weeks with nitrogen. Soil pH was maintained in the range of 5.5-6.5.

All seedlings were well watered by means of the existing irrigation system until August 23, 1982. At this date, the dry weight distribution in the seedlings was approximately 45% roots and 55% shoots. Immediately following this date, two water regimes were initiated for both seed sources. The first was described as the "well-watered" treatment, meaning that the seedlings were rewatered whenever the predawn xylem pressure potential of the stem reached a value of -2.5 bars (250 KPa). The other water treatment was identified as "water-stressed," meaning that the seedlings were not re-watered until the xylem pressure potential of the stem reached a minimum value of -7.5 bars (750 KPa) (pre-dawn).

Diurnal patterns of seedling water potential were monitored on October for both seed sources growing under both water treatments. Three seedlings from each seed source and treatment were harvested and seedling water potential was obtained by means of a pressure bomb (Soil Moisture Equipment Corporation, Santa Barbara, California, Model 3005 Plant Water Status Console). Five measurements were recorded at five different times at two-hour intervals, starting at pre-dawn. Care was taken to prevent water loss from seedlings following harvest; the entire top portion of the seedling was wrapped in Saran Wrap® prior to lifting from the ground, shaded while the roots were cut, and immediately placed in the pressure chamber. Resin exuding from the exposed stem surface was repeatedly dabbed with a tissue until the end point (balance) was clearly reached, as evidenced by the appearance of the water front. Use of a 10X magnifier glass aided the determination of the end point. Data was recorded in bar units.

In addition to measurements of diurnal water potential, data was collected via the "pressure-volume (P-V) method to try to characterize the in-plant response to the water treatments. Through these measurements, curves were constructed to provide information on the influence of the irrigation treatments on the turgor maintenance capacity of the seedlings. It was especially desired to know whether the loblolly pine seedlings had the capacity for osmotic adjustment, how the treatments influenced this process, the magnitude of the adjustment, and whether the adjustment (and other cell properties) were permanent or transitory in nature.

The methodology for the P-V determination was as follows: At monthly intervals (Sept., Oct., Nov., 1982, and Jan., 1983), seedlings from each treatment and seed source were randomly lifted from the beds, immediately placed in an iced cooler, and transported to Stillwater (Oklahoma State University). Upon arrival, four stems from each seed source and treatment were placed with roots intact in a covered bucket containing water and left overnight at room temperature to insure that the seedlings would be fully hydrated prior to the initiation of the P-V work.

At the start of the P-V determination, the sampled seedling was severed at the root collar, 2 cm of bark was stripped from the base, and the shoot was weighed to the nearest .01 g to obtain the fresh weight. Then the shoot was covered with a perforated plastic bag to minimize transpiration and reduce water loss and put into the pressure chamber. In addition, a moist paper towel was placed in the bottom of the pressure chamber. The pressure was slowly raised until the water front was seen with hand lens to wet the entire cut surface (the balance point). This was in the range of 1.5 bars to 3.0

bars. Subsequent release of the gas pressure in the chamber decreased the water potential of the cells in the leaf, which caused the cells to withdraw water from the outside. The cut end of the shoot was then fitted with a 5 cm Tygon tube filled with tissue paper (20). An increase of the pressure by 5 bars over the previous balance pressure, when held for a 10-minute period, was sufficient for collecting a suitable volume of expressed water and to allow water potential equilibibration between the symplast and the apoplast. Then the Tygon tube was removed and weighed on a Mettler balance to an accuracy of 1 mg immediately after each collection. The procedure was repeated until balance pressures reached 40 to 43 bars, which was the upper limit of the instrument gauge. At the end of the test, the sample was removed and weighted, and then was oven dried (70^{o} C for 48 hours) and reweighed. This procedure generally follows that of Hellkvist et al. (45).

Subsequent to the diurnal and P-V measurements, a study was designed to test the hypothesis that seedlings which were induced by the nursery irrigation treatments to osmotically adjust would show the greatest root regeneration potential.

By January 15, 1983, sufficient chilling hours had occurred to allow lifting of the seedlings from the nursery beds. Following a random selection, seedlings were transported to Stillwater in shipping bags and placed in a cooler at 3^{o} C. From the seedlings which were harvested, 288 samples from both seed sources and treatments were planted in 1/2-gallon pots filled with a sandy soil (pH 6.7). Two growth chambers were used in the study to provide controlled air conditions as given in Table I.

A randomized block design was used, containing 24 seedlings from each treatment (North Carolina well-watered, water-stressed; Oklahoma well-watered, water-stressed) replicated in six blocks. Thus, each chamber contained a total of 144 seedlings. Measurements of day/night soil temperature provided values of 23^{o} C/18^{o} C and 9^{o} C/7^{o} C, respectively, for the two chambers. Seedlings were well watered throughout the experiment.

To monitor root growth potential, a subsample consisting of 6, 12, and 18 samples from each treatment and growth chamber were excavated on days 15, 25, and 35, respectively, following the initiation of the experiment, and the number of the white roots longer than 1 cm were recorded by treatment.

Data Processing Theory

The P-V analysis was carried out using a Scholander-type pressure bomb to estimate the internal water relations of the seedlings growing under the two irrigation treatments. Phenological observations were recorded at each measurement date. P-V analysis enables estimation of the values of total water potential (ψw), bulk osmotic potential ($\psi \pi$), and bulk turgor potential (ψp) across a full range of tissue water contents. P-V theory is based upon the Van't Hoff's (1886) "Gas Solute" law which is written in a linear relationship between pressure

TABLE I

GROWTH CHAMBER ENVIRONMENTAL CONDITIONS

Chamber	Day (Hours)	Night (Hours)	Day Air Temp. (°C)	Night Air Temp. (°C)	Day R. H. (%)	Night R. H. (%)	Light Intensity uEm^{-2}/S
Cold	16	8	10	8	80	98	560
Warm	16	8	25	20	64	68	560

and volume enabling extrapolation beyond the measured range of values (102):

$$1/P = 1/\psi_{\pi} = (V_o - V_e)/RTN_s$$

where: V_o = The original volume of sap in the tissue symplast

V_e = The volume expressed at that pressure

RTN_s = The ideal gas constant, absolute temperature, and number of moles of solute in symplast, respectively

This law is now well developed (129, 109, 94, 131, 130).

The P-V curves were produced by plotting the reciprocal balance pressure against the relative water content (RWC), which is calculated from the equation:

$$RWC = 100 - \left(\frac{S_j - C}{W_i - W_d} \times 100\right)$$

where: W_i (g) = The fresh weight of the tissue sample

W_d (g) = The oven-dry weight of the tissue sample

S_j (g) = The weight of the xylem sap collected up through that pressure

C (g) = The correction factor for the water lost from the system into the chamber and given by the equation:

$$C = \frac{(W_i - W_f) - S_t}{n}$$

where: W_f (g) = The final weight of the tissue sample after the test and before the oven drying

S_t (g) = The total weight of the xylem sap collected during the test

n = The number of the balance pressures applied during the test

C is used as a correction method, with the assumption that the water loss inside the pressure chamber is uniform throughout the test period.

The P-V curves, four for each date, seed source, and water treatment, were constructed from the raw data and 1/P and RWC were calculated by computer and then the curves were manually fit into an "average" curve (as described by Ritchie et al. (102)).

The regions "A" and "B" of each P-V curve were fitted separately by least squares techniques and their intersection represented the point of incipient plasmolysis "C" (Figure 4).

An analysis of variance was used to compare the osmotic potential at full turgor, $\psi_{\pi o}$, in response to the cultural treatment applied in the nursery and to determine if there was a significant osmotic adjustment for the different seed sources by date. Results of the analysis producing an observed significance level of ≤ 0.05 were considered statistically significant.

CHAPTER V

RESULTS

P-V Curves and Bulk Parameters

Three key water relations parameters that can be derived from a P-V curve are shown in Tables III and IV, Appendix A. Results are presented separately for each parameter.

The Osmotic Potential at Full Turgor ($\psi_{\pi o}$)

This is the most important parameter because it establishes the maximum turgor pressure which can exist in the tissue. The values for the North Carolina loblolly pine showed marked seasonal fluctuations over the course of the experiment (Table III, Appendix A and Figures 5-12, Appendix B). In September (one month after initiation of the treatment) the mean value for the water-stressed treatment was higher (less negative) than the well-watered controls. However, in subsequent months, the values for the stressed trees were progressively lower than that of the well-watered controls, providing evidence of an osmotic adjustment. In October the differences between the treatments were slight, while in November and January greater treatment differences occurred. The lowest mean value recorded for the water-stressed seedlings was -14.23 bars (in November), while the control seedlings reached an average low value of -14.31 bars in September. Greatest treatment differences occurred in January, with the water-stressed seedlings showing a mean difference of -4.05 bars below the control seedlings (Figure 29, Appendix B). In reference to the Oklahoma seed source of loblolly pine, seasonal fluctuation also was evident (Table IV, Appendix A and Figures 13-20, Appendix B). However, the trends differed from those exhibited by the North Carolina seedlings. Minimum values for the stressed treatment were found in September with -13.95 bars, while the lowest control values occurred in October (-13.29 bars). Largest treatment differences were seen in November. However, because the application of the water-stressed treatment to the Oklahoma seedlings was not monitored closely, caution is advised when interpreting this data.

The Osmotic Potential at Zero Turgor ($\psi_{\pi z}$)

The magnitude of this value establishes the lower limit to the water potential at which positive turgor can exist (20). In other words, this value provides an estimate of the point at which wilting would theoretically occur. For the North Carolina Loblolly pine, the trend was similar to that found for $\psi_{\pi o}$ (Table III, Appendix A and Figure 29, Appendix B). The water-stressed seedlings gave higher values in September, followed by more negative values in subsequent months (i.e., lower than for control seedlings). Minimum values occurred in September for the control seedlings (-32.25 bars) while the minimum value for the stressed seedlings occurred in November (-32.25 bars). Largest treatment differences were found in November.

The values for the well-watered Oklahoma seedlings also varied seasonably, with lower numbers found in October and January (Table IV, Appendix A). It should be noted that during these two months, the values for the well-watered Oklahoma seedlings were lower than those for the North Carolina seedlings by 2.38 bars in October and 1.63 bars in January. Data for the Oklahoma water-stressed seedlings reflects the fact that a pre-dawn stress level of -7.5 bars was not consistently maintained throughout the course of the experiment.

$\psi_{\pi o} - \psi_{\pi z}$

The seasonal course of both $\psi_{\pi o}$ and $\psi_{\pi z}$ for the North Carolina seedlings is shown in Figure 29, Appendix B. Subtraction of $\psi_{\pi z}$ from $\psi_{\pi o}$, on a monthly basis, showed that the mimimal difference between these two parameters for the well-watered seedlings was found in November (-13.89 bars), while the largest difference was found in January (-18.87 bars). For the water-stressed trees, the minimum difference was found in September (-12.00 bars), and the largest difference was found in October (-18.41 bars). In October and November the values for the difference between the osmotic potentials at full and zero turgor for the well-watered seedlings were 15.34 bars and 13.89 bars, respectively, while the values for the same months for the water-stressed seedlings were 18.41 bars and 18.02 bars, respectively.

The Symplast Volume (SV)

A third parameter which can be derived from a P-V curve is the percent of tissue water at full turgor which is held in the symplast (SV). This value is obtained from the X-intercept of the osmotic potential regression line (Table II, Appendix A). For the North Carolina well-watered seedlings, an initial value of 69.68% was found in September. Higher values were recorded in October and November, declining slightly in January. A similar trend was noted for the water-stressed seedlings. However, stressed seedlings had lower values in October, November, and January compared to the North Carolina well-watered seedlings. A comparison of the well-watered seedlings from North Carolina and Oklahoma indicated that only in September were there substantial differences in the values (approximately 7%), with the Oklahoma seedlings showing a larger value. In all other months differences between the seed sources for the well-watered seedlings were less than three bars.

Water Potential Isotherm

The relationship between ψ_w and RWC at equilibrium and constant temperature is called a "water potential isotherm" (89). This relationship is shown by month in Figures 21, 22, 23, and 24, Appendix B for both the well-watered control seedlings and the water-stressed seedlings from the North Carolina seed source. Since this curve depicts the magnitude of the drop in ψ_w associated with the loss of a given amount of water, it can be used as one measure of drought adaptation (127). While the slope of the lines for both irrigation treatments became steeper from September to November, there was little difference for any month between the treatments themselves.

Turgor Maintenance

Turgor pressure (ψ_p) is a very meaningful water relations parameter because of its effect on many key physiological processes (55). While the pressure chamber does not provide direct information concerning turgor potential, the P-V curve provides a means of estimating ψ_p as a function of more readily-measured parameters. Only data for the North Carolina seedlings are shown because of the uncertainty of the water-stressed treatment as applied to the Oklahoma seedlings (Tables V-VIII, Appendix A and Figures 25-28, Appendix B).

The values for the treatments showed a seasonal pattern similar to that observed in previously mentioned parameters. In September, approximately one month after the initiation of the water-stressed treatment, values of ψ_p for a given ψ_w value were considerably higher for the well-watered seedlings. As the duration of the treatment progressed, however, this pattern was reversed. By January, the values of ψ_p were substantially greater for the water-stressed seedlings at a given level of ψ_w. For example, in January the turgor value at -7.2 bars ψ_w for the well-watered seedling was 4.52 bars, whereas at this same ψ_w value the turgor potential for the water-stressed seedlings was nearly doubled at 8.99 bars.

Diurnal Water Potential

Diurnal measurements of water potential (ψ_w) were measured in October, by irrigation treatment, utilizing seedlings from both the North Carolina and Oklahoma seed sources (Table IX, Appendix A).

Data for North Carolina seedlings indicated that the ψ_w values for the well-watered seedlings (rewatered when predawn xylem pressure potential reached -2.5 bars) remained consistently higher than those recorded for the water-stressed seedlings (rewatered at -7.5 bars). Peak evapotranspirational demands occurred at 13:00, when the values for the control and stressed seedlings were -15.8 bars and -21.6 bars, respectively (Figure 30, Appendix B). Corresponding values for Oklahoma seedlings were -10.0 bars and -13.4 bars, respectively. However, the lowest ψ_w values were recorded at 15:00 for the Oklahoma seedlings.

In comparing the well-watered treatment values for the two seed sources, it is noteworthy that for Oklahoma seedlings the peak stress period occurred later in the day, and at a lower ψ_w value, than for the North Carolina seedlings, although the magnitude of the peak ψ_w difference was not great (-1.27 bars). Because of the uncertainty of the water-stressed treatment as applied to the Oklahoma seedlings, comparisons between seed sources should be made with caution.

Growth Chamber Experiment

Root Regeneration Potential

The root regeneration potential (RRP), or the capacity of the seedlings to elongate new roots following planting, is of critical importance for the establishment and growth of the seedling.

In this study, RRP was monitored for both seed sources and treatments utilizing growth chambers maintained at different day/night temperatures to investigate the relationship between nursery culture (i.e., water-stressed or well-watered) and subsequent root regeneration following lifting. Following the start of the growth chamber experiment, all seedlings were kept well watered. The results are shown in Figures 31, 32, 33, and 34, (Appendix B), by seed source and chamber temperature.

In reference to the North Carolina seed source, the average number of new roots initiated by the water-stressed seedlings in the warm chamber after 15, 25, and 35 days was 22.3, 31.9, and 28.8, respectively. Corresponding values for the well-watered seedlings were 24.3, 27.6, and 43.1. The average RRP for the water-stressed North Carolina seedlings grown in the cold chamber after 15, 25, and 35 days was 0.5, 3.6, and 7.1, respectively. Corresponding values for the well-watered seedlings were 0.17, 1.5, and 2.4.

Statistical comparisons of the North Carolina seedlings by means of LSD values at the .05 level (Table XVII, Appendix C) indicated that differences in RRP within the cold chamber between the two different treatments were significant at 25 and 35 days. Significant differences were found within the water-stressed treatment for all three sample dates, while the RRP for the well-watered North Carolina seedlings showed a significant difference only for the first date (15 days). Within the warm chamber, however, statistical differences in RRP between the North Carolina seedlings grown under the two irrigation regimes was significant only for the third date (after 35 days). No significant differences were found between the three dates within the water-stressed treatment, and within the well-watered treatment, the statistical differences were found only between 25 and 35 days.

Regarding the Oklahoma seed source, mean RRP values for the water-stressed seedlings grown within the warm growth chamber were 15.0, 40.8, and 61.7, respectively. Corresponding RRP values for the Oklahoma well-watered seedlings were 20.0, 32.8, and 74.9, respectively. Within the cold chamber, RRP values for the water-stressed Oklahoma seedlings were 0.67, 2.8, and 3.0 for the three harvest times. Corresponding values for the seedlings that had been grown under a well-watered nursery regime were 0.0, 1.2, and 3.5 after 15, 25, and 35 days, respectively.

Statistical analyses indicated that for the Oklahoma seedlings grown in the cold chamber, treatment differences were significant only for the harvest at 15 days. Within the water-stressed treatment, a significant statistical difference was found only between 15 and 25 days only, whereas within the well-watered treatment, the values for RRP were significant between 15 and 25 days and between 25 and 35 days. Analyses of RRP for the Oklahoma seedlings grown in the warm chamber showed no significant treatment differences at any sample date. Within the water-stressed treatment, a significant difference was found between all three dates, whereas the RRP for the well-watered treatment in the warm chamber was significantly different only between 25 and 35 days.

Height Growth

Mean values of seedling height were calculated after 15, 25, and 35 days for each seed source and nursery irrigation regime for both the warm and cold chamber environments. Results are shown in Figures 35, 36, 37, and 38, Appendix B.

For the North Carolina seed source, the average height in the warm chamber of the water-stressed seedlings was 18.3 cm, 24.2 cm, and 27.0 cm after 15, 25, and 35 days. Corresponding values for the well-watered seedlings were 20.5 cm, 24.9 cm, and 27.7 cm respectively. The average height of the water-stressed North Carolina seedlings in the cold chamber for the three sample times were 19.0, 19.8, and 20.6 cm. For the well-watered treatment, corresponding values were 18.0 cm, 18.7 cm, and 18.9 cm, respectively.

For the Oklahoma seed source, the average height of the water-stressed seedlings in the warm chamber was 19.0 cm, 24.5 cm, and 28.3 cm after 15, 25, and 35 days. Corresponding values for the well-watered seedlings were 23.8 cm, 26.9 cm, and 30.3 cm, respectively. The average height of the water-stressed Oklahoma seedlings in the cold chamber for the three sample times was 20.8 cm, 21.1 cm, and 23.3 cm. For the well-watered treatment, corresponding values were 20.2 cm, 21.0 cm, and 22.0 cm, respectively.

In regard to the timing of bud break, differences were found between growth chamber temperatures, but no seed source differences were found within a chamber. In the warm chamber, 30% of the seedlings had initiated height growth after six days, and 95% after eight days. However, in the cold chamber, only 5% had flushed after eight days, and only after 16 days had 95% flushed.

Statistical analyses (Tables XVIII, XIX, and XX, Appendix C) of data collected from the warm growth chamber indicated that highly significant height differences were found between seed sources, nursery irrigation treatments, and sample date. However, no significant difference at the .05 level was found between irrigation treatments within a seed source, nor were there significant height differences by sample date within a seed source. Within the cold chamber, the only statistically significant difference in seedling height was between seed sources.

CHAPTER VI

DISCUSSION

As described in the objective section, the overall goal of this study was to investigate the opportunities that may exist for using nursery irrigation to tailor seedling morphology and physiology toward the production of a target seedling designed for reforestation on a target site. While previous work has shown that moderate water stress will restrict seedling height growth but allow for increased caliper growth (unpublished Weyerhaeuser Research Report), information detailing the impact on seedling physiology was lacking.

Two seed sources of loblolly pine were tested in this study, one from coastal North Carolina and the other from Southeastern Oklahoma. It was expected that these sources would represent the range in adaptation to water-stress. In addition, selection of these seed sources reflected current operational practices by the Weyerhaeuser Company: nearly 60% of the company ownership in Oklahoma and Arkansas is being reforested with loblolly pine families from North Carolina (C. Boyd, personal communication). The advantage of moving seed sources was reported by Cech et al. (19), who found that North Carolina trees produced 30% more volume after ten years than trees native to Oklahoma or Arkansas when tested in Arkansas.

In this study, the internal water relations of the seedlings were characterized in response to two levels of irrigation (rewatered at pre-dawn ψw of -2.5 or -7.5 bars) using the P-V method. Seasonal P-V curves were generated monthly from September to November, 1982 and for January, 1983.

The following discussions will emphasize interpretation of the treatment effects on the North Carolina seedlings. Because the level of the water-stressed treatment was not closely monitered when applied to the Oklahoma seed source, caution should be exercised in making inferences from the Oklahoma data.

The pressure-bomb technique used has provided internal plant-water relations information which was estimated through different parameters such as the values of the osmotic potential at full turgor ($\psi_{\pi o}$). This parameter is important because it establishes the maximum turgor which can develop at full hydration; the lower this value, the higher the initial turgor.

It should be noted that the duration of the water-stressed treatment was approximately one month (September), following which normal seasonal rainfall negated the treatment (Table X, Appendix A). Nonetheless, the response by the North Carolina stressed seedlings indicated that this particular family of loblolly pine is capable of adjusting osmotically, as inferred from changes in the values of $\psi_{\pi o}$ over time. An adjustment of -2.48 bars was seen in November, rising to -4.05 bars in January. Statistical analysis indicated that treatment differences were only significant in January (Table XII, Appendix C).

The ability of a seedling to osmotically adjust in response to water-stress may be an important survival mechanism. An osmotic adjustment has been reported to allow the maintenance of cell elongation (80) and stomatal opening and photosynthesis (5, 37), as well as enhancing tolerance to dehydration and promoting exploration of greater soil volume for water through root growth (60).

The values of $\psi_{\pi o}$ obtained for the North Carolina seedlings were higher than those reported for other conifers by Ritchie and Shula (103). In their study, the values of $\psi_{\pi o}$ ranged from -14.7 bars for Douglas-fir to -20.0 bars for western hemlock. However, they were working with both 2 + 0 and 2 + 1 seedlings subjected to various storage times, i.e., conditions very dissimilar to those under which this study was conducted. Krueger and Trappe (74) have described low mid-winter $\psi_{\pi o}$ values not as evidence of drought adaptation, but rather as a result of higher foliar sugar concentrations. Conifers such as Douglas-fir actively photosynthesize during the winter when growth is negligible and respiration is very low, resulting in carbohydrate accumulation (47, 78). In this study, however, the lowest values of $\psi_{\pi o}$ for the North Carolina seedlings were found in November, prior to the onset of a lengthy chilling period.

The parameter $\psi_{\pi z}$ is important because it establishes the lower limit of water potential at which positive turgor can be maintained, or theoretically indicates when wilting would occur. A low value of $\psi_{\pi z}$ would enable a plant to maintain positive turgor under water stress.

The monthly trend contrasting the water-stressed vs. the well-watered seedlings was similar to the pattern shown for $\psi_{\pi o}$, i.e., progressively lower seasonal values for the water-stressed seedlings. The $\psi_{\pi z}$ values for the North Carolina seedlings in this study were lower than those reported for other conifers (103), although the seedlings tested in that study had been cultured differently, were of different ages, and were tested under different seasons.

A third parameter noted on the P-V curves is the percent of tissue water at full turgor which is held in the symplasm (SV). Literature values of SV for leaf and stem tissue vary from about 50 to 75 percent, although the physiological significance of those values is unknown (102). The values of SV found in this study were within the range or slightly higher than those reported by others (102). The SV values for the water-stressed seedlings became less than those for the well-watered seedlings as the experiment progressed. However, because no data exists concerning changes in cell elasticity, caution is advised in interpreting the SV data. Ritchie and Shula (103), examining trends similar to those reported here, i.e., generally lower (more negative) values of $\psi_{\pi z}$ and higher values of SV in loblolly pine, suggested that loblolly might be better adapted to droughty conditions than are douglas-fir or western hemlock.

Further information concerning seedling stress adaptation can be obtained by examining values of the total osmotic drop between full turgor ($\psi_{\pi o}$) and incipient plasmolysis ($\psi_{\pi z}$) at various sample dates. Hsaio et al. (55) have shown that simple cell dehydration alone can only account for an osmotic drop of about three bars between these points. In this study, values for this difference ranged from approximately 12 bars to 18 bars for the water-stressed seedlings, and from 14 bars to 19 bars for the well-watered seedlings. This pattern is consistent with that reported by Ritchie and Dunham (102) who inferred, therefore, that the seedlings must have been able to either manufacture or accumulate additional osmotically active materials in the cells during dehydration in the pressure chamber. Such an ability to osmo-regulate would enable a plant tissue to maintain low ψ_{π} (hence high turgor) over a wide range of water potentials and is currently viewed as an adaptation to drought (44, 55). This was supported by the work of Turnstall and Connor (124) who found that previously stressed <u>Acacia phyllodes</u> had elevated solute concentrations resulting in turgor pressures up to 10 bars higher than unstressed plants over a 35 bar range of water potential.

Turgor pressure (ψp) effects many physiological processes (55). However, its direct measurement in higher plants is extremely difficult. One useful feature of the P-V technique is that it provides a means of estimating ψp as a function of more readily measured parameters such as RWC or ψw (103).

In this study, after one month of the irrigation treatments, the well-watered North Carolina seedlings had higher turgor values at any level of water potential than the water-stressed seedlings, but as the season progressed, this was reversed. By January, for example, the turgor potential at -7.3 bars for the water-stressed (osmotically adjusted) seedlings (9.2 bars vs. 4.2 bars). The ability to maintain positive turgor at decreasing water potentials is a direct measure of a seedling's ability to carry out metabolic and growth processes while under water stress (102). It is not unreasonable, therefore, that those seedlings exposed to a pre-dawn stress of -7.5 bars would be capable of more rapid establishment than unstressed nursery seedlings when outplanted in January.

Similar work has been conducted with a number of agronomic crops. In a study of wheat leaves, as the water potential decreased from -1.0 to -13.0 bars, *Triticum dicocum* showed full turgor maintenance, whereas *T. aestrineum* showed no osmotic adjustment over the same range. In addition, under dry conditions, the yield from the variety capable of osmoregulation was more than twice that of commercial cultivars (84, 85).

Another way to quantitatively examine the effects of the nursery irrigation treatments on seedling water relations is through the development of a water potential isotherm. Ritchie and Shula (103) stated that a seedling displaying a relatively large ψw drop with respect to a given loss in RWC would establish a larger ψw gradient between itself and the environment, enabling it to extract and hold water from drier soils. In this study, both the well-watered and water-stressed North Carolina seedlings underwent progressively steeper ψw depressions with water loss from September through January, although there was little treatment difference at any sample date.

The water potential isotherm provides a method to quantify the ψw and RWC at which a seedling would reach the point of incipient plasmolysis, or wilting. For the North Carolina water-stressed seedlings, the ψw values for this point ranged from -22.2 bars (October) to -31.2 bars (June), with corresponding values of RWC of 90.5% and 87.1%, respectively. Other researchers (108) reported sorghum plants wilted at a leaf water potential of -16.0 bars and a RWC of 55%, while values for wilted corn were -13.0 bars and a RWC of 71%. Thus, in comparison to these crops, Loblolly pine appears to be considerably more tolerant of water stress.

To observe the relationship between the nursery cultural treatments, as they affected the internal water relations of the seedlings, and subsequent seedling growth following lifting, a controlled environment growth chamber study was conducted using two treatment temperatures. Root regeneration potential and seedling height were sampled after 15, 25 and 35 days.

In reference to the North Carolina seedlings, within the cold chamber ($9^{O}C$ day, $7^{O}C$ night) the root regeneration of the nursery-stressed seedlings was significantly greater than that of the nursery well-watered seedlings at each sample date ($p < 0.05$). For example, after 35 days those seedlings which had been subjected to moderate water-stress in the nursery had initiated three times as many new roots as those which had been unstressed in the nursery. This is important because most regeneration foresters consider RRP to be the most critical determinant for successful establishment following outplanting. It should be noted that forest industries in Oklahoma commonly plant seedlings in January, when soil temperatures are similar to those tested in the colder growth chamber.

The ability of the water-stressed seedlings to more rapidly regenerate roots in cold soil, if true for field plantings, would allow these seedlings to respond more favorably to vegetative competition for available soil moisture. However, factors other than high RRP have been demonstrated to affect early survival, including weather, soil conditions, method of planting, and the overall physiological condition of the stock (15).

While many more roots were regenerated when grown in the warmer growth chamber, the effect of the nursery cultural treatments were, in general, not significantly different from one another. It was noteworthy that after 35 days, the well-watered Oklahoma seedlings had regenerated a far greater average number of roots than the well-watered North Carolina seedlings (75 vs. 43). This may have been due to a larger leaf area, and thus greater photosynthetic capacity, by the Oklahoma seedlings. Foliage differences were not readily apparent, although no leaf weight or area measurements were taken. Alternatively, the Oklahoma seedlings may be genetically predisposed to allocate greater amounts of early spring photosynthate to the roots, considering the environment in which they have evolved: a large root absorbing surface would be advantageous for survival during seasonal drought.

In order to more completely evaluate the response of the roots to the nursery treatments, it is also useful to monitor height growth, as much evidence exists to document growth periodically by woody plants. For example, Gordon et al. (36), studying five-year-old red pine (P. resinosa Ait), found that translocation of current photosynthate to the roots was high when bud break occurred, then decreased rapidly as the new roots expanded. Statistical analysis indicated that no significant differences existed in height growth in response to the nursery irrigation treatments when grown in either the cold or warm soil temperature. The North Carolina seedlings grown under the colder environment appears to have significant differences seen in the RRP by nursery treatment that were not detrimental to height growth. For example, after 35 days in the colder soil, while the water-stressed seedlings had initiated an average of three times more roots than the well-watered seedlings, the average heights of the seedlings for the two nursery treatments were similar (20.6 centimeters and 18.9 centimeters, respectively).

When grown in the warmer growth chamber, seedling heights were similar to those in the colder chamber after 15 days for both nursery treatments. However, height growth for the seedlings in the warmer chamber exceeded that of those grown in the colder chamber after both 25 and 35 days, although the responses were nearly the same between nursery treatments within the warmer chamber. These results are consistent with those of Kramer (7), who reported that loblolly pine seedlings grown under higher temperatures resumed growth earlier than those grown in lower temperatures.

Because of uncertainty regarding the application of the nursery water-stressed treatment for the Oklahoma seed source, comparisons of treatment effects regarding both root and height growth are difficult. However, an examination of the data concerning the nursery well-watered treatment indicated that root growth was much more variable over time than height growth, particularly when the seedlings were grown in the warmer chamber. For example, between 25 and 35 days, the average root number for the well-watered Oklahoma seedlings increased 128%, while height growth for the same period increased only 13%. This indicated that after approximately one month exposure to the warmer soil temperature, either photosynthate was not being massively redirected from the root zone to the top, or that there was a delay in mobilizing stored carbohydrate reserves in the roots to drive new root initiation. A similar pattern in root-shoot growth was seen after 35 days by the North Carolina seedlings when grown in the warmer chamber. While the responses of the seedlings to the warmer chamber are of physiological interest, it should be noted that the responses to the colder environment probably are a more accurate predictor of seedling response following field planting, which operationally is conducted from December through March in the southern United States.

CHAPTER VII

CONCLUSIONS AND RECOMMENDATIONS

While the present data was collected from only two sources of loblolly pine during one season at one location, several conclusions can be drawn. First, a predawn water stress treatment of -7.5 bars, when applied in late August, induces changes in both the turgor and osmotic potentials in loblolly pine seedlings from family 8-44, native to coastal North Carolina. The magnitude of the adjustment in the osmotic potential at full turgor, as determined from pressure-volume curves derived from seedlings allowed to dry within a pressure chamber, reached -4.05 bars in January for the water-stressed seedlings, as compared to values for the well-watered seedlings. Whether this degree of osmotic adjustment would persist following outplanting is unknown. Similarly, the values for the osmotic potential at zero turgor were lower in October, November and January for the water-stressed seedlings. This indicates that the stressed seedlings would be capable of maintaining a positive turgor at a lower value of water potential than the unstressed seedlings. This is supported by an analysis of the turgor maintenance curves, which indicated that in January, for example, a well-watered North

Carolina seedling at a water potential of -7.24 bars was capable of producing a positive turgor of 4.52 bars, whereas the turgor level that could be reached by a water-stressed (osmotically adjusted) seedling at the same level of water potential was 8.99 bars. It is hypothesized that this difference could be important in early seedling establishment.

Second, those seedlings which were exposed to a moderate level of water-stress in the nursery were found to have significantly greater root regeneration potential when grown in a soil temperature of 9°C day/7°C night than seedlings which were unstressed in the nursery. These differences in RRP were significant after 15, 25 and 35 days. This should be of great interest to regeneration foresters.

Third, differences existed between North Carolina and southeast Oklahoma sources of loblolly in the timing and amount of root regeneration, suggesting that seedlings from Oklahoma may be genetically predisposed to allocate greater amounts of early seasonal photosynthate to the root zone. These seedlings would be more suited for planting on harsher sites having soils with lower moisture-holding capacity than those from North Carolina.

Fourth, empirical observation indicated that nursery water management is a valuable tool for influencing seedling morphology as well as seedling physiology. Height growth was restricted by those seedlings exposed to a moderate level of water-stress in August, although caliper growth continued. Operationally, regulation of height growth in this fashion (as opposed to top pruning) is the primary goal of nursery water management, although results from this study indicate that important physiological properties related to moisture stress tolerance are also affected. While a pre-dawn stress level of -4 to -5 bars is probably sufficient for the control of height growth, it is not unreasonable to expect that greater osmotic adjustment could be obtained in response to higher levels of stress than tested in this study.

Several challenges are presented as a result of this study. First, the changes in seedling morphology and physiology which are induced by nursery irrigation regimes must be related to field survival and performance. For example, the effect of a -4 bar osmotic adjustment should be evaluated as it relates to seedling tolerance to exposure during lifting and storage, and as it relates to moisture stress tolerance following planting. Currently, no literature exists to address this challenge.

Second, if the ability of a species to osmo-regulate in response to a moderate level of nursery water-stress is found to be an important determinant for field establishment, evaluations are needed to resolve if it is possible to make genetic selections for families possessing this ability. Similar selections have been made in agronomic crops (e.g., wheat) resulting in large increases in yield when grown under dry conditions (84).

Lastly, there is a need to better understand the interaction of nursery water-stress and undercutting/wrenching treatments in the culture of seedlings possessing morphological and physiological attributes designed to enhance survival and growth, i.e., development of target seedlings for target sites.

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APPENDIXES

APPENDIX A

TABLES

TABLE II

MEAN VALUES OF THE SYMPLAST VOLUME (SV)

Loc	Trt	Date	N	Slope	Intercept	SV
1	1	1	4	-0.00231	0.06989	69.68
1	1	2	4	-0.00504	0.08557	83.05
1	1	3	2	-0.00631	0.08513	86.52
1	1	4	4	-0.00710	0.11228	84.20
1	2	1	4	-0.00272	0.07691	71.72
1	2	2	4	-0.00408	0.07786	80.91
1	2	3	2	-0.00407	0.07028	82.74
1	2	4	4	-0.00347	0.07715	77.77
2	1	1	4	-0.00335	0.07837	76.64
2	1	2	4	-0.00426	0.07527	82.33
2	1	3	2	-0.00838	0.10808	87.11
2	1	4	4	-0.00469	0.08668	81.53
2	2	1	4	-0.00325	0.07171	77.93
2	2	2	4	-0.00389	0.07479	80.78
2	2	3	2	-0.00456	0.08384	81.60
2	2	4	4	-0.00419	0.07862	81.22

Loc

1 = North Carolina
2 = Oklahoma

Trt

1 = Well-Watered
2 = Water-Stressed

Date

1 = September
2 = October
3 = November
4 = January

The unit of SV is % and calculated from the equation of the regression line y = intercept + slope x SV.

TABLE III

BULK WATER RELATIONS PARAMETERS BY CULTURAL TREATMENT FOR 1 + 0 LOBLOLLY PINE SEEDLINGS, NORTH CAROLINA SEED SOURCE

Month	Treatment	Ψ_{π_o} Bar	Ψ_{π_z} Bar	SV %	N
September	NC Well-Watered	-14.31	-32.25	69.68	4
	NC Water-Stressed	-13.00	-25.00	71.72	4
October	NC Well-Watered	-11.69	-27.03	83.05	4
	NC Water-Stressed	-12.84	-31.25	80.91	4
November	NC Well-Watered	-11.75	-25.64	86.52	2
	NC Water-Stressed	-14.23	-32.25	82.74	2
January	NC Well-Watered	-8.91	-27.78	84.20	4
	NC Water-Stressed	-12.96	-31.25	77.77	4

Well-Watered = -2.5 bars max. pre-dawn leaf water potential.

Water-Stressed = -7.5 bars min. pre-dawn leaf water potential.

Ψ_{π_o} = osmotic potential at full turgor

Ψ_{π_z} = osmotic potential at zero turgor (estimated from the P-V.

SV = volume of the symplast (estimated from the regression line equation).

TABLE IV

BULK WATER RELATIONS PARAMATERS BY CULTURAL TREATMENT FOR 1 + 0 LOBLOLLY PINE SEEDLINGS, OKLAHOMA SEED SOURCE

Month	Treatment	Ψ_{π_o} Bar	Ψ_{π_z} Bar	SV %	N
September	OK Well-Watered	-12.76	-25.64	76.64	4
	OK Water-Stressed	-13.95	-28.57	77.93	4
October	OK Well-Watered	-13.29	-29.41	82.33	4
	OK Water-Stressed	-13.37	-31.25	80.78	4
November	OK Well-Watered	-9.25	-24.39	87.11	2
	OK Water-Stressed	-11.93	-25.64	81.60	2
January	OK Well-Watered	-11.54	-29.41	81.53	4
	OK Water-Stressed	-12.72	-28.57	81.22	4

Well-Watered = -2.5 bars max. pre-dawn leaf water potential.

Water-Stressed = -7.5 bars min. pre-dawn leaf water potential.

Ψ_{π_o} = osmotic potential at full turgor.

Ψ_{π_z} = osmotic potential at zero turgor (estimated from the P-V).

SV = volume of the symplast (estimated from the regression line equation).

TABLE V

SELECTED TISSUE-WATER PARAMETERS FOR LOBLOLLY PINE SEEDLINGS NORTH CAROLINA SEED SOURCE BY CULTURAL TREATMENT, IN SEPTEMBER

Ob.	RWC (%) W.W.	RWC (%) W.S.	ψw (Bar) W.W.	ψw (Bar) W.S.	$\psi \pi$ (Bar) W.W.	$\psi \pi$ (Bar) W.S.	ψp (Bar) W.W.	ψp (Bar) W.S.
1	96.3	96.1	-7.41	-7.25	-16.13	-13.89	8.72	6.64
2	93.9	93.4	-12.66	-11.63	-18.52	-15.87	5.86	4.24
3	91.3	91.0	-18.52	-15.38	-22.22	-17.86	3.70	2.48
4	88.2	88.4	-21.74	-20.41	-26.32	-22.22	4.58	1.81
5	85.3	85.3	-32.25	-25.00	-32.25	-25.00	0.00	0.00
6	82.6	83.0	-35.71	-33.33	-35.71	-33.33	0.00	0.00
7	80.4	81.2	-38.46	-37.04	-38.46	-37.04	0.00	0.00
8	78.9	81.4	-41.67	-41.67	-41.67	-41.67	0.00	0.00

N = 4

W.W. = Well-watered; -2.5 bars max. pre-dawn leaf water potential.

W.S. = Water-stressed; -7.5 bars min. pre-dawn leaf water potential

RWC = Relative water content (%)

ψw = Water potential (bar)

$\psi \pi$ = Osmotic potential (bar) (estimated from the P-V curve)

ψp = Turgor potential (bar) (estimated from the equation $\psi w = \psi p + \psi \pi$)

TABLE VI

SELECTED TISSUE-WATER PARAMETERS FOR LOBLOLLY PINE SEEDLINGS NORTH CAROLINA SEED SOURCE BY CULTURAL TREATMENT, IN OCTOBER

	RWC (%)		ψw (Bar)		ψπ (Bar)		ψp (Bar)	
Ob.	W.W.	W.S.	W.W.	W.S.	W.W.	W.S.	W.W.	W.S.
1	94.3	95.0	-7.81	-8.06	-16.67	-17.24	8.86	9.18
2	93.0	93.0	-12.66	-13.16	-19.23	-20.00	6.57	6.84
3	91.0	91.6	-20.41	-17.54	-22.73	-23.81	2.32	6.27
4	88.8	90.5	-27.03	-22.22	-27.03	-27.03	0.00	4.80
5	88.0	89.2	-27.78	-31.25	-27.78	-31.25	0.00	0.00
6	87.3	88.3	-33.33	-35.71	-33.33	-35.71	0.00	0.00
7	86.1	86.0	-38.46	-40.00	-38.46	-40.00	0.00	0.00

N = 4

W.W. = Well-watered; -2.5 bars max. pre-dawn leaf water potential

W.S. = Water-stressed; -7.5 bars min. pre-dawn leaf water potential

RWC = Relative water content (%)

ψw = Water potential (bar)

ψπ = Osmotic potential (bar) (estimated from the P-V curve)

ψp = Turgor potential (bar) (estimated from the equation $\psi w = \psi p + \psi \pi$)

TABLE VII

SELECTED TISSUE-WATER PARAMETERS FOR LOBLOLLY PINE SEEDLINGS NORTH CAROLINA SEED SOURCE BY CULTURAL TREATMENT, IN NOVEMBER

Ob.	RWC (%) W.W.	RWC (%) W.S.	ψw (Bar) W.W.	ψw (Bar) W.S.	$\psi \pi$ (Bar) W.W.	$\psi \pi$ (Bar) W.S.	ψp (Bar) W.W.	ψp (Bar) W.S.
1	94.6	95.5	-7.69	-7.25	-15.38	-16.39	7.69	9.14
2	94.1	95.0	-12.82	-12.05	-18.18	-18.18	5.36	6.13
3	92.9	93.9	-18.52	-16.67	-21.28	-22.54	2.76	5.87
4	92.4	92.5	-25.64	-22.73	-25.60	-27.00	0.00	4.27
5	91.5	90.5	-29.41	-32.25	-29.41	-32.25	0.00	0.00
6	90.7	89.6	-35.71	-38.46	-35.71	-38.46	0.00	0.00
7	88.8	88.0	-41.67	-43.48	-41.48	-43.48	0.00	0.00

N = 2
W.W. = Well-watered; -2.5 bars max. pre-dawn leaf water potential
W.S. = Water-stressed; -7.5 bars min. pre-dawn leaf water potential
RWC = Relative water content (%)
ψw = Water potential (bar)
$\psi \pi$ = Osmotic potential (bar) (estimated from the P-V curve)
ψp = Turgor potential (bar) (estimated from the equation $\psi w = \psi p + \psi \pi$)

TABLE VIII

SELECTED TISSUE-WATER PARAMETERS FOR LOBLOLLY PINE SEEDLINGS NORTH CAROLINA SEED SOURCE BY CULTURAL TREATMENT, IN JANUARY

	RWC (%)		ψw (Bar)		ψπ (Bar)		ψp (Bar)	
Ob.	W.W.	W.S.	W.W.	W.S.	W.W.	W.S.	W.W.	W.S.
1	95.6	95.3	-7.24	7.14	-11.76	-16.13	4.52	8.99
2	93.2	92.8	-10.19	11.49	-14.70	-19.23	4.51	7.74
3	91.1	90.6	-15.86	16.13	-19.23	-21.28	3.37	5.15
4	89.8	88.7	-21.27	22.22	-23.81	-26.32	2.54	4.10
5	88.7	87.1	-27.78	31.25	-27.78	-31.25	0.00	0.00
6	87.8	86.1	-33.33	37.04	-33.33	-37.04	0.00	0.00
7	86.9	85.6	-38.46	41.67	-38.46	-41.67	0.00	0.00
8	86.4	-	-43.48	-	-43.48	-	0.00	-

N = 4
W.W. = Well-watered; -2.5 bars max. pre-dawn leaf water potential
W.S. = Water-stressed; -7.5 bars min. pre-dawn leaf water potential
RWC = Relative water content (%)
ψw = Water potential (bar)
ψπ = Osmotic potential (bar) (estimated from the P-V curve)
ψp = Turgor potential (bar) (estimated from the equation $\psi w = \psi p + \psi \pi$)

TABLE IX

DIURNAL WATER POTENTIALS (ψw) FOR LOBLOLLY PINE SEEDLINGS, NORTH CAROLINA AND OKLAHOMA SEED SOURCES BY CULTURAL TREATMENT IN OCTOBER

		North Carolina		Oklahoma	
	Time	Well-Watered	Water-Stressed	Well-Watered	Water-Stressed
1	7:00	-3.47	-5.72	-3.42	-3.42
2	9:00	-3.77	-9.47	-6.50	-8.47
3	13:00	-15.80	-21.60	-10.03	-13.43
4	15:00	-13.90	-19.67	-14.53	-15.90
5	17:00	-12.00	-16.63	-11.33	-11.67

N = 3

TABLE X

CLIMATOLOGICAL DATA FOR HUGO STATION

	Aug. 82	Sept. 82	Oct. 82	Nov. 82	Dec. 82	Jan. 83
Temperature (^{o}C)	28.2	23.5	17.8	12.1	9.0	5.5
Precipitation (mm)	100.6	1.27	60.7	101.3	162.3	18.0

Source: Climatological Data, Oklahoma, National Oceanic and Atmospheric Administration, Vol. 91 (82); Vol. 92 (83).

APPENDIX B

FIGURES

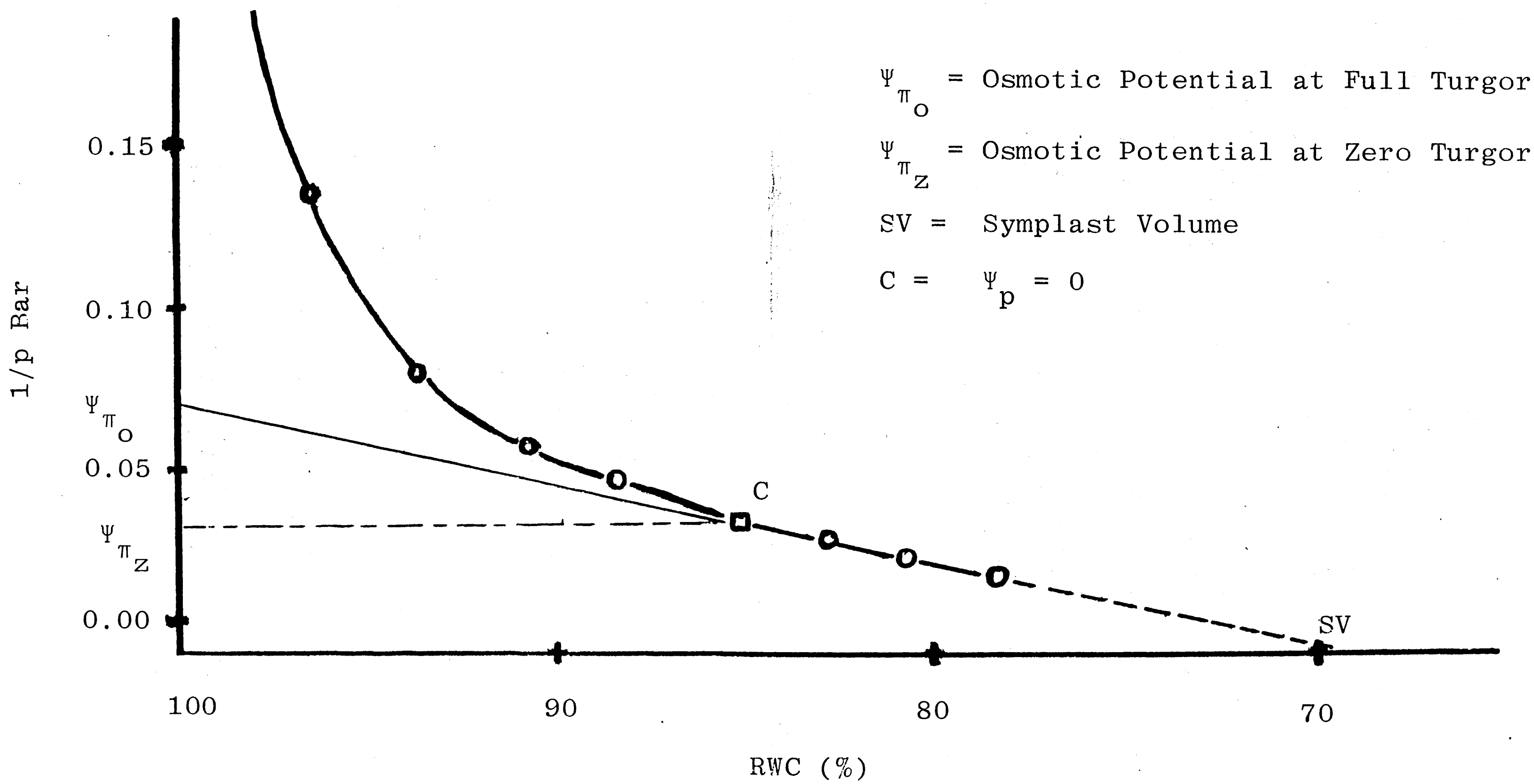

Figure 5. Pressure-Volume (P-V) Curve for Loblolly Pine Seedlings, North Carolina Seed Source, Well-Watered Treatment, in September. N = 4.

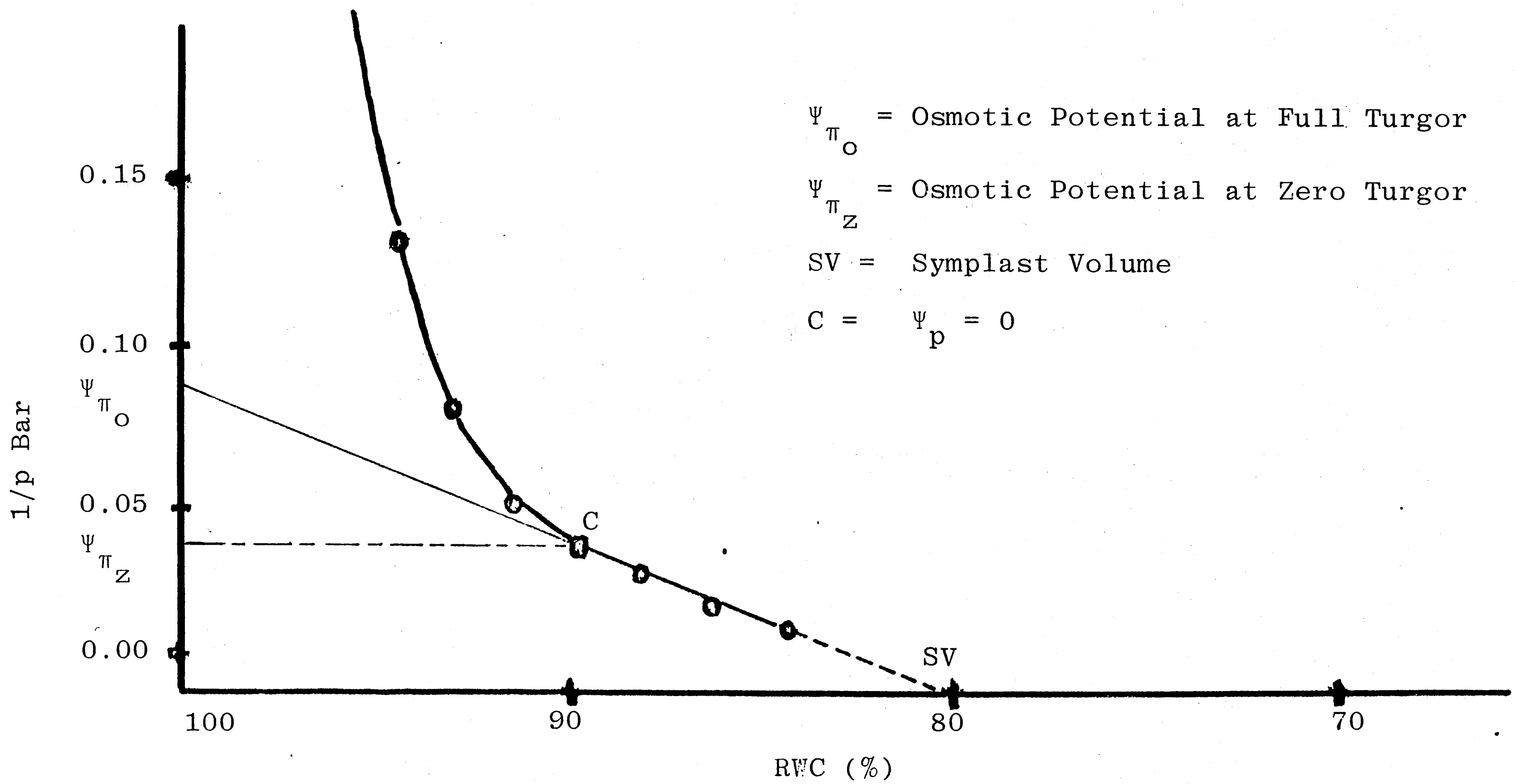

Figure 6. Pressure-Volume (P-V) Curve for Loblolly Pine Seedlings, North Carolina Seed Source, Well-Watered Treatment, in October. N = 4.

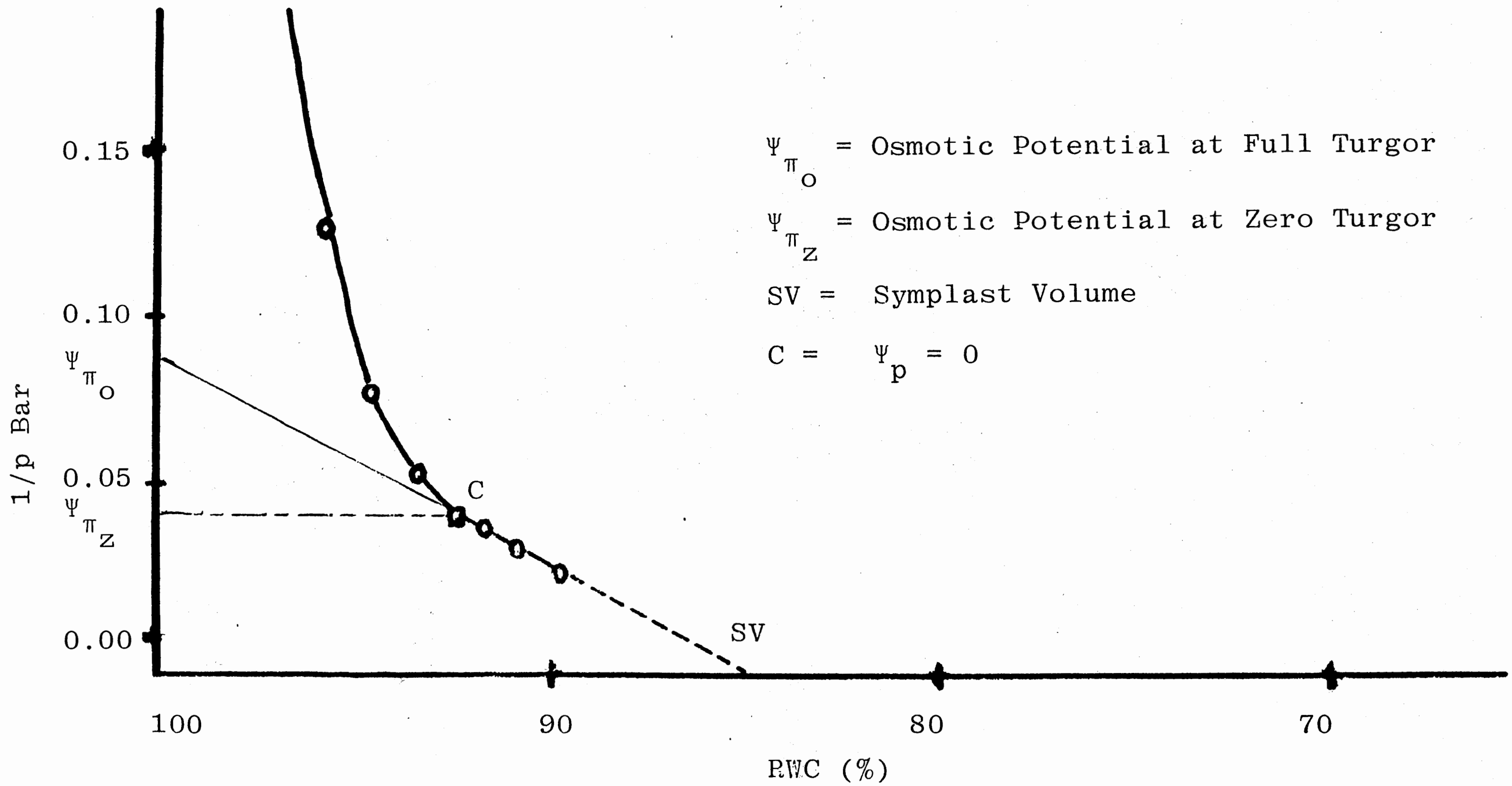

Figure 7. Pressure-Volume (P-V Curve for Loblolly Pine Seedlings, North Carolina Seed Source, Well-Watered Treatment, in November. N = 2.

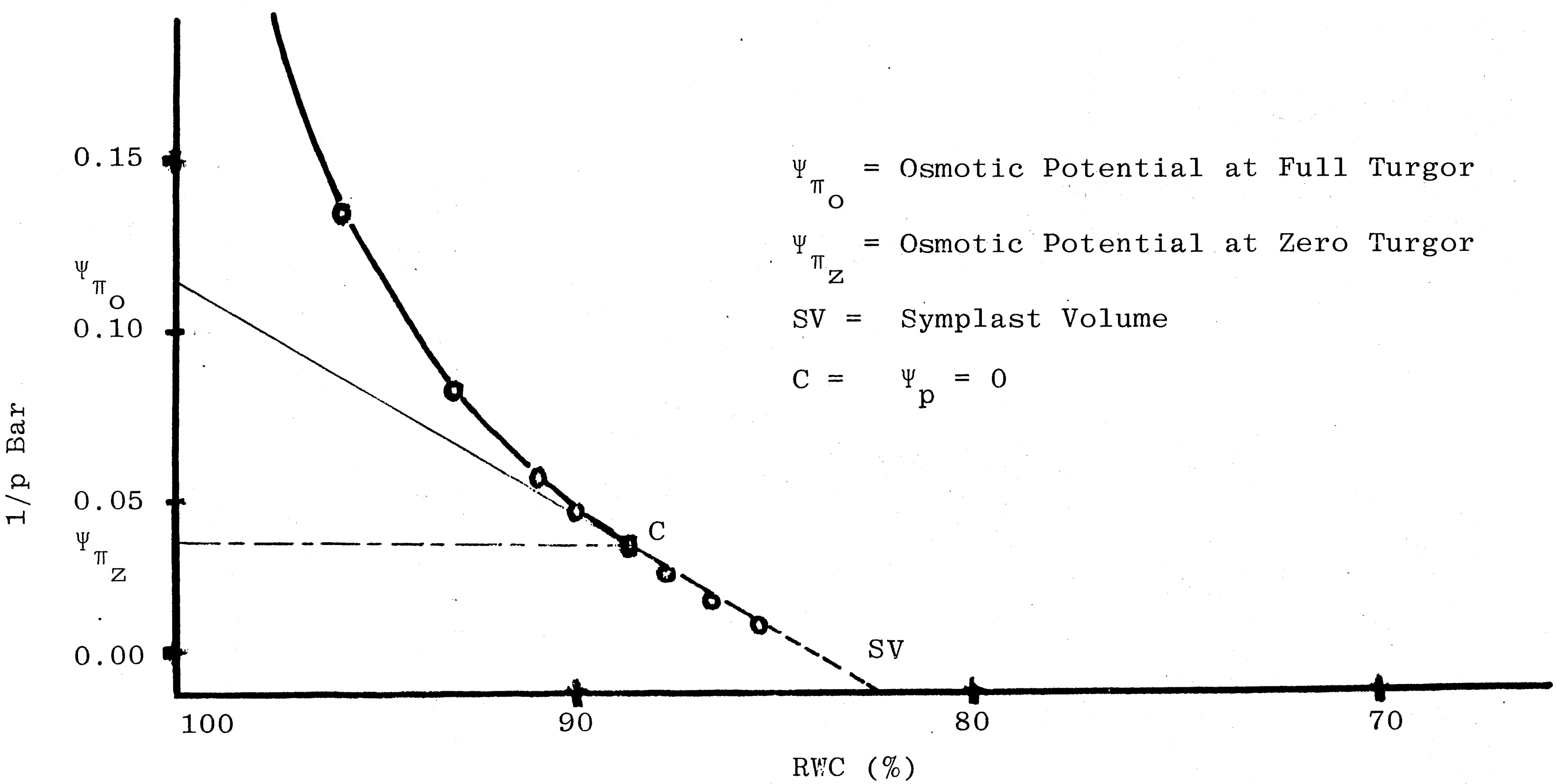

Figure 8. Pressure-Volume (P-V Curve for Loblolly Pine Seedlings, North Carolina Seed Source, Well-Watered Treatment, in January. N = 4.

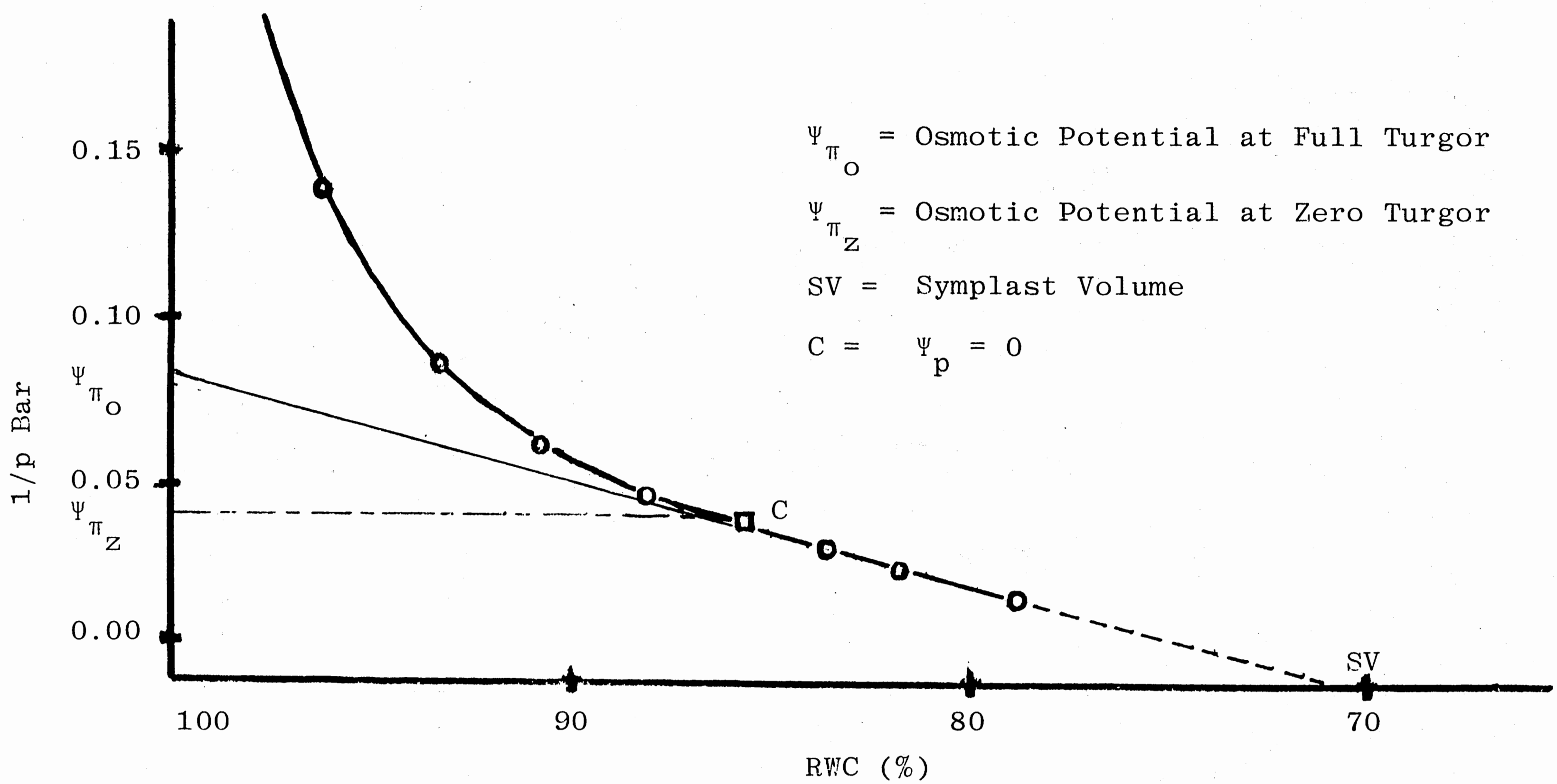

Figure 9. Pressure-Volume (P-V) Curve for Loblolly Pine Seedlings, North Carolina Seed Source, Water-Stressed Treatment, in September. N = 4.

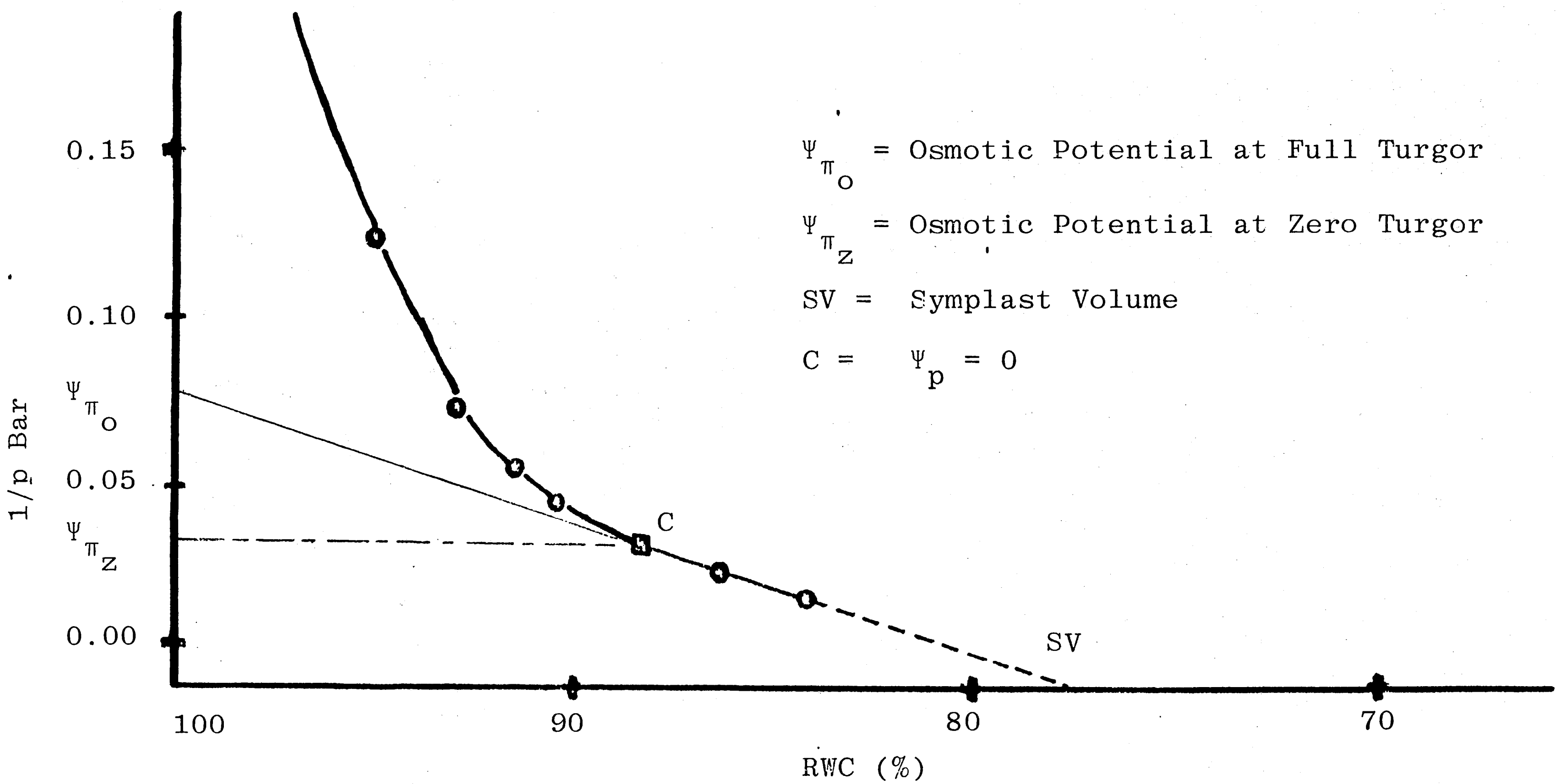

Figure 10. Pressure-Volume (P-V) Curve for Loblolly Pine Seedlings, North Carolina Seed Source, Water-Stressed Treatment, in October. N = 4.

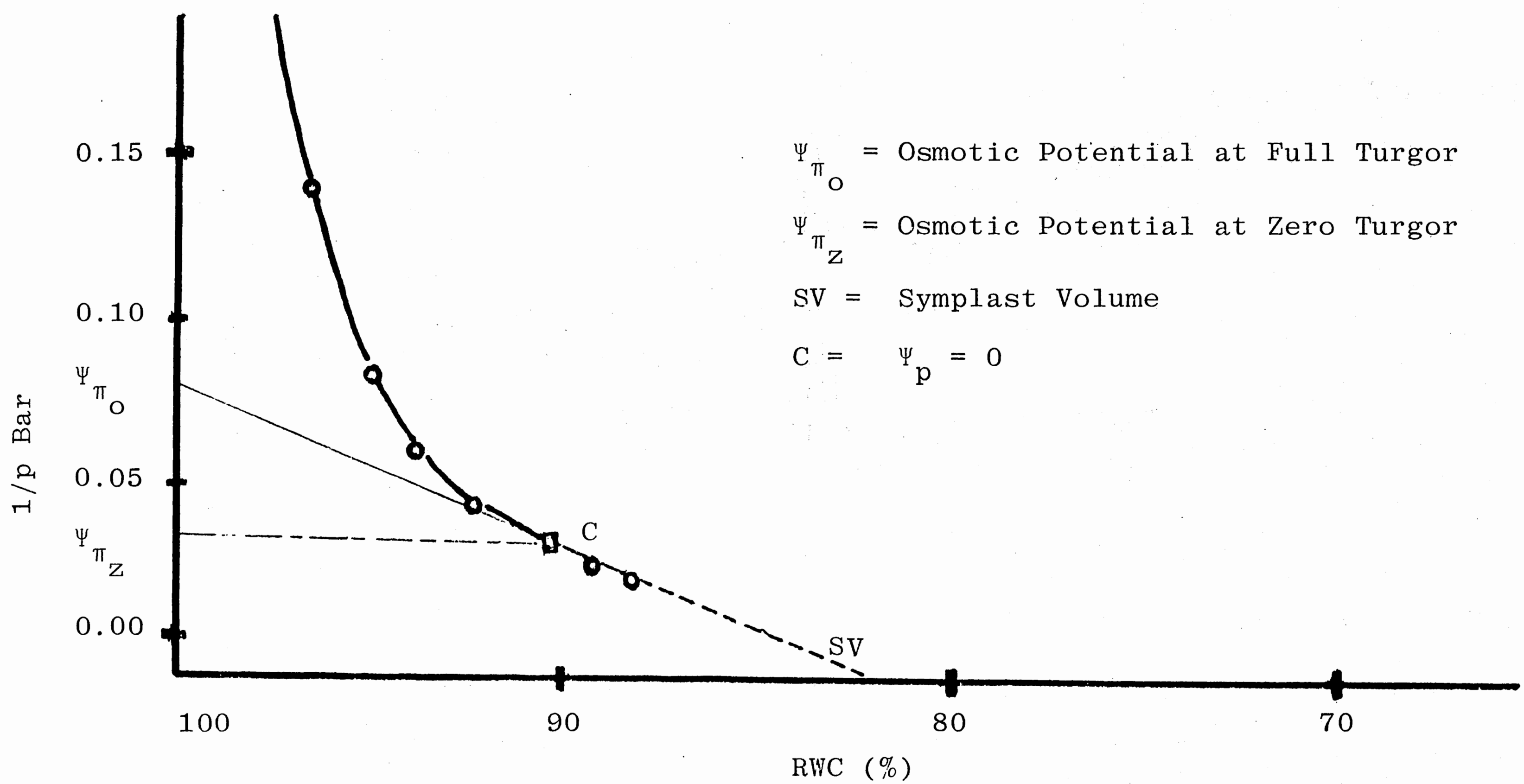

Figure 11. Pressure-Volume (P-V) Curve for Loblolly Pine Seedlings, North Carolina Seed Source, Water-Stressed Treatment, in November. N = 2.

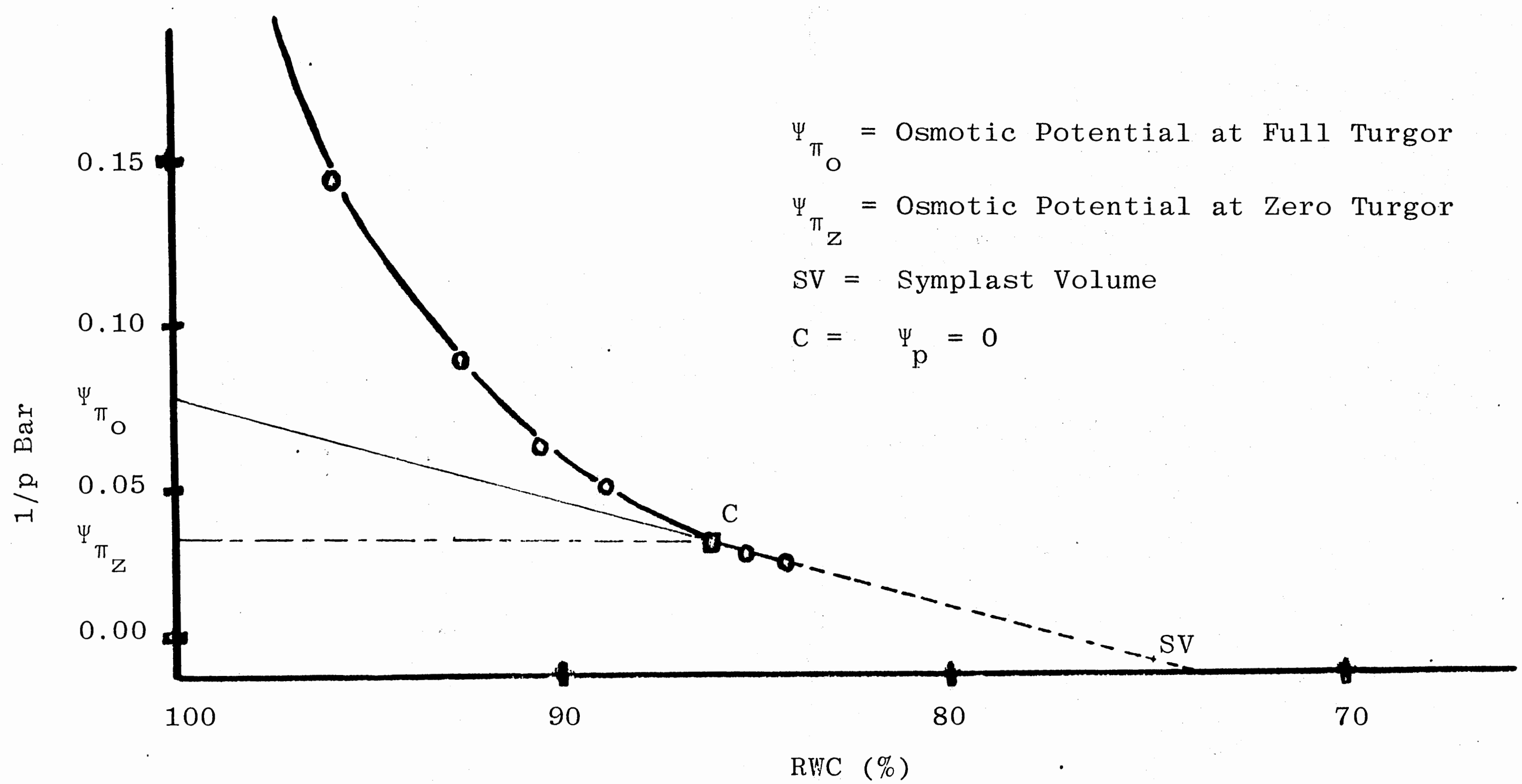

Figure 12. Pressure-Volume (P-V) Curve for Loblolly Pine Seedlings, North Carolina Seed Source, Water-Stressed Treatment, in January. N = 4.

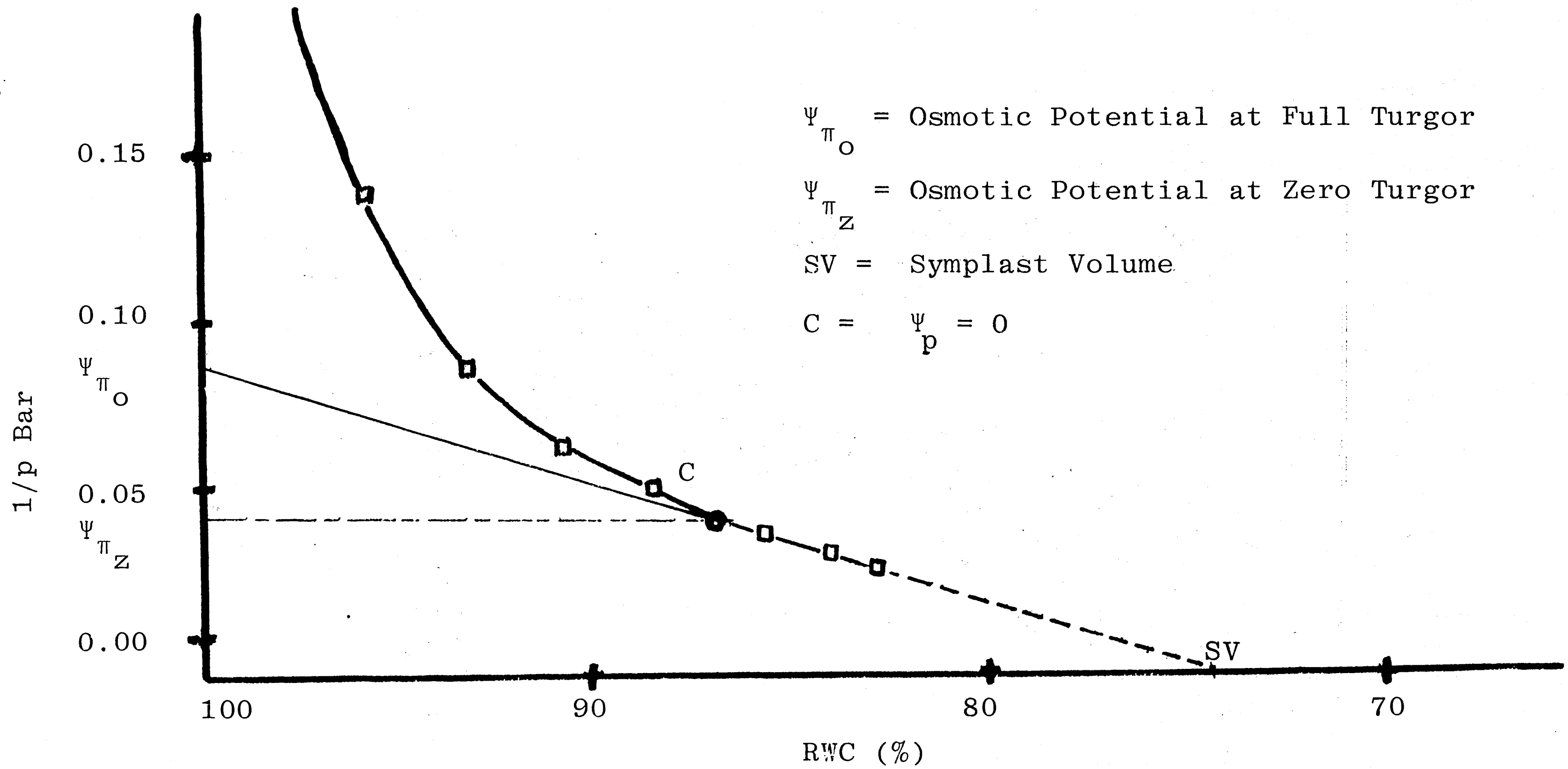

Figure 13. Pressure-Volume (P-V) Curve for Loblolly Pine Seedlings, Oklahoma Seed Source, Well-Watered Treatment, in September. N = 4.

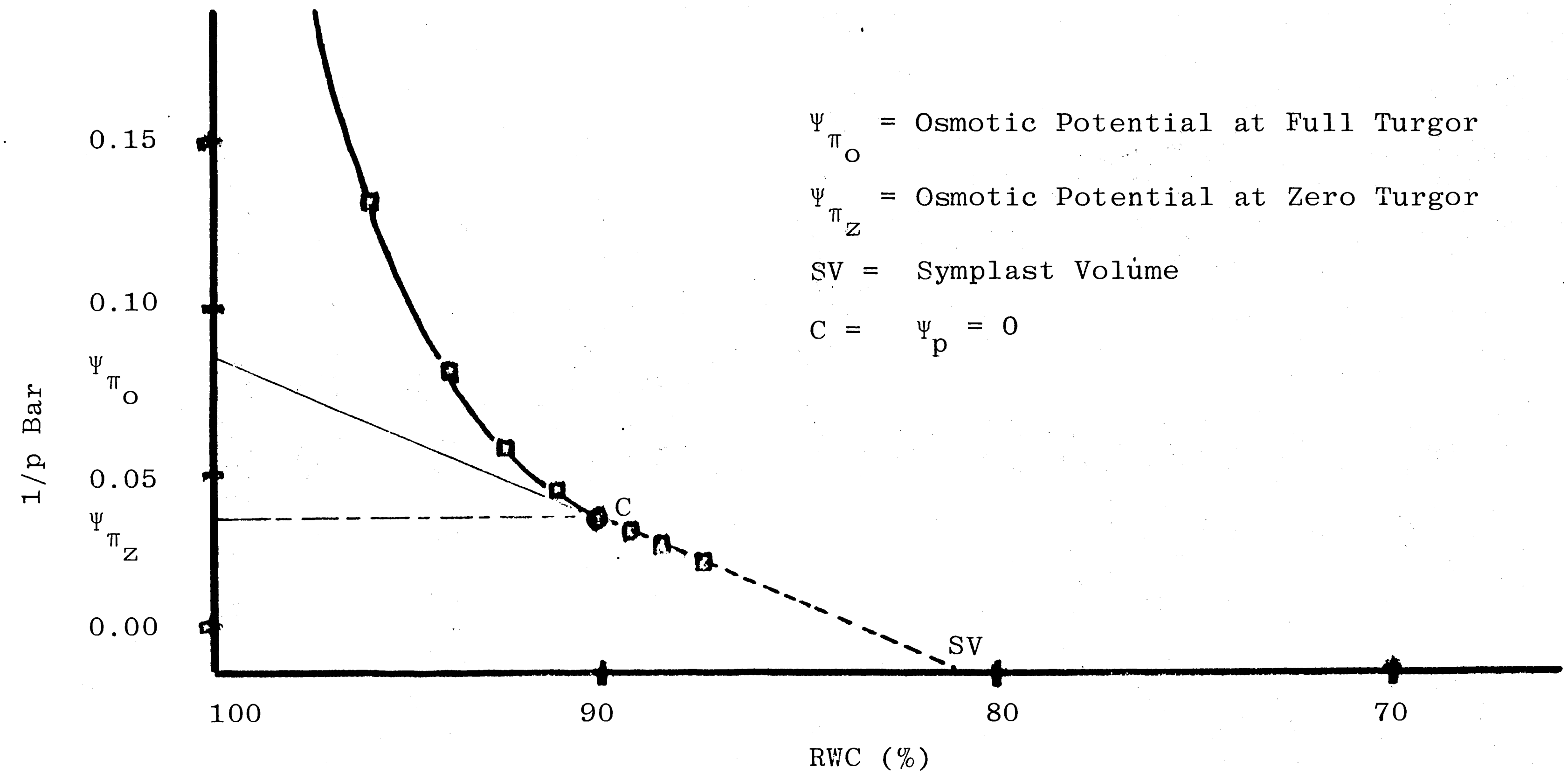

Figure 14. Pressure-Volume (P-V) Curve for Loblolly Pine Seedlings, Oklahoma Seed Source, Well-Watered Treatment, in October. N = 4.

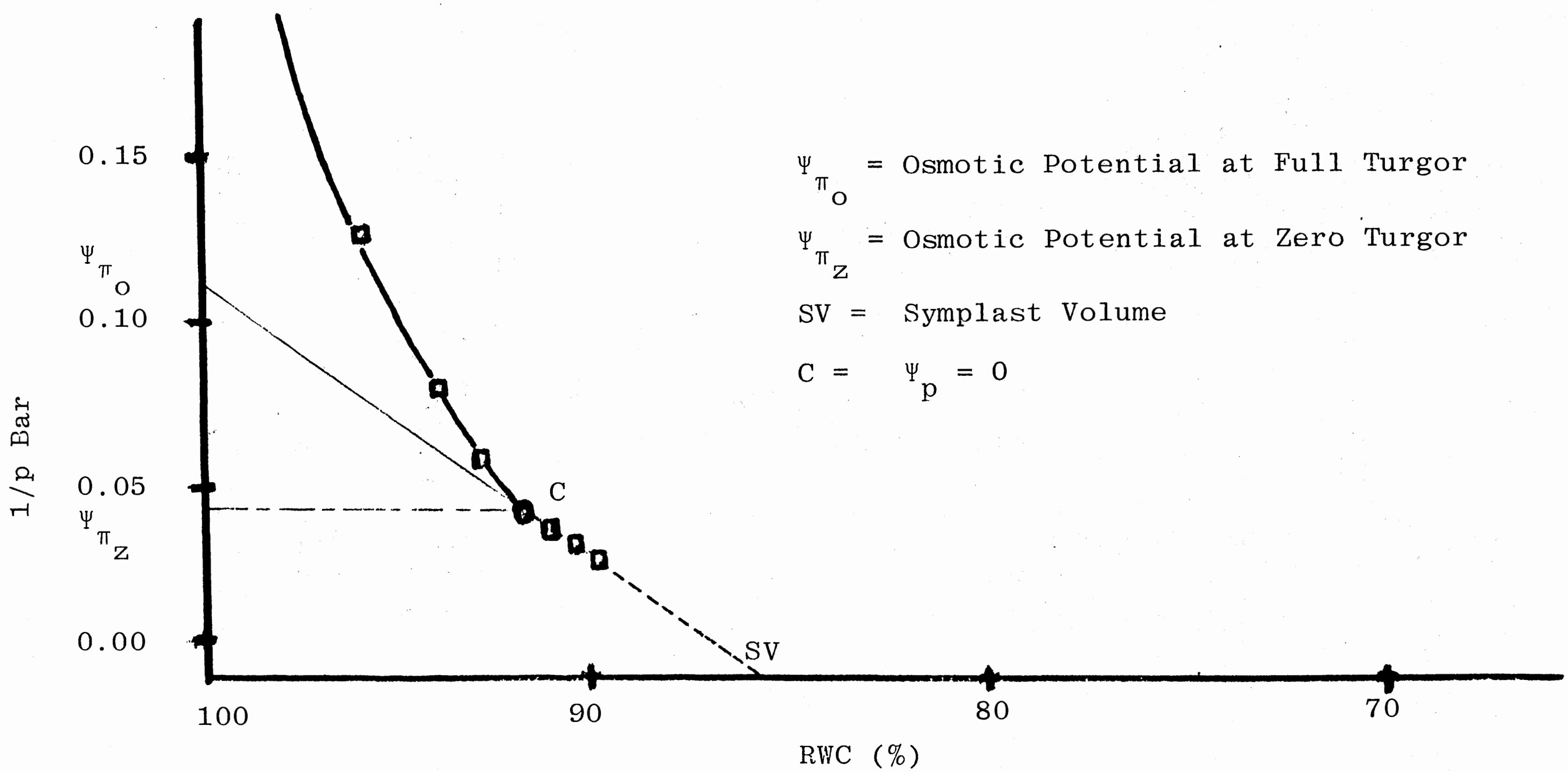

Figure 15. Pressure-Volume (P-V) Curve for Loblolly Pine Seedlings, Oklahoma Seed Source, Well-Watered Treatment, in November. N = 2.

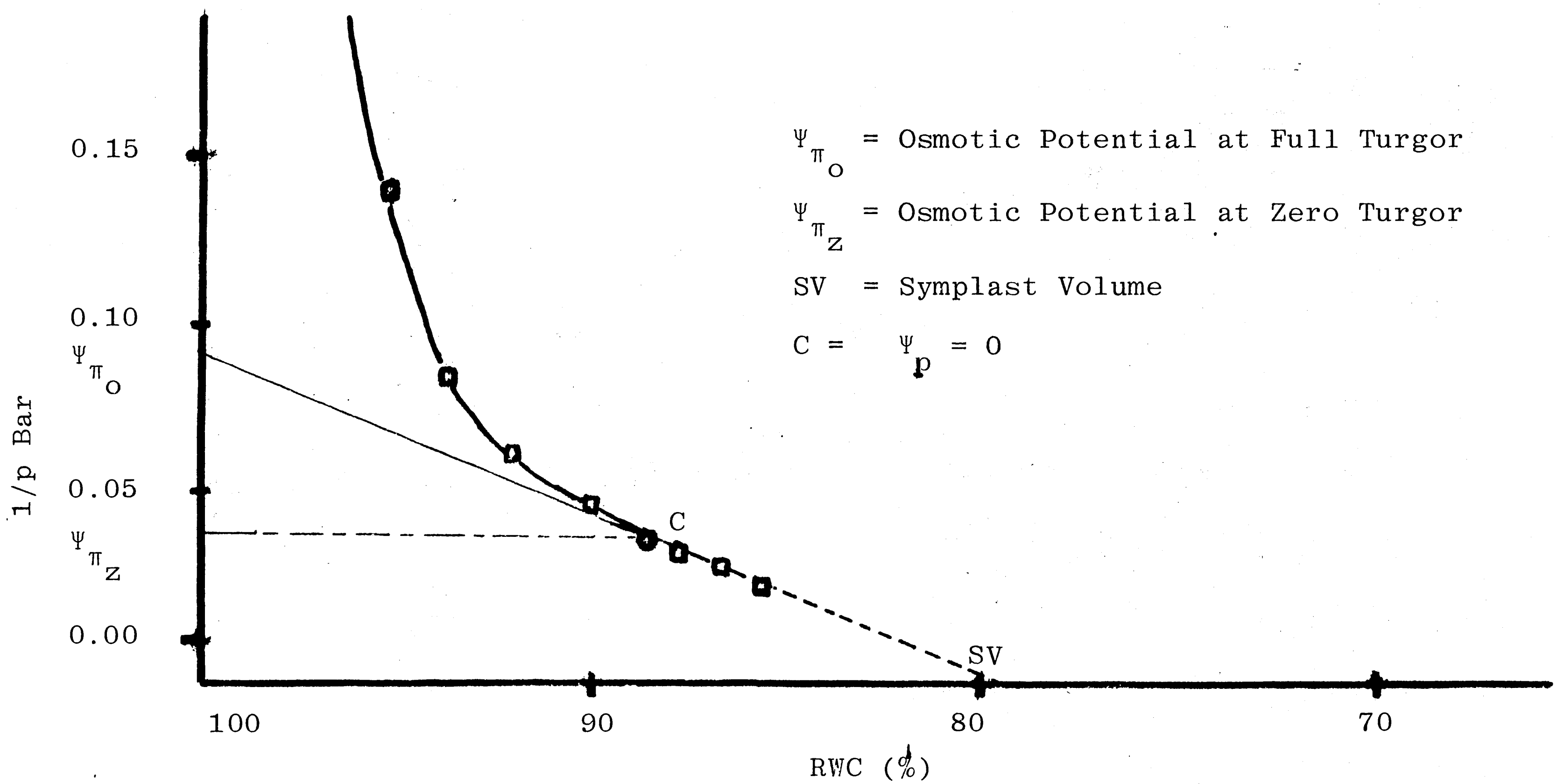

Figure 16. Pressure-Volume (P-V) Curve for Loblolly Pine Seedlings, Oklahoma Seed Source, Well-Watered Treatment, in January. N = 4.

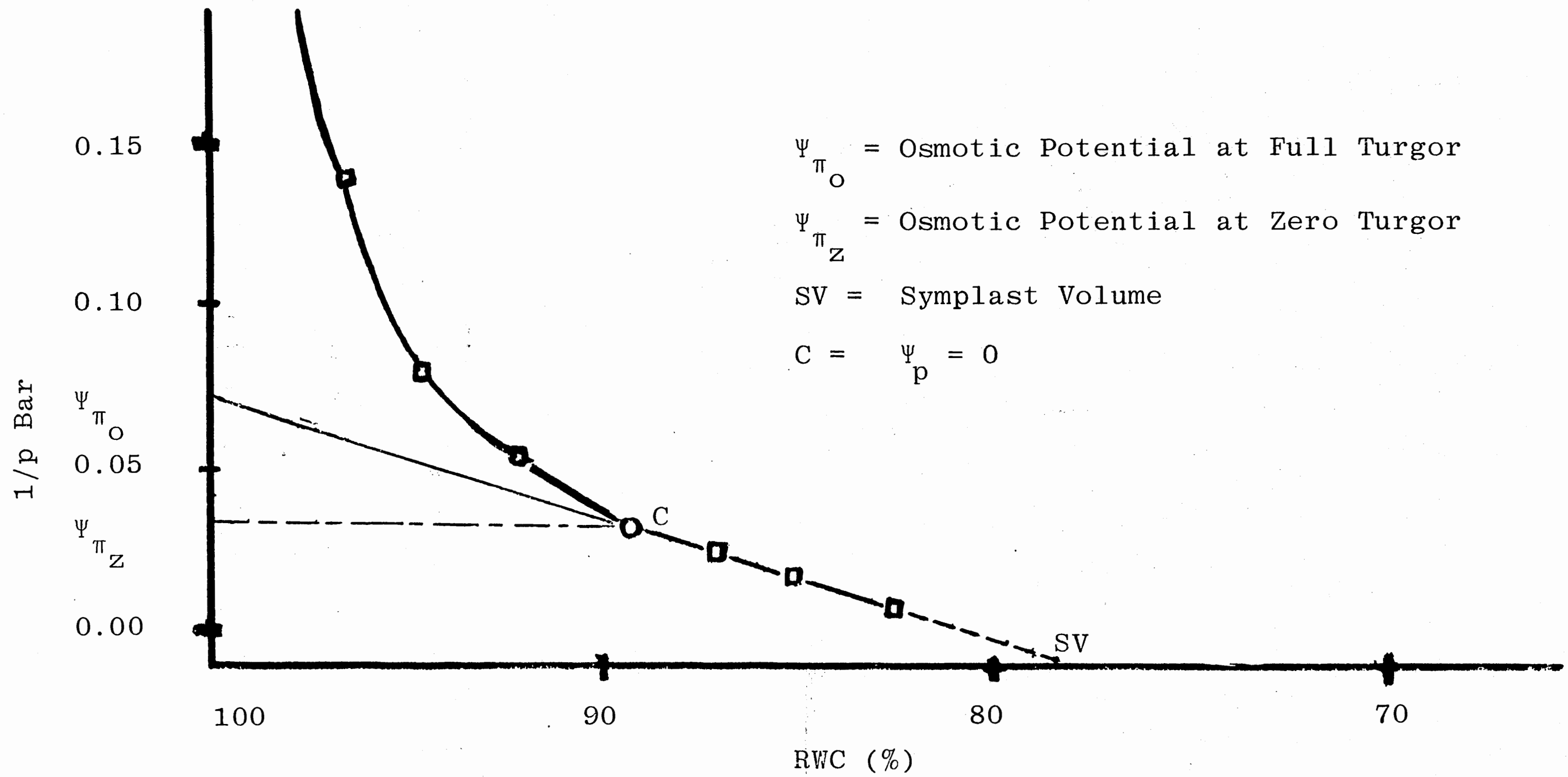

Figure 17. Pressure-Volume (P-V) Curve for Loblolly Pine Seedlings, Oklahoma Seed Source, Water-Stressed Treatment, in September. N = 4.

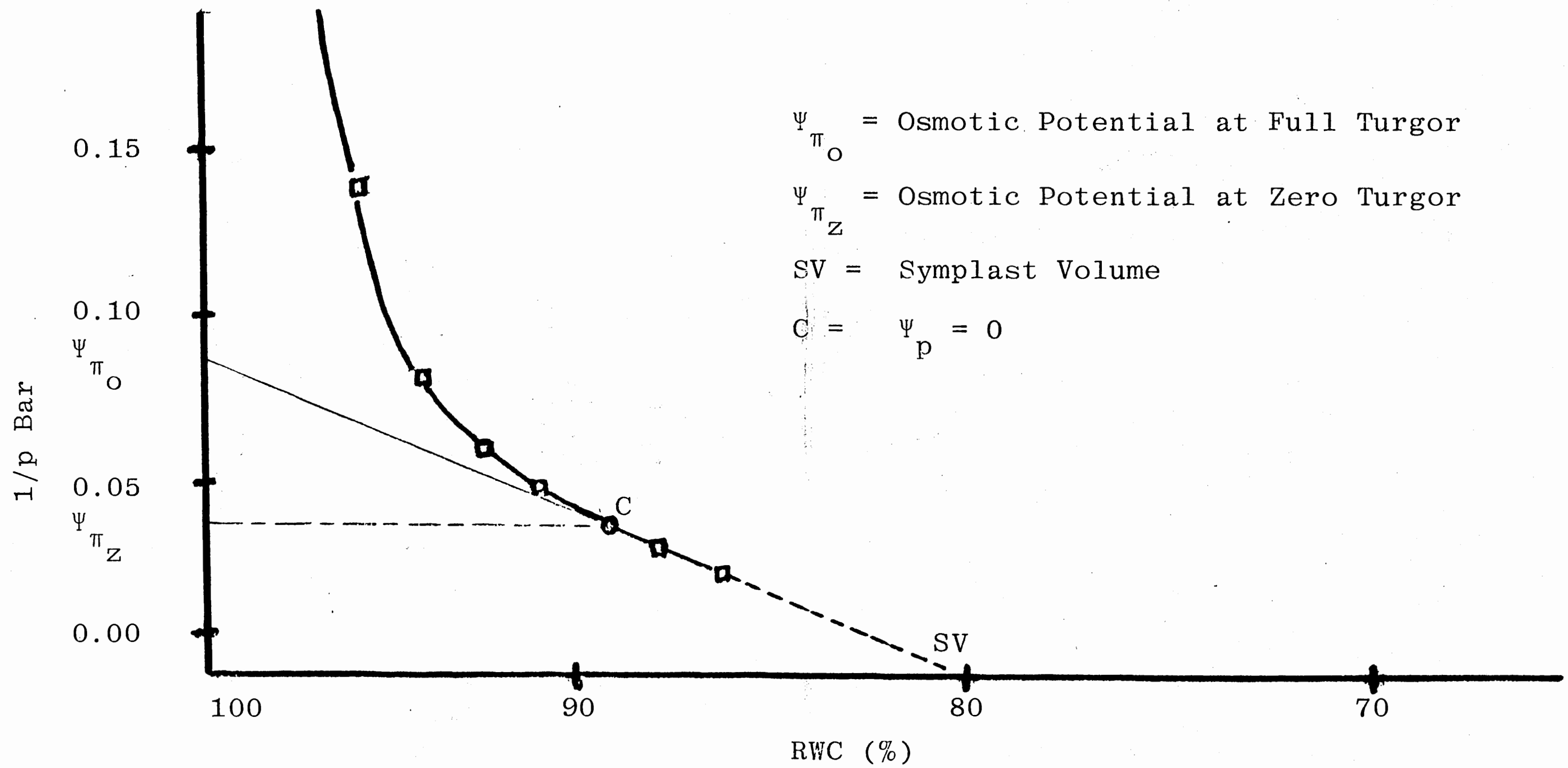

Figure 18. Pressure-Volume (P-V) Curve for Loblolly Pine Seedlings, Oklahoma Seed Source, Water-Stressed Treatment, in October. N = 4.

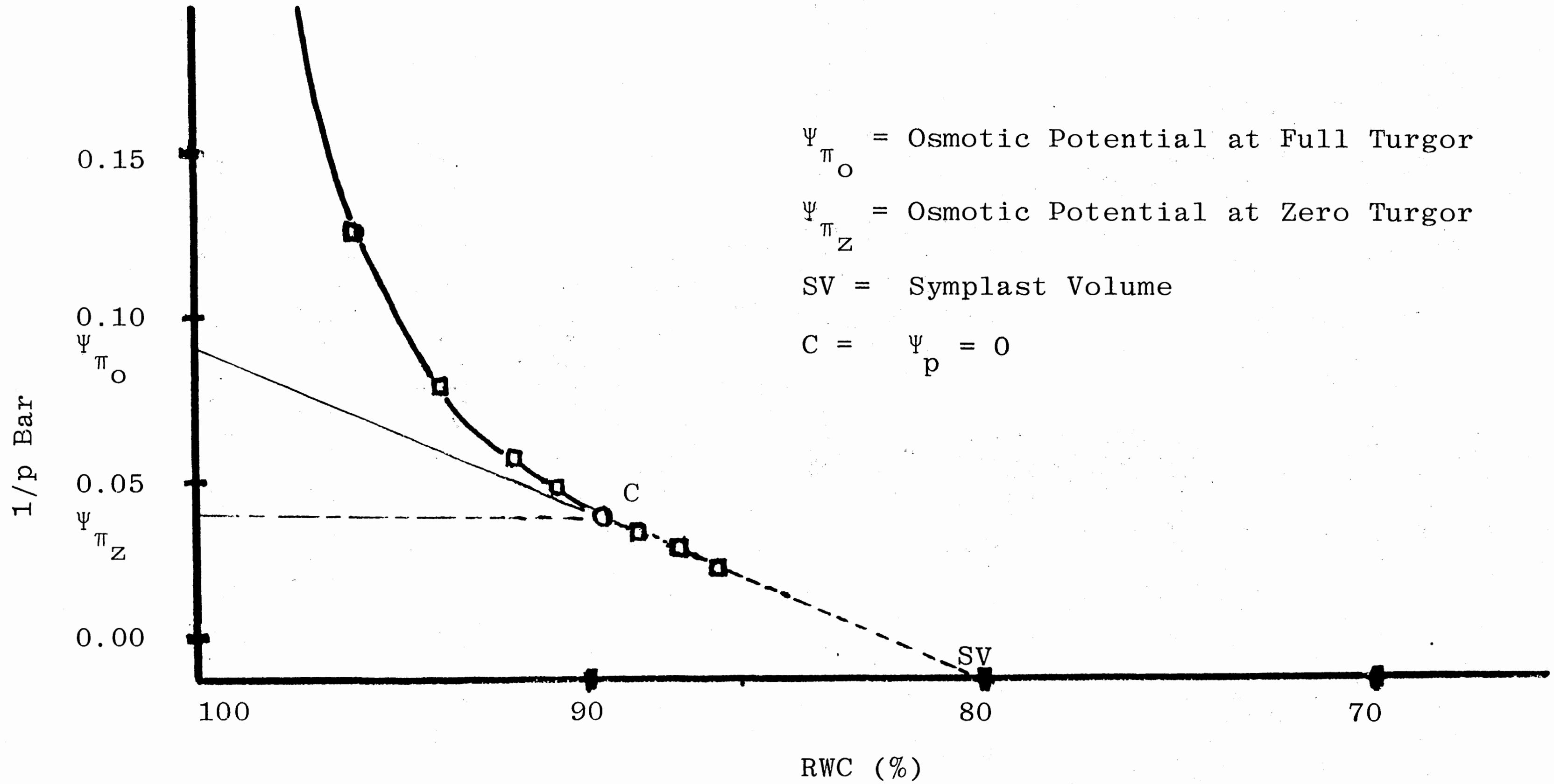

Figure 19. Pressure-Volume (P-V) Curve for Loblolly Pine Seedlings, Oklahoma Seed Source, Water-Stressed Treatment, in November. N = 2.

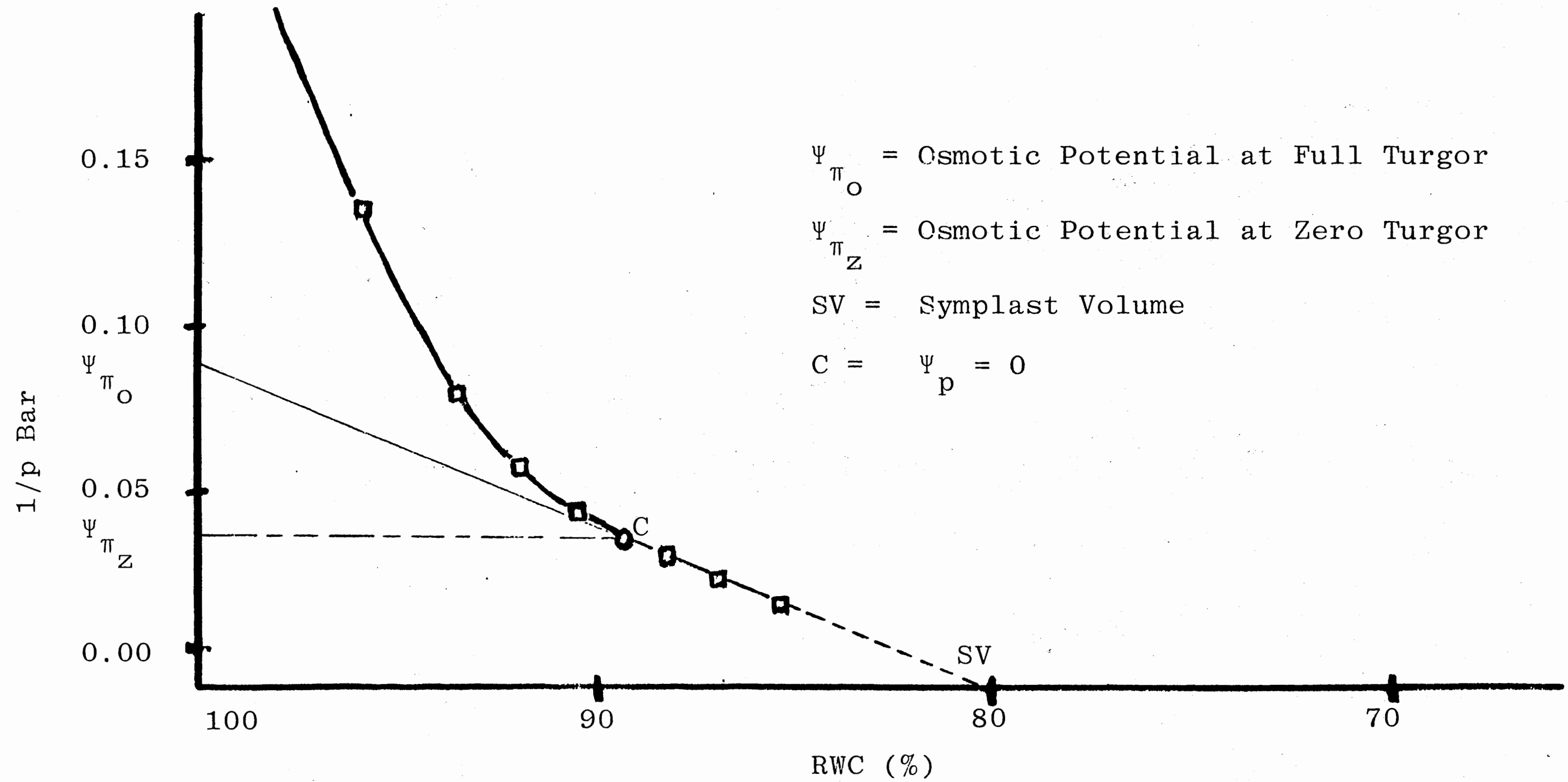

Figure 20. Pressure-Volume (P-V) Curve for Loblolly Pine Seedlings, Oklahoma Seed Source, Water-Stressed Treatment, in January. N = 4.

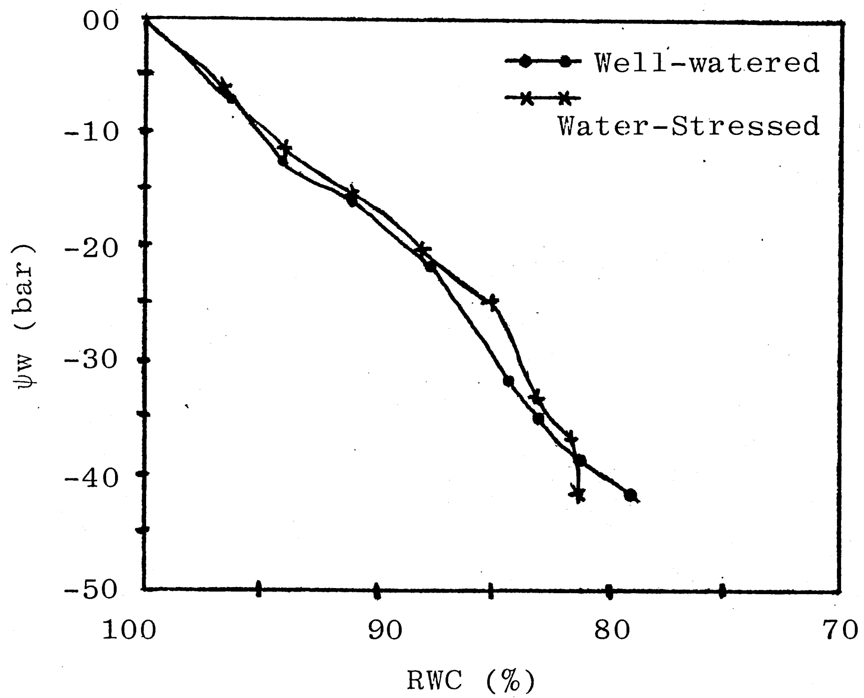

Figure 21. Water potential isotherms for Loblolly pine seedlings, North Carolina seed source by cultural treatment, in September. (N = 4)

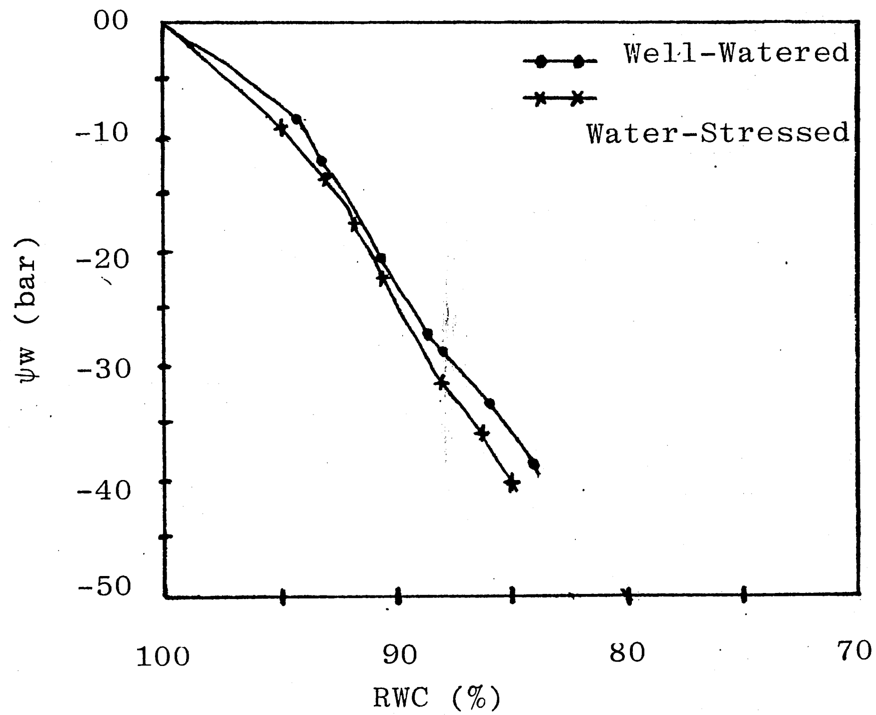

Figure 22. Water potential isotherms for Loblolly pine seedlings, North Carolina seed source by cultural treatment, in October. (N = 4)

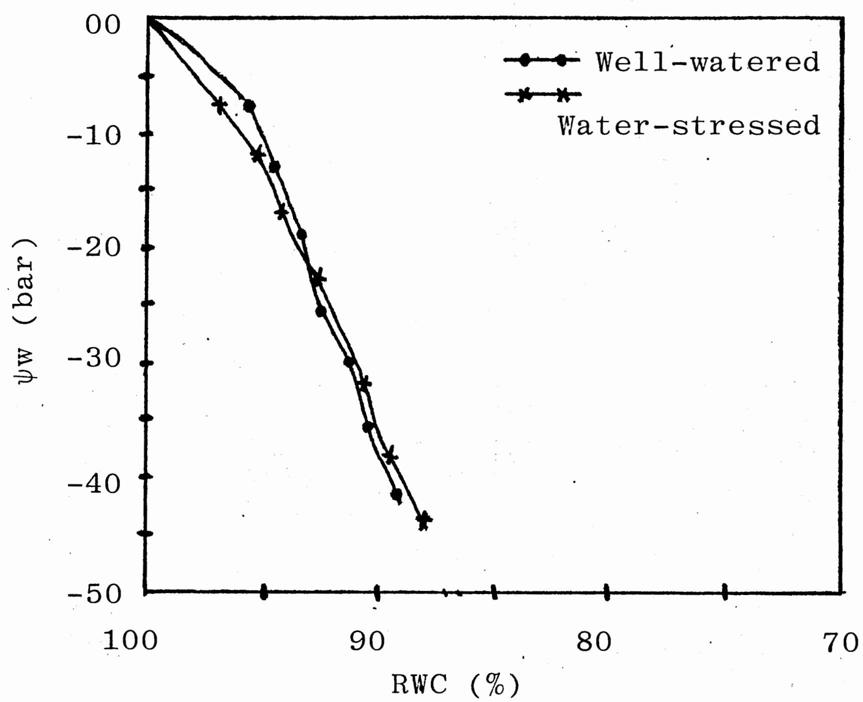

Figure 23. Water potential isotherms for Loblolly Pine seedlings, North Carolina seed source by cultural treatment, in November. (N = 2)

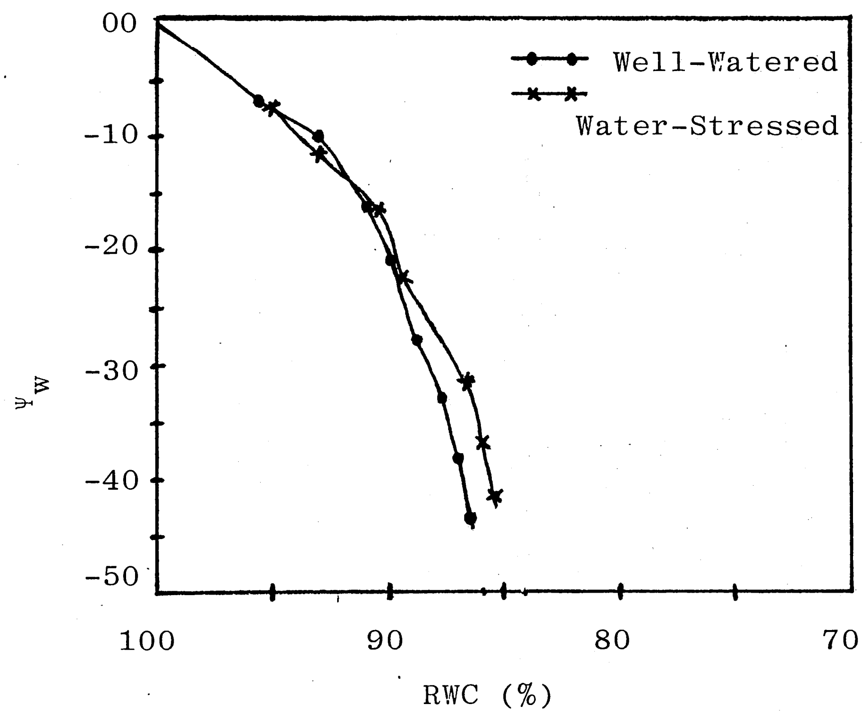

Figure 24. Water potential isotherms for Loblolly Pine seedlings, North Carolina seed source by cultural treatment, in January. (N = 4)

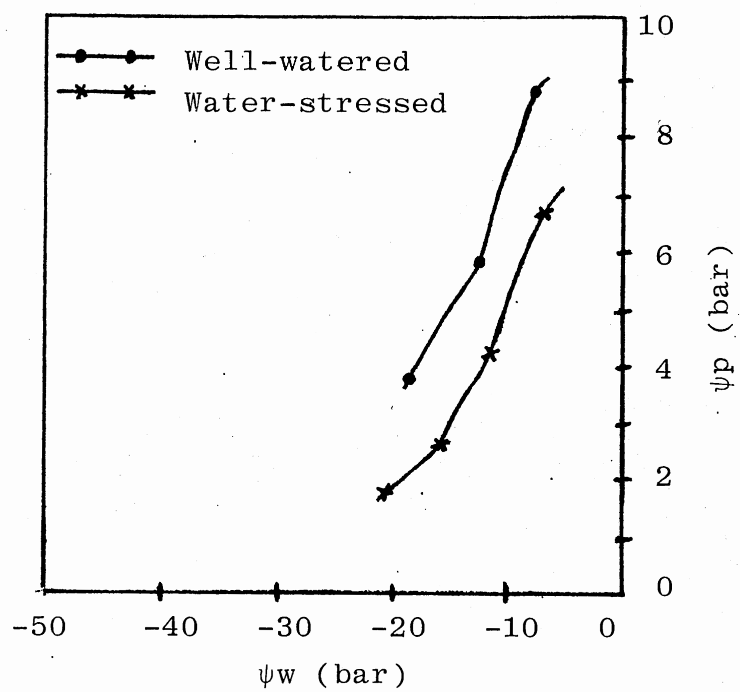

Figure 25. Turgor maintenance for Loblolly Pine seedlings, North Carolina seed source by cultural treatment, in September. (N = 4)

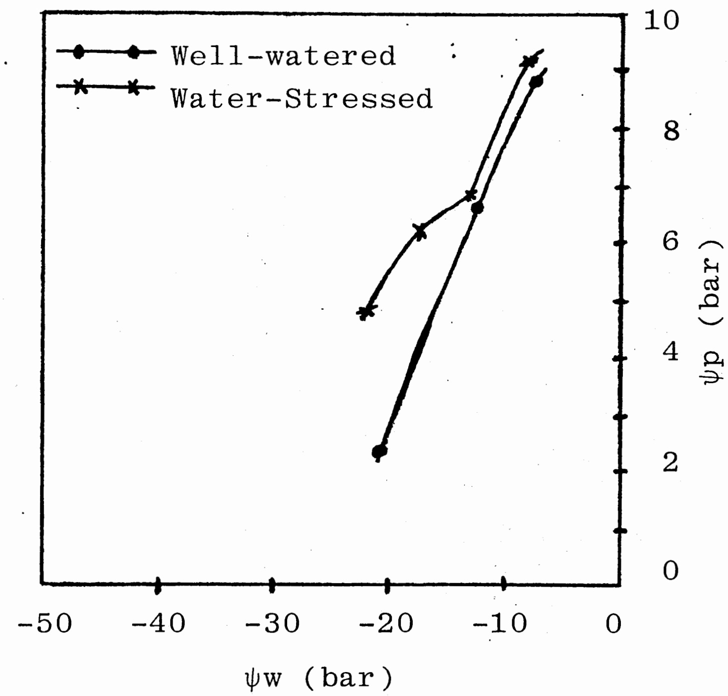

Figure 26. Turgor maintenance for Loblolly Pine seedlings, North Carolina seed source by cultural treat-ent, in October. (N = 4)

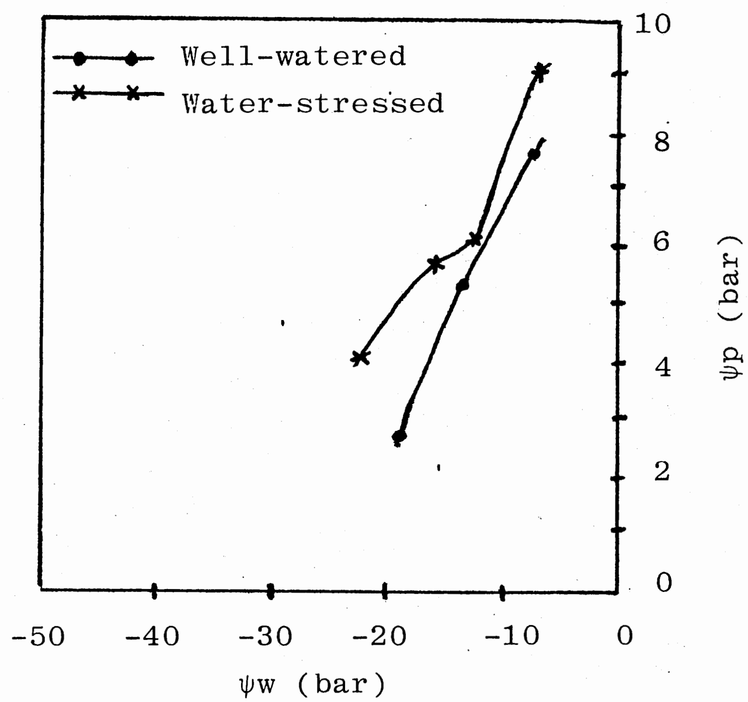

Figure 27. Turgor maintenance for Loblolly Pine seedlings, North Carolina seed source by cultural treatment, in November. (N = 2)

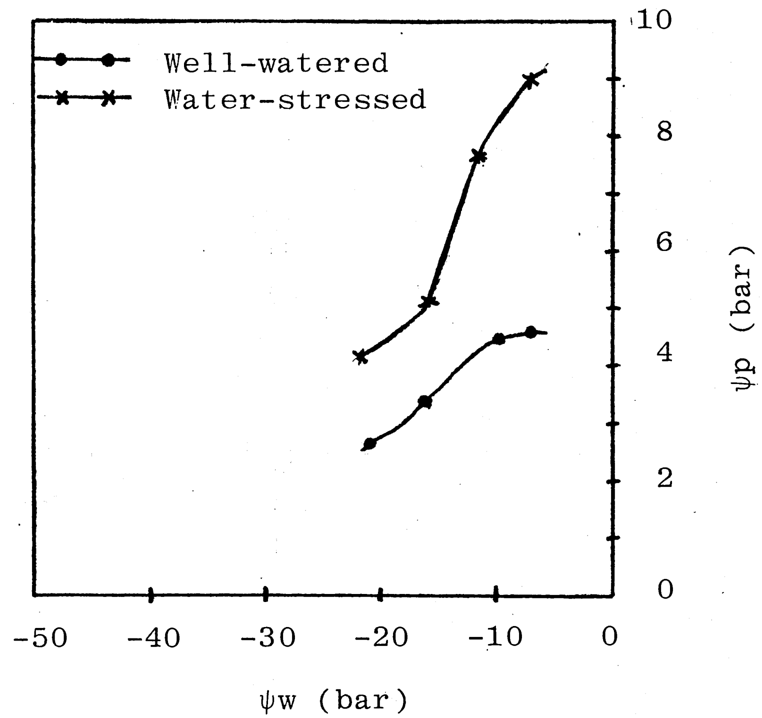

Figure 28. Turgor maintenance for Loblolly Pine seedlings, North Carolina seed source by cultural treatment, in January. (N = 4)

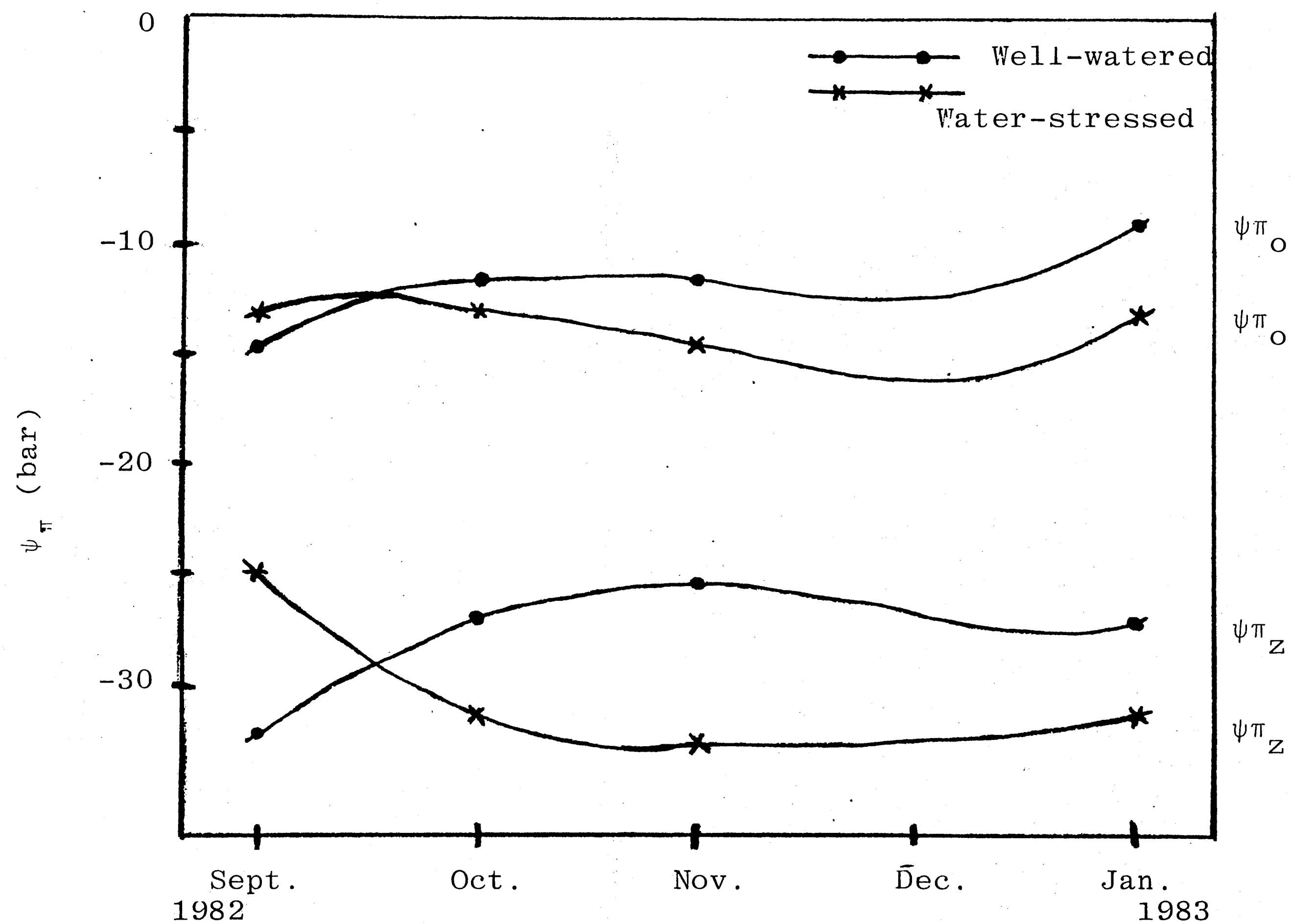

Figure 29. Seasonal course of osmotic potential at full turgor ($\psi\pi_o$) and zero turgor ($\psi\pi_z$) for Loblolly Pine seedlings, North Carolina seed source by cultural treatment. Each point is a mean of 2 or 4 determinations.

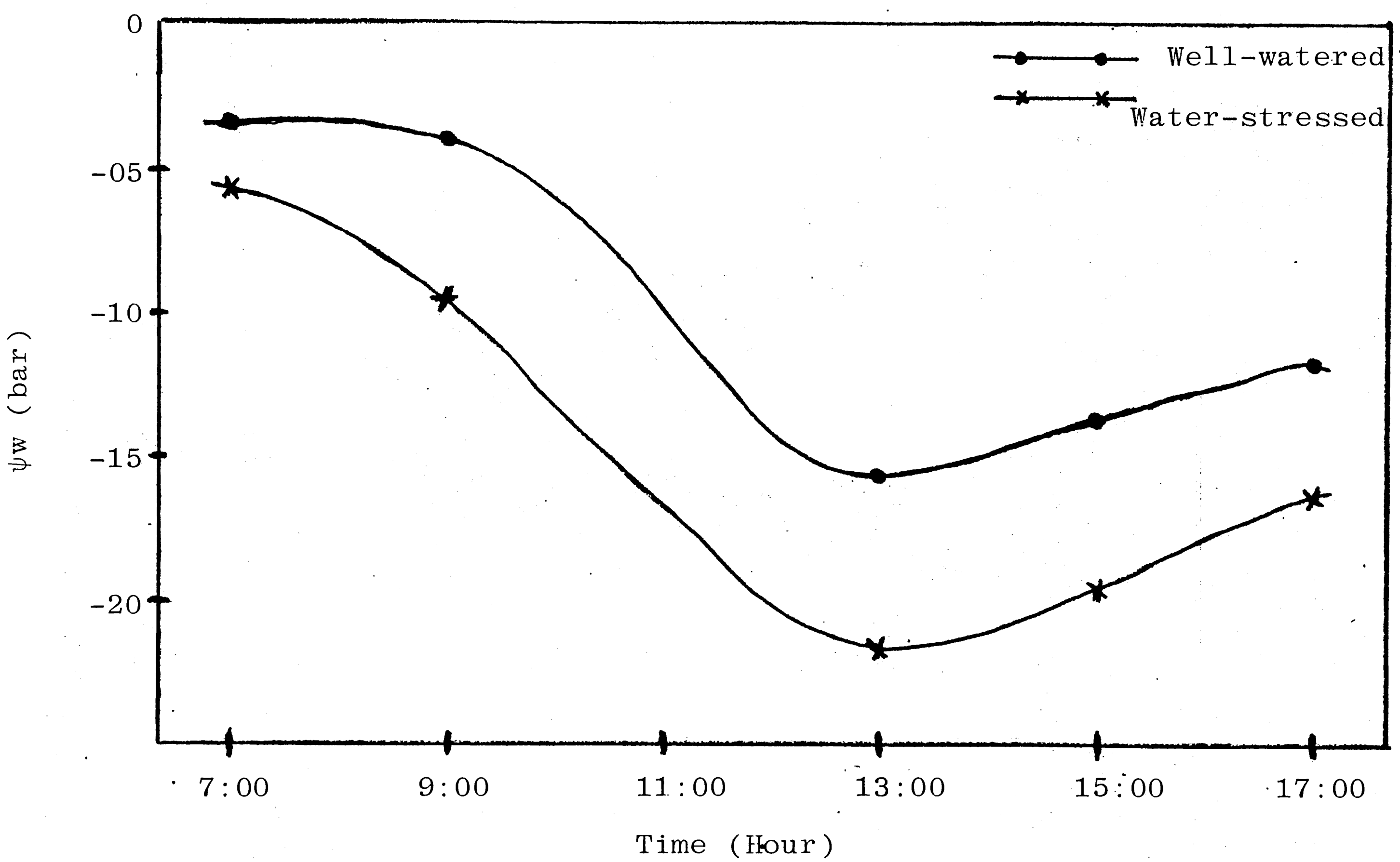

Figure 30. Diurnal curve of water potential (ψw) for Loblolly Pine seedlings, North Carolina seed source by cultural treatment. Each point is a mean of 3 determinations, in October.

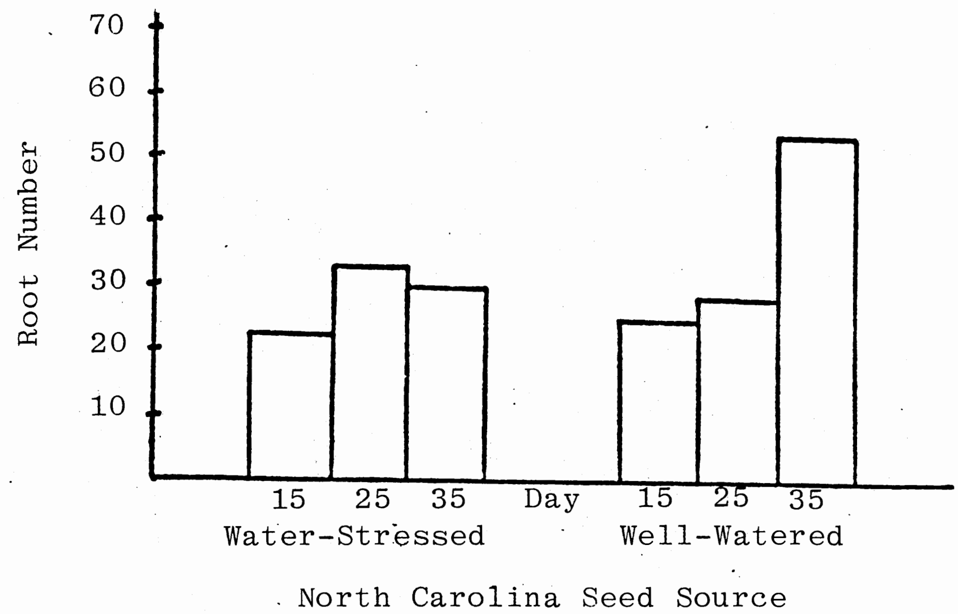

Figure 31. Root Regeneration by Time and Nursery Cultural Treatment, Warm Growth Chamber.

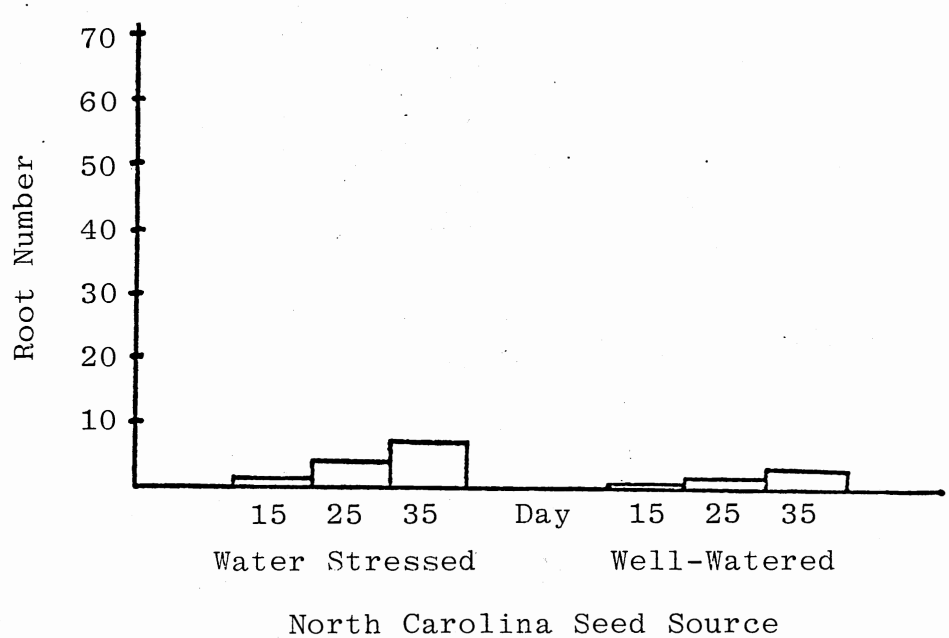

Figure 32. Root Regeneration by Time and Nursery Cultural Treatment, Cold Growth Chamber.

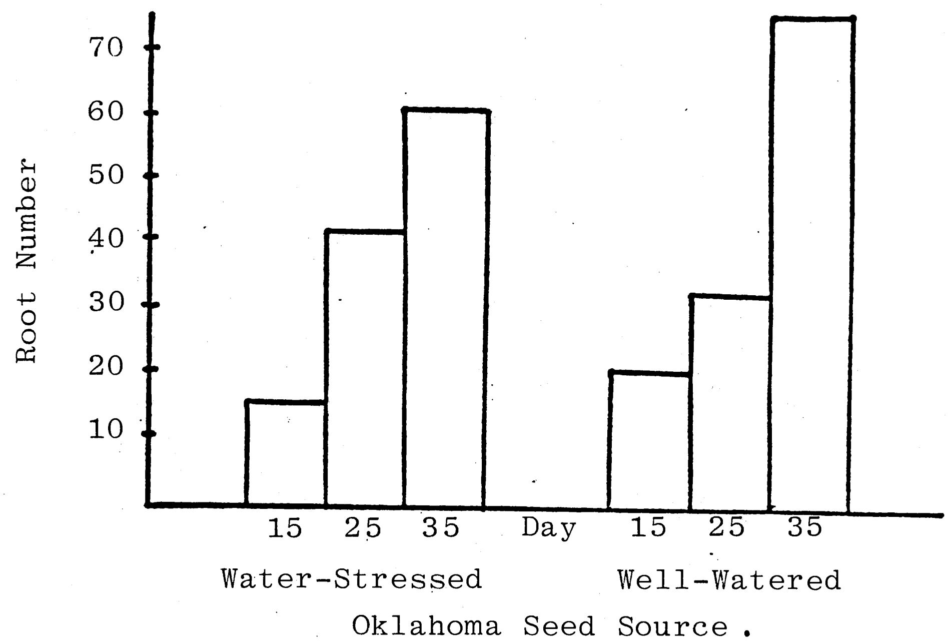

Figure 33. Root Regeneration by Time and Nursery Cultural Treatment, Warm Growth Chamber.

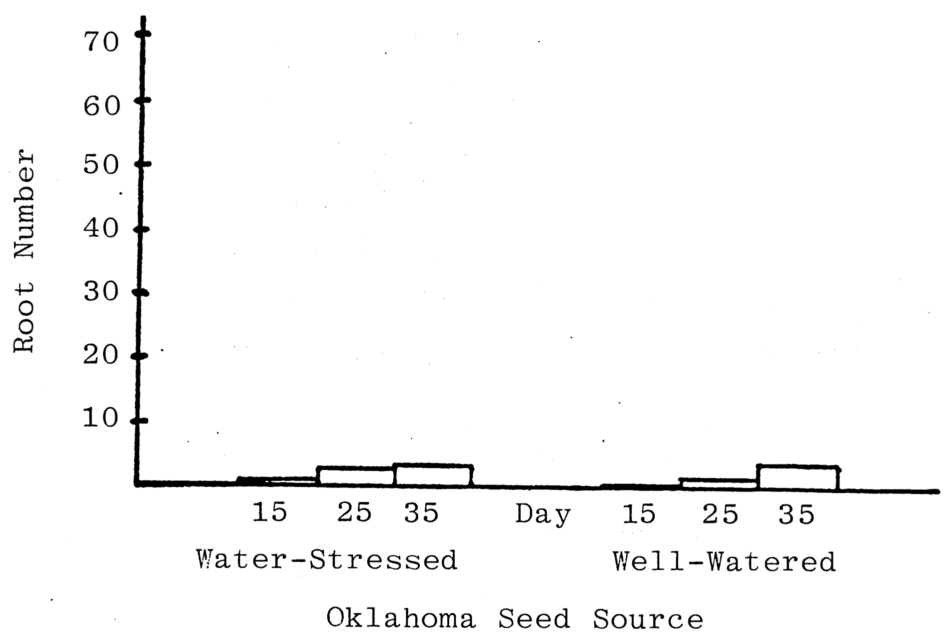

Figure 34. Root Regeneration by Time and Nursery Cultural Treatment, Cold Growth Chamber.

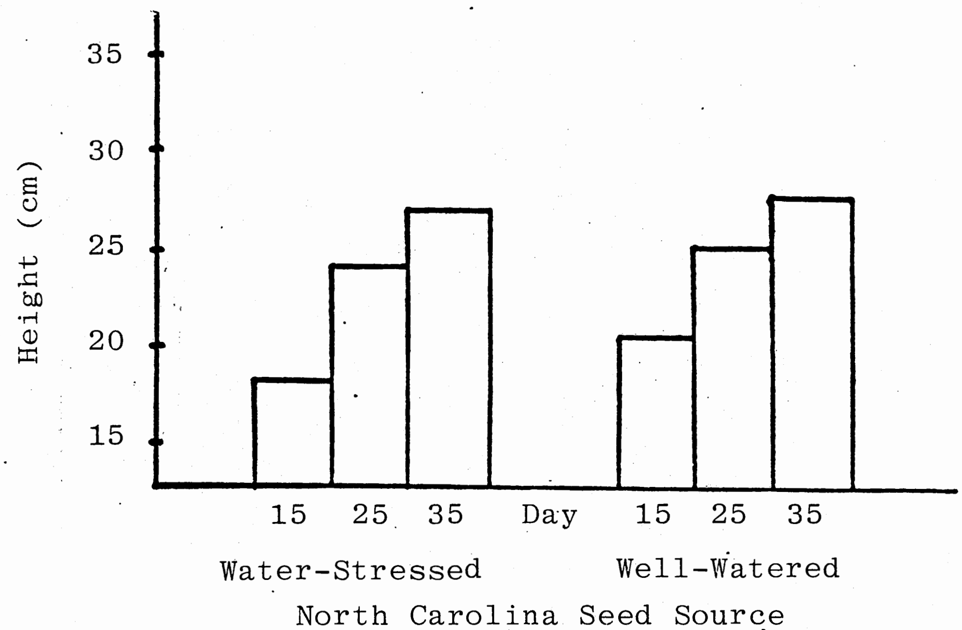

Figure 35. Height by Time and Nursery Cultural Treatment, Warm Growth Chamber.

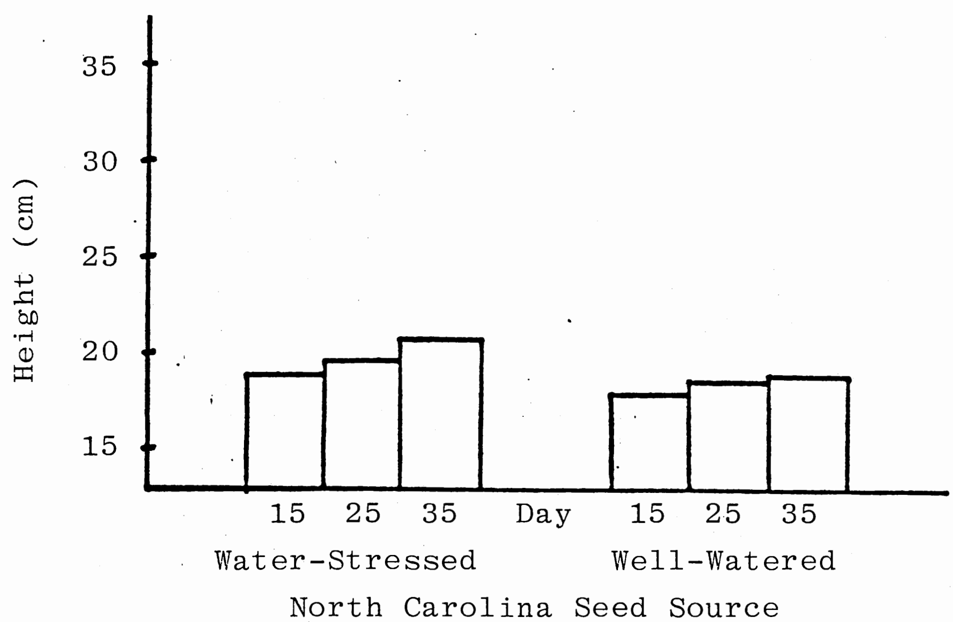

Figure 36. Height by Time and Nursery Cultural Treatment, Cold Growth Chamber.

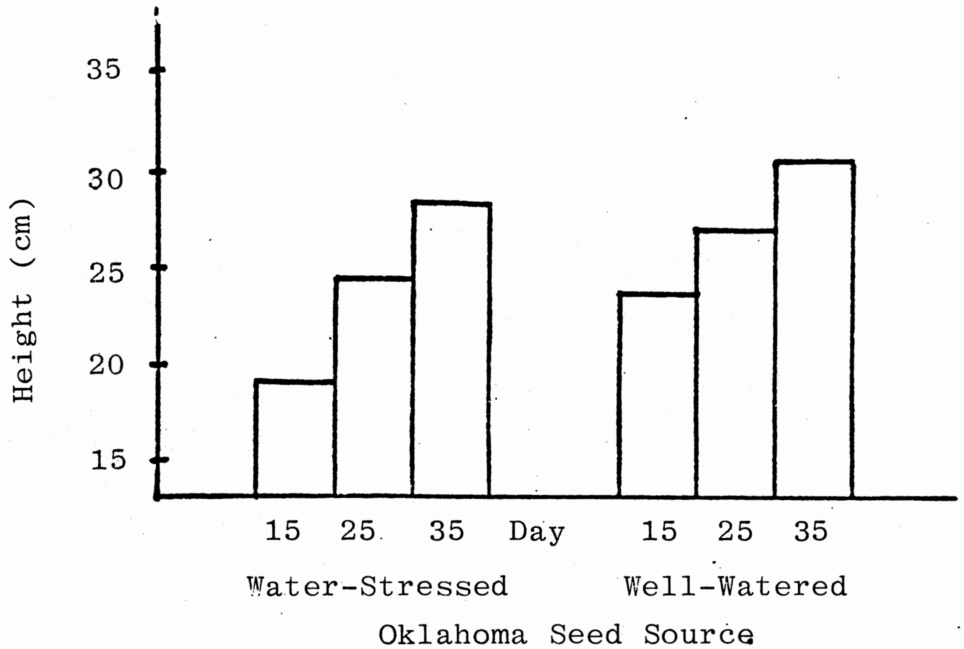

Figure 37. Height by Time and Nursery Cultural Treatment, Warm Growth Chamber.

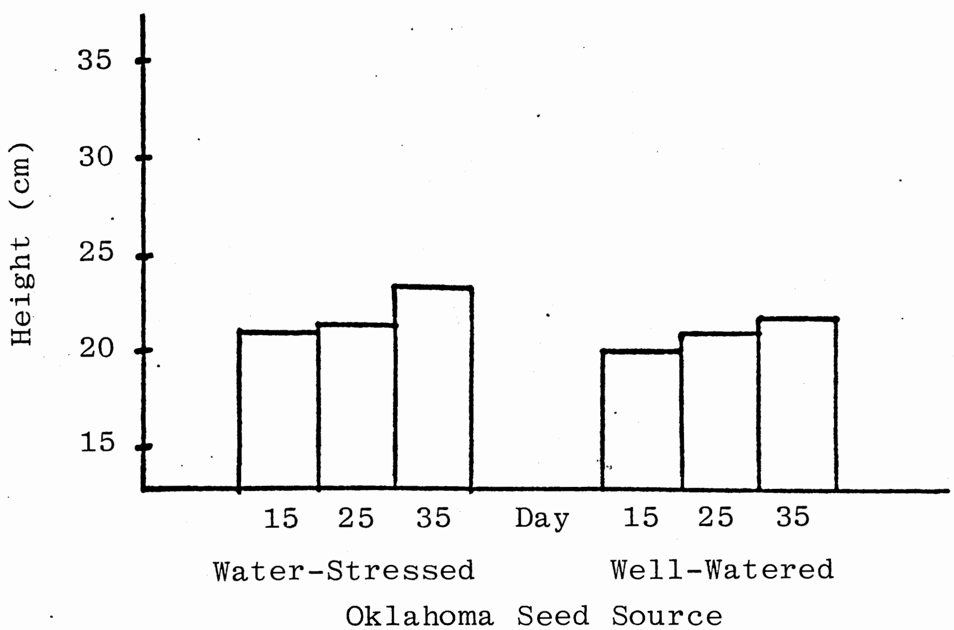

Figure 38. Height by Time and Nursery Cultural Treatment, Cold Growth Chamber.

APPENDIX C

STATISTICAL ANALYSES AND MEAN TABLES

TABLE XI

MEAN VALUES FOR THE RECIPROCAL INVERSE THE PRESSURE AND THE RELATIVE WATER CONTENT BY LOCATION, TREATMENT, AND SAMPLE DATE FOR LOBLOLLY PINE (PINUS TAEDA L.)

Legend

Location		P =	The pressure applied (bar)
Loc 1 = North Carolina		Tube 1 =	The weight of the Tygon tube before test (g)
Loc 2 = Oklahoma		Tube 2 =	The weight of the Tygon tube after test (g)
Treatment		WI =	Weight initial (fresh weight of the sample) (g)
Trt 1 = Well-watered		WF =	Final weight (weight of the sample after testing (g)
Trt 2 = Water-Stressed		WD =	Oven-dried weight of the sample
Sample Date		SI =	The sap expressed at that pressure (g)
Date 1 = September		ST =	The cumulative sap expressed (g)
Date 2 = October		N =	Number of the balance pressures applied
Date 3 = November		INVP =	Reciprocal inverse pressure (bar)
Date 4 = January		C =	Coefficient of correction for water lost
		RWC =	Relative water content (%)

TABLE XI (Continued)

OBS	LOC	TRT	DATE	SEEDLING	P	TUBE1	TUBE2	WI	WF	WD	SEQ	SI	ST	N	INVP	C	RWC
1	1	1	1	1	8.2	1.6037	1.7586	6.54	5.28	1.64	2	0.1549	0.9904	7	0.121951	0.038514	96.0528
2	1	1	1	2	6.9	1.6204	1.8018	8.36	6.87	2.26	2	0.1814	1.2594	8	0.144928	0.028825	96.5537
3	1	1	1	3	8.2	1.5196	1.7118	10.29	8.57	2.65	2	0.1922	1.0795	7	0.121951	0.091500	96.2866
4	1	1	1	4	7.7	1.6907	1.8472	7.03	5.52	1.77	2	0.1565	1.1485	7	0.129870	0.051643	96.0429
5	1	1	1	1	13.2	1.5833	1.7079	6.54	5.28	1.64	3	0.2795	0.9904	7	0.075758	0.038514	93.5099
6	1	1	1	2	11.9	1.6095	1.7890	8.36	6.87	2.26	3	0.3609	1.2594	8	0.084034	0.028825	93.6111
7	1	1	1	3	13.2	1.7142	1.8851	10.29	8.57	2.65	3	0.3631	1.0795	7	0.075758	0.091500	94.0497
8	1	1	1	4	12.7	1.7456	1.8351	7.03	5.52	1.77	3	0.2460	1.1485	7	0.078740	0.051643	94.3414
9	1	1	1	1	18.2	1.5667	1.6900	6.54	5.28	1.64	4	0.4028	0.9904	7	0.054945	0.038514	90.9936
10	1	1	1	2	16.9	1.6942	1.8530	8.36	6.87	2.26	4	0.5197	1.2594	8	0.059172	0.028825	91.0078
11	1	1	1	3	18.2	1.7367	1.8812	10.29	8.57	2.65	4	0.5076	1.0795	7	0.054945	0.091500	92.1584
12	1	1	1	4	17.7	1.5543	1.7229	7.03	5.52	1.77	4	0.4146	1.1485	7	0.056497	0.051643	91.1361
13	1	1	1	1	23.2	1.5935	1.7507	6.54	5.28	1.64	5	0.5600	0.9904	7	0.043103	0.038514	87.7854
14	1	1	1	2	21.9	1.6830	1.8481	8.36	6.87	2.26	5	0.6848	1.2594	8	0.045662	0.028825	88.3012
15	1	1	1	3	23.2	1.6207	1.7902	10.29	8.57	2.65	5	0.6771	1.0795	7	0.043103	0.091500	89.9398
16	1	1	1	4	22.7	1.6478	1.8782	7.03	5.52	1.77	5	0.6450	1.1485	7	0.044053	0.051643	86.7558
17	1	1	1	1	28.2	1.4342	1.5941	6.54	5.28	1.64	6	0.7199	0.9904	7	0.035461	0.038514	84.5222
18	1	1	1	2	26.9	1.5673	1.7348	8.36	6.87	2.26	6	0.8523	1.2594	8	0.037175	0.028825	85.5553
19	1	1	1	3	28.2	1.6363	1.7788	10.29	8.57	2.65	6	0.8196	1.0795	7	0.035461	0.091500	88.0746
20	1	1	1	4	27.7	1.5503	1.7494	7.03	5.52	1.77	6	0.8441	1.1485	7	0.036101	0.051643	82.9707
21	1	1	1	1	33.2	1.7235	1.8861	6.54	5.28	1.64	7	0.8825	0.9904	7	0.030120	0.038514	81.2038
22	1	1	1	2	31.9	1.7700	1.9400	8.36	6.87	2.26	7	1.0223	1.2594	8	0.031348	0.028825	82.7684
23	1	1	1	3	33.2	1.6221	1.7735	10.29	8.57	2.65	7	0.9710	1.0795	7	0.030120	0.091500	86.0929
24	1	1	1	4	32.7	1.6522	1.7850	7.03	5.52	1.77	7	0.9769	1.1485	7	0.030581	0.051643	80.4460
25	1	1	1	1	38.2	1.6641	1.7720	6.54	5.28	1.64	8	0.9904	0.9904	7	0.026178	0.038514	79.0017
26	1	1	1	2	36.9	1.5739	1.6919	8.36	6.87	2.26	8	1.1403	1.2594	8	0.027100	0.028825	80.8340
27	1	1	1	3	38.2	1.5949	1.7034	10.29	8.57	2.65	8	1.0795	1.0795	7	0.026178	0.091500	84.6728
28	1	1	1	4	37.7	1.4556	1.6272	7.03	5.52	1.77	8	1.1485	1.1485	7	0.026525	0.051643	77.1836
29	1	1	1	2	41.9	1.6375	1.7566	8.36	6.87	2.26	9	1.2594	1.2594	8	0.023866	0.028825	78.8816
30	1	1	2	1	7.4	1.5362	1.8200	8.11	6.57	2.59	2	0.2838	0.9264	7	0.135135	0.087657	93.2707
31	1	1	2	2	7.6	1.6161	1.7371	7.05	6.04	2.15	2	0.1210	0.4335	7	0.131579	0.082357	95.8499
32	1	1	2	3	8.5	1.5559	1.6380	6.62	5.55	2.15	2	0.0821	0.2694	7	0.117647	0.114371	95.6017
33	1	1	2	4	8.5	1.7677	1.9999	6.62	5.28	1.77	2	0.2322	0.6920	7	0.117647	0.092571	93.3037
34	1	1	2	1	12.4	1.6762	1.7519	8.11	6.57	2.59	3	0.3595	0.9264	7	0.080645	0.087657	91.8993
35	1	1	2	2	12.6	1.6786	1.7401	7.05	6.04	2.15	3	0.1825	0.4335	7	0.079365	0.082357	94.5948
36	1	1	2	3	13.5	1.6441	1.6922	6.62	5.55	2.15	3	0.1302	0.2694	7	0.074074	0.114371	94.5286
37	1	1	2	4	13.5	1.6877	1.7946	6.62	5.28	1.77	3	0.3391	0.6920	7	0.074074	0.092571	91.0996
38	1	1	2	1	17.4	1.6145	1.7158	8.11	6.57	2.59	4	0.4608	0.9264	7	0.057471	0.087657	90.0642
39	1	1	2	2	17.6	1.6890	1.7206	7.05	6.04	2.15	4	0.2141	0.4335	7	0.056818	0.082357	93.9499
40	1	1	2	3	18.5	1.6167	1.6432	6.62	5.55	2.15	4	0.1567	0.2694	7	0.054054	0.114371	93.9358
41	1	1	2	4	18.5	1.7250	1.7948	6.62	5.28	1.77	4	0.4089	0.6920	7	0.054054	0.092571	89.6604
42	1	1	2	1	22.4	1.7115	1.8356	8.11	6.57	2.59	5	0.5849	0.9264	7	0.044643	0.087657	87.8160
43	1	1	2	2	22.6	1.5600	1.5983	7.05	6.04	2.15	5	0.2524	0.4335	7	0.044248	0.082357	93.1682
44	1	1	2	3	23.5	1.6489	1.6770	6.62	5.55	2.15	5	0.1848	0.2694	7	0.042553	0.114371	93.3071
45	1	1	2	4	23.5	1.6993	1.7767	6.62	5.28	1.77	5	0.4863	0.6920	7	0.042553	0.092571	88.0645
46	1	1	2	1	27.4	1.5553	1.6671	8.11	6.57	2.59	6	0.6967	0.9264	7	0.036496	0.087657	85.7906
47	1	1	2	2	27.6	1.6826	1.7553	7.05	6.04	2.15	6	0.3251	0.4335	7	0.036232	0.082357	91.6845
48	1	1	2	3	28.5	1.6914	1.7177	6.62	5.55	2.15	6	0.2111	0.2694	7	0.035088	0.114371	92.7188
49	1	1	2	4	28.5	1.6509	1.7223	6.62	5.28	1.77	6	0.5577	0.6920	7	0.035088	0.092571	86.5923
50	1	1	2	1	32.4	1.6946	1.8300	8.11	6.57	2.59	7	0.8321	0.9264	7	0.030864	0.087657	83.3377
51	1	1	2	2	32.6	1.6251	1.6884	7.05	6.04	2.15	7	0.3884	0.4335	7	0.030675	0.082357	90.3927
52	1	1	2	3	33.5	1.7727	1.7969	6.62	5.55	2.15	7	0.2353	0.2694	7	0.029851	0.114371	92.1774
53	1	1	2	4	33.5	1.5775	1.6435	6.62	5.28	1.77	7	0.6237	0.6920	7	0.029851	0.092571	85.2315
54	1	1	2	1	37.4	1.6500	1.7443	8.11	6.57	2.59	8	0.9264	0.9264	7	0.026738	0.087657	81.6294
55	1	1	2	2	37.6	1.7233	1.7684	7.05	6.04	2.15	8	0.4335	0.4335	7	0.026596	0.082357	89.4723
56	1	1	2	3	38.5	1.6463	1.6804	6.62	5.55	2.15	8	0.2694	0.2694	7	0.025974	0.114371	91.4145

TABLE XI (Continued)

OBS	LOC	TRT	DATE	SEEDLING	P	TUBE1	TUBE2	WI	WF	WD	SEQ	SI	ST	N	INVP	C	RWC
57	1	1	2	4	38.5	1.7065	1.7748	6.62	5.28	1.77	8	0.6920	0.6920	7	0.025974	0.092571	83.8233
58	1	1	3	1	7.6	1.6000	1.7100	8.07	6.74	2.49	2	0.1100	0.5140	8	0.131579	0.102000	96.2007
59	1	1	3	2	8.1	1.4270	1.5680	8.48	6.81	2.20	2	0.1410	0.3840	7	0.123457	0.183714	94.8294
60	1	1	3	1	12.6	1.5700	1.5930	8.07	6.74	2.49	3	0.1330	0.5140	8	0.079365	0.102000	95.7885
61	1	1	3	2	13.1	1.6690	1.7600	8.48	6.81	2.20	3	0.2320	0.3840	7	0.076336	0.183714	93.3803
62	1	1	3	1	17.6	1.5200	1.5540	8.07	6.74	2.49	4	0.1670	0.5140	8	0.056818	0.102000	95.1792
63	1	1	3	2	18.1	1.6750	1.6920	8.48	6.81	2.20	4	0.2490	0.3840	7	0.055249	0.183714	93.1096
64	1	1	3	1	22.6	1.6490	1.7430	8.07	6.74	2.49	5	0.2610	0.5140	8	0.044248	0.102000	93.4946
65	1	1	3	2	23.1	1.6120	1.6540	8.48	6.81	2.20	5	0.2910	0.3840	7	0.043290	0.183714	92.4409
66	1	1	3	1	27.6	1.6190	1.6620	8.07	6.74	2.49	6	0.3040	0.5140	8	0.036232	0.102000	92.7240
67	1	1	3	2	28.1	1.5980	1.6210	8.48	6.81	2.20	6	0.3140	0.3840	7	0.035587	0.183714	92.0746
68	1	1	3	1	32.6	1.7080	1.7810	8.07	6.74	2.49	7	0.3770	0.5140	8	0.030675	0.102000	91.4158
69	1	1	3	2	33.1	1.6300	1.6590	8.48	6.81	2.20	7	0.3430	0.3840	7	0.030211	0.183714	91.6128
70	1	1	3	1	37.6	1.4890	1.5420	8.07	6.74	2.49	8	0.4300	0.5140	8	0.026596	0.102000	90.4659
71	1	1	3	2	38.1	1.6600	1.7010	8.48	6.81	2.20	8	0.3840	0.3840	7	0.026247	0.183714	90.9600
72	1	1	3	1	42.6	1.6310	1.7150	8.07	6.74	2.49	9	0.5140	0.5140	8	0.023474	0.102000	88.9606
73	1	1	4	1	7.8	1.5590	1.7030	7.10	6.10	2.54	2	0.1440	0.3860	8	0.128205	0.076750	95.1590
74	1	1	4	2	7.3	1.5600	1.7030	7.23	6.29	2.55	2	0.1430	0.5490	8	0.136986	0.048875	95.9001
75	1	1	4	3	7.5	1.6890	1.7950	4.69	4.00	1.59	2	0.1060	0.4590	8	0.133333	0.028875	95.6492
76	1	1	4	4	7.5	1.6840	1.8600	7.05	6.35	2.34	2	0.1760	0.5310	5	0.133333	0.033800	95.5456
77	1	1	4	1	12.8	1.5510	1.6250	7.10	6.10	2.54	3	0.2180	0.3860	8	0.078125	0.076750	93.5362
78	1	1	4	2	12.3	1.6920	1.7790	7.23	6.29	2.55	3	0.2300	0.5490	8	0.081301	0.048875	94.0411
79	1	1	4	3	12.5	1.7200	1.8310	4.69	4.00	1.59	3	0.2170	0.4590	8	0.080000	0.028875	92.0685
80	1	1	4	4	12.5	1.6540	1.7600	7.05	6.35	2.34	3	0.2820	0.5310	5	0.080000	0.033800	93.2951
81	1	1	4	1	17.8	1.7120	1.7680	7.10	6.10	2.54	4	0.2740	0.3860	8	0.056180	0.076750	92.3081
82	1	1	4	2	17.3	1.7100	1.7860	7.23	6.29	2.55	4	0.3060	0.5490	8	0.057803	0.048875	92.4172
83	1	1	4	3	17.5	1.7340	1.7800	4.69	4.00	1.59	4	0.2630	0.4590	8	0.057143	0.028875	90.5847
84	1	1	4	4	17.5	1.7140	1.8000	7.05	6.35	2.34	4	0.3680	0.5310	5	0.057143	0.033800	91.4692
85	1	1	4	1	22.8	1.6800	1.7180	7.10	6.10	2.54	5	0.3120	0.3860	8	0.043860	0.076750	91.4748
86	1	1	4	2	22.3	1.6280	1.6900	7.23	6.29	2.55	5	0.3680	0.5490	8	0.044843	0.048875	91.0924
87	1	1	4	3	22.5	1.6380	1.7300	4.69	4.00	1.59	5	0.3550	0.4590	8	0.044444	0.028875	87.6169
88	1	1	4	4	22.5	1.7300	1.8100	7.05	6.35	2.34	5	0.4480	0.5310	5	0.044444	0.033800	89.7707
89	1	1	4	1	27.8	1.6600	1.6900	7.10	6.10	2.54	6	0.3420	0.3860	8	0.035971	0.076750	90.8169
90	1	1	4	2	27.3	1.7300	1.7670	7.23	6.29	2.55	6	0.4050	0.5490	8	0.036630	0.048875	90.3018
91	1	1	4	3	27.5	1.7390	1.7700	4.69	4.00	1.59	6	0.3860	0.4590	8	0.036364	0.028875	86.6169
92	1	1	4	4	27.5	1.5790	1.6620	7.05	6.35	2.34	6	0.5310	0.5310	5	0.036364	0.033800	88.0085
93	1	1	4	1	32.8	1.7420	1.7550	7.10	6.10	2.54	7	0.3550	0.3860	8	0.030488	0.076750	90.5318
94	1	1	4	2	32.3	1.5450	1.6270	7.23	6.29	2.55	7	0.4870	0.5490	8	0.030960	0.048875	88.5497
95	1	1	4	3	32.5	1.7780	1.8050	4.69	4.00	1.59	7	0.4130	0.4590	8	0.030769	0.028875	85.7460
96	1	1	4	1	37.8	1.6030	1.6330	7.10	6.10	2.54	8	0.3850	0.3860	8	0.026455	0.076750	89.8739
97	1	1	4	2	37.3	0.0000	0.0000	7.23	6.29	2.55	8	0.4870	0.5490	8	0.026810	0.048875	88.5497
98	1	1	4	3	37.5	1.7450	1.7700	4.69	4.00	1.59	8	0.4380	0.4590	8	0.026667	0.028875	84.9395
99	1	1	4	1	42.8	1.7110	1.7120	7.10	6.10	2.54	9	0.3860	0.3860	8	0.023364	0.076750	89.8520
100	1	1	4	2	42.3	1.5180	1.5800	7.23	6.29	2.55	9	0.5490	0.5490	8	0.023641	0.048875	87.2249
101	1	1	4	3	42.5	1.7560	1.7770	4.69	4.00	1.59	9	0.4590	0.4590	8	0.023529	0.028875	84.2621
102	1	2	1	1	7.4	1.7226	1.8539	7.42	6.11	1.94	2	0.1313	0.9324	7	0.135135	0.053943	96.6197
103	1	2	1	2	8.2	1.7758	1.9230	6.72	5.55	1.83	2	0.1472	0.8480	7	0.121951	0.046000	96.0491
104	1	2	1	3	7.0	1.5400	1.6669	4.82	4.08	1.22	2	0.1269	0.6613	8	0.142857	0.009837	96.2017
105	1	2	1	4	7.2	1.5356	1.7154	6.15	5.06	1.75	2	0.1798	0.9181	7	0.138889	0.024557	95.3555
106	1	2	1	1	12.4	1.6543	1.8148	7.42	6.11	1.94	3	0.2918	0.9324	7	0.080645	0.053943	93.6908
107	1	2	1	2	13.2	1.6158	1.7337	6.72	5.55	1.83	3	0.2651	0.8480	7	0.075758	0.046000	93.6380
108	1	2	1	3	12.0	1.6263	1.7188	4.82	4.08	1.22	3	0.2194	0.6613	8	0.083333	0.009837	93.6323
109	1	2	1	4	12.2	1.6445	1.7695	6.15	5.06	1.75	3	0.3048	0.9181	7	0.081967	0.024557	92.5146
110	1	2	1	1	17.4	1.6573	1.8092	7.42	6.11	1.94	4	0.4437	0.9324	7	0.057471	0.053943	90.9189
111	1	2	1	2	18.2	1.6373	1.7444	6.72	5.55	1.83	4	0.3722	0.8480	7	0.054945	0.046000	91.4479
112	1	2	1	3	17.0	1.5957	1.6859	4.82	4.08	1.22	4	0.3096	0.6613	8	0.058824	0.009837	91.1267

TABLE XI (Continued)

OBS	LOC	TRT	DATE	SEEDLING	P	TUBE1	TUBE2	WI	WF	WD	SEQ	SI	ST	N	INVP	C	RWC
113	1	2	1	4	17.2	1.6833	1.8007	6.15	5.06	1.75	4	0.4222	0.9181	7	0.058140	0.024557	89.8464
114	1	2	1	1	22.4	1.6349	1.7855	7.42	6.11	1.94	5	0.5943	0.9324	7	0.044643	0.053943	88.1708
115	1	2	1	2	23.2	1.5147	1.6268	6.72	5.55	1.83	5	0.4843	0.8480	7	0.043103	0.046000	89.1554
116	1	2	1	3	22.0	1.6220	1.7121	4.82	4.08	1.22	5	0.3997	0.6613	8	0.045455	0.009837	88.6240
117	1	2	1	4	22.2	1.6128	1.7173	6.15	5.06	1.75	5	0.5267	0.9181	7	0.045045	0.024557	87.4714
118	1	2	1	1	27.4	1.6888	1.8390	7.42	6.11	1.94	6	0.7445	0.9324	7	0.036496	0.053943	85.4299
119	1	2	1	2	28.2	1.7321	1.8876	6.72	5.55	1.83	6	0.6398	0.8480	7	0.035461	0.046000	85.9755
120	1	2	1	3	27.0	1.5738	1.7156	4.82	4.08	1.22	6	0.5415	0.6613	8	0.037037	0.009837	84.6851
121	1	2	1	4	27.2	1.6717	1.7836	6.15	5.06	1.75	6	0.6386	0.9181	7	0.036765	0.024557	84.9282
122	1	2	1	1	32.4	1.4448	1.5474	7.42	6.11	1.94	7	0.8471	0.9324	7	0.030864	0.053943	83.5576
123	1	2	1	2	33.2	1.6614	1.7905	6.72	5.55	1.83	7	0.7689	0.8480	7	0.030120	0.046000	83.3354
124	1	2	1	3	32.0	1.6990	1.7253	4.82	4.08	1.22	7	0.5678	0.6613	8	0.031250	0.009837	83.9545
125	1	2	1	4	32.2	1.5253	1.6854	6.15	5.06	1.75	7	0.7987	0.9181	7	0.031056	0.024557	81.2896
126	1	2	1	1	37.4	1.5571	1.6424	7.42	6.11	1.94	8	0.9324	0.9324	7	0.026738	0.053943	82.0010
127	1	2	1	2	38.2	1.6573	1.7364	6.72	5.55	1.83	8	0.8480	0.8480	7	0.026178	0.046000	81.7178
128	1	2	1	3	37.0	1.7000	1.7520	4.82	4.08	1.22	8	0.6198	0.6613	8	0.027027	0.009837	82.5101
129	1	2	1	4	37.2	1.5832	1.7026	6.15	5.06	1.75	8	0.9181	0.9181	7	0.026882	0.024557	78.5760
130	1	2	1	3	42.0	1.7150	1.7565	4.82	4.08	1.22	9	0.6613	0.6613	8	0.023810	0.009837	81.3573
131	1	2	2	1	8.5	1.5911	1.7535	6.12	4.99	1.91	2	0.1624	0.6562	7	0.117647	0.067686	94.5348
132	1	2	2	2	8.0	1.5864	1.7419	6.05	5.11	1.78	2	0.1555	0.6721	7	0.125000	0.038271	95.4620
133	1	2	2	3	8.2	1.6743	1.7823	5.01	4.25	1.78	2	0.1080	0.2960	7	0.121951	0.066286	94.6042
134	1	2	2	4	8.0	1.7182	1.8339	4.79	4.07	1.42	2	0.1157	0.3047	7	0.125000	0.059329	94.8063
135	1	2	2	1	13.5	1.6293	1.7200	6.12	4.99	1.91	3	0.2531	0.6562	7	0.074074	0.067686	92.3804
136	1	2	2	2	13.0	1.6835	1.8129	6.05	5.11	1.78	3	0.2849	0.6721	7	0.076923	0.038271	92.4316
137	1	2	2	3	13.2	1.6616	1.6963	5.01	4.25	1.78	3	0.1427	0.2960	7	0.075758	0.066286	93.5299
138	1	2	2	4	13.0	1.6082	1.6673	4.79	4.07	1.42	3	0.1748	0.3047	7	0.076923	0.059329	93.0526
139	1	2	2	1	18.5	1.6901	1.7719	6.12	4.99	1.91	4	0.3349	0.6562	7	0.054054	0.067686	90.4374
140	1	2	2	2	18.0	1.6983	1.7557	6.05	5.11	1.78	4	0.3423	0.6721	7	0.055556	0.038271	91.0873
141	1	2	2	3	18.2	1.5869	1.6073	5.01	4.25	1.78	4	0.1631	0.2960	7	0.054945	0.066286	92.8983
142	1	2	2	4	18.0	1.5877	1.6223	4.79	4.07	1.42	4	0.2094	0.3047	7	0.055556	0.059329	92.0259
143	1	2	2	1	23.5	1.6577	1.7139	6.12	4.99	1.91	5	0.3911	0.6562	7	0.042553	0.067686	89.1025
144	1	2	2	2	23.0	1.7080	1.7800	6.05	5.11	1.78	5	0.4143	0.6721	7	0.043478	0.038271	89.4011
145	1	2	2	3	23.2	1.4669	1.4788	5.01	4.25	1.78	5	0.1750	0.2960	7	0.043103	0.066286	92.5299
146	1	2	2	4	23.0	1.6372	1.6700	4.79	4.07	1.42	5	0.2422	0.3047	7	0.043478	0.059329	91.0526
147	1	2	2	1	28.5	1.6836	1.7573	6.12	4.99	1.91	6	0.4648	0.6562	7	0.035088	0.067686	87.3519
148	1	2	2	2	28.0	1.6467	1.7200	6.05	5.11	1.78	6	0.4876	0.6721	7	0.035714	0.038271	87.6845
149	1	2	2	3	28.2	1.6157	1.6515	5.01	4.25	1.78	6	0.2108	0.2960	7	0.035461	0.066286	91.4215
150	1	2	2	4	28.0	1.7171	1.7426	4.79	4.07	1.42	6	0.2677	0.3047	7	0.035714	0.059329	90.2959
151	1	2	2	1	33.5	1.6709	1.7515	6.12	4.99	1.91	7	0.5454	0.6562	7	0.029851	0.067686	85.4374
152	1	2	2	2	33.0	1.6833	1.7587	6.05	5.11	1.78	7	0.5630	0.6721	7	0.030303	0.038271	85.9187
153	1	2	2	3	33.2	1.6683	1.6827	5.01	4.25	1.78	7	0.2252	0.2960	7	0.030120	0.066286	90.9757
154	1	2	2	4	33.0	1.6531	1.6642	4.79	4.07	1.42	7	0.2788	0.3047	7	0.030303	0.059329	89.9665
155	1	2	2	1	38.5	1.6764	1.7872	6.12	4.99	1.91	8	0.6562	0.6562	7	0.025974	0.067686	82.8056
156	1	2	2	2	38.0	1.4509	1.5600	6.05	5.11	1.78	8	0.6721	0.6721	7	0.026316	0.038271	83.3637
157	1	2	2	3	38.2	1.7047	1.7755	5.01	4.25	1.78	8	0.2960	0.2960	7	0.026178	0.066286	88.7837
158	1	2	2	4	38.0	1.5858	1.6117	4.79	4.07	1.42	8	0.3047	0.3047	7	0.026316	0.059329	89.1980
159	1	2	3	1	7.3	1.5390	1.6690	12.01	10.11	4.11	2	0.1300	1.0230	8	0.136986	0.109625	96.9668
160	1	2	3	2	7.0	1.5050	1.6490	9.51	8.08	2.92	2	0.1440	0.5100	8	0.142857	0.115000	96.0698
161	1	2	3	1	12.3	1.5180	1.6850	12.01	10.11	4.11	3	0.2970	1.0230	8	0.081301	0.109625	94.8528
162	1	2	3	2	12.0	1.6480	1.6800	9.51	8.08	2.92	3	0.1760	0.5100	8	0.083333	0.115000	95.5842
163	1	2	3	1	17.3	1.5880	1.7300	12.01	10.11	4.11	4	0.4390	1.0230	8	0.057803	0.109625	93.0554
164	1	2	3	2	17.0	1.7420	1.7800	9.51	8.08	2.92	4	0.2140	0.5100	8	0.058824	0.115000	95.0076
165	1	2	3	1	22.3	1.5980	1.7430	12.01	10.11	4.11	5	0.5840	1.0230	8	0.044843	0.109625	91.2199
166	1	2	3	2	22.0	1.4960	1.5510	9.51	8.08	2.92	5	0.2690	0.5100	8	0.045455	0.115000	94.1730
167	1	2	3	1	27.3	1.6000	1.7780	12.01	10.11	4.11	6	0.7620	1.0230	8	0.036630	0.109625	88.9668
168	1	2	3	2	27.0	1.3970	1.4520	9.51	8.08	2.92	6	0.3240	0.5100	8	0.037037	0.115000	93.3384

TABLE XI (Continued)

OBS	LOC	TRT	DATE	SEEDLING	P	TUBE1	TUBE2	WI	WF	WD	SEQ	SI	ST	N	INVP	C	RWC
169	1	2	3	1	32.3	1.6910	1.7450	12.01	10.11	4.11	7	0.8160	1.0230	8	0.030960	0.109625	88.2832
170	1	2	3	2	32.0	1.5670	1.6050	9.51	8.08	2.92	7	0.3620	0.5100	8	0.031250	0.115000	92.7618
171	1	2	3	1	37.3	1.6530	1.7320	12.01	10.11	4.11	8	0.8950	1.0230	8	0.026810	0.109625	87.2832
172	1	2	3	2	37.0	1.5530	1.6200	9.51	8.08	2.92	8	0.4290	0.5100	8	0.027027	0.115000	91.7451
173	1	2	3	1	42.3	1.7120	1.8400	12.01	10.11	4.11	9	1.0230	1.0230	8	0.023641	0.109625	85.6630
174	1	2	3	2	42.0	1.5780	1.6590	9.51	8.08	2.92	9	0.5100	0.5100	8	0.023810	0.115000	90.5159
175	1	2	4	1	6.5	1.6420	1.7890	5.85	4.84	2.01	2	0.1470	0.4820	8	0.153846	0.066000	94.4531
176	1	2	4	2	7.1	1.6530	1.7810	6.24	5.31	2.23	2	0.1280	0.4850	8	0.140845	0.055625	95.4208
177	1	2	4	3	6.9	1.6700	1.7950	5.60	4.82	2.18	2	0.1250	0.5300	8	0.144928	0.031250	95.4313
178	1	2	4	4	6.6	1.6500	1.8120	4.89	4.00	1.88	2	0.1620	0.5850	8	0.151515	0.038125	93.3513
179	1	2	4	1	11.5	1.6610	1.7580	5.85	4.84	2.01	3	0.2440	0.4820	8	0.086957	0.066000	91.9271
180	1	2	4	2	12.1	1.6900	1.7500	6.24	5.31	2.23	3	0.1880	0.4850	8	0.082645	0.055625	93.9246
181	1	2	4	3	11.9	1.7280	1.8130	5.60	4.82	2.18	3	0.2100	0.5300	8	0.084034	0.031250	92.9459
182	1	2	4	4	11.6	1.7010	1.7660	4.89	4.00	1.88	3	0.2270	0.5850	8	0.086207	0.038125	91.1919
183	1	2	4	1	16.5	1.4490	1.5110	5.85	4.84	2.01	4	0.3060	0.4820	8	0.060606	0.066000	90.3125
184	1	2	4	2	17.1	1.6580	1.7190	6.24	5.31	2.23	4	0.2490	0.4850	8	0.058480	0.055625	92.4034
185	1	2	4	3	16.9	1.6430	1.6990	5.60	4.82	2.18	4	0.2660	0.5300	8	0.059172	0.031250	91.3085
186	1	2	4	4	16.6	1.6320	1.7100	4.89	4.00	1.88	4	0.3050	0.5850	8	0.060241	0.038125	88.6005
187	1	2	4	1	21.5	1.5880	1.6200	5.85	4.84	2.01	5	0.3380	0.4820	8	0.046512	0.066000	89.4792
188	1	2	4	2	22.1	1.6600	1.7210	6.24	5.31	2.23	5	0.3100	0.4850	8	0.045249	0.055625	90.8822
189	1	2	4	3	21.9	1.6500	1.7000	5.60	4.82	2.18	5	0.3160	0.5300	8	0.045662	0.031250	89.8465
190	1	2	4	4	21.6	1.6800	1.7310	4.89	4.00	1.88	5	0.3560	0.5850	8	0.046296	0.038125	86.9061
191	1	2	4	1	26.5	1.7700	1.7990	5.85	4.84	2.01	6	0.3670	0.4820	8	0.037736	0.066000	88.7240
192	1	2	4	2	27.1	1.5750	1.6310	6.24	5.31	2.23	6	0.3660	0.4850	8	0.036900	0.055625	89.4857
193	1	2	4	3	26.9	1.7000	1.7580	5.60	4.82	2.18	6	0.3740	0.5300	8	0.037175	0.031250	88.1506
194	1	2	4	4	26.6	1.5880	1.6250	4.89	4.00	1.88	6	0.3930	0.5850	8	0.037594	0.038125	85.6769
195	1	2	4	1	31.5	1.6590	1.7010	5.85	4.84	2.01	7	0.4090	0.4820	8	0.031746	0.066000	87.6302
196	1	2	4	2	32.1	1.7260	1.7580	6.24	5.31	2.23	7	0.3980	0.4850	8	0.031153	0.055625	88.6877
197	1	2	4	3	31.9	1.6400	1.7030	5.60	4.82	2.18	7	0.4370	0.5300	8	0.031348	0.031250	86.3085
198	1	2	4	4	31.6	1.6900	1.7670	4.89	4.00	1.88	7	0.4700	0.5850	8	0.031646	0.038125	83.1188
199	1	2	4	1	36.5	1.6080	1.6310	5.85	4.84	2.01	8	0.4320	0.4820	8	0.027397	0.066000	87.0312
200	1	2	4	2	37.1	1.6680	1.7220	6.24	5.31	2.23	8	0.4520	0.4850	8	0.026954	0.055625	87.3410
201	1	2	4	3	36.9	1.4700	1.5190	5.60	4.82	2.18	8	0.4860	0.5300	8	0.027100	0.031250	84.8757
202	1	2	4	4	36.6	1.6560	1.7200	4.89	4.00	1.88	8	0.5340	0.5850	8	0.027322	0.038125	80.9925
203	1	2	4	1	41.5	1.6600	1.7100	5.85	4.84	2.01	9	0.4820	0.4820	8	0.024096	0.066000	85.7292
204	1	2	4	2	42.1	1.6570	1.6900	6.24	5.31	2.23	9	0.4850	0.4850	8	0.023753	0.055625	86.5181
205	1	2	4	3	41.9	1.7390	1.7830	5.60	4.82	2.18	9	0.5300	0.5300	8	0.023866	0.031250	83.5892
206	1	2	4	4	41.6	1.4440	1.4950	4.89	4.00	1.88	9	0.5850	0.5850	8	0.024038	0.038125	73.2982
207	2	1	1	1	7.7	1.5388	1.7555	9.96	8.44	2.50	2	0.2167	1.0829	7	0.129870	0.062443	96.2581
208	2	1	1	2	7.8	1.6489	1.7589	7.13	6.10	1.86	2	0.1100	0.6551	7	0.128205	0.053557	96.8964
209	2	1	1	3	7.0	1.5964	1.8090	7.86	6.24	1.89	2	0.2126	0.9609	8	0.142857	0.082387	95.0588
210	2	1	1	4	7.2	1.6244	1.8801	8.82	7.12	2.30	2	0.2557	1.0832	7	0.138889	0.088114	94.7268
211	2	1	1	1	12.7	1.5939	1.7621	9.96	8.44	2.50	3	0.3849	1.0829	7	0.078740	0.062443	94.0034
212	2	1	1	2	12.8	1.5464	1.6702	7.13	6.10	1.86	3	0.2338	0.6551	7	0.078125	0.053557	94.5473
213	2	1	1	3	12.0	1.6389	1.7415	7.86	6.24	1.89	3	0.3152	0.9609	8	0.083333	0.082387	93.3402
214	2	1	1	4	12.2	1.6349	1.8090	8.82	7.12	2.30	3	0.4298	1.0832	7	0.081967	0.088114	92.0565
215	2	1	1	1	17.7	1.5722	1.7260	9.96	8.44	2.50	4	0.5387	1.0829	7	0.056497	0.062443	91.9418
216	2	1	1	2	17.8	1.6552	1.7643	7.13	6.10	1.86	4	0.3429	0.6551	7	0.056180	0.053557	92.4771
217	2	1	1	3	17.0	1.7025	1.8462	7.86	6.24	1.89	4	0.4589	0.9609	8	0.058824	0.082387	90.9332
218	2	1	1	4	17.2	1.6379	1.7900	8.82	7.12	2.30	4	0.5819	1.0832	7	0.058140	0.088114	89.7237
219	2	1	1	1	22.7	1.7590	1.9141	9.96	8.44	2.50	5	0.6938	1.0829	7	0.044053	0.062443	89.8627
220	2	1	1	2	22.8	1.6246	1.7086	7.13	6.10	1.86	5	0.4269	0.6551	7	0.043860	0.053557	90.8832
221	2	1	1	3	22.0	1.5761	1.6851	7.86	6.24	1.89	5	0.5679	0.9609	8	0.045455	0.082387	89.1074
222	2	1	1	4	22.2	1.6783	1.8216	8.82	7.12	2.30	5	0.7252	1.0832	7	0.045045	0.088114	87.5259
223	2	1	1	1	27.7	1.7340	1.8790	9.96	8.44	2.50	6	0.8388	1.0829	7	0.036101	0.062443	87.9190
224	2	1	1	2	27.8	1.6906	1.7486	7.13	6.10	1.86	6	0.4849	0.6551	7	0.035971	0.053557	89.7826

TABLE XI (Continued)

OBS	LOC	TRT	DATE	SEEDLING	P	TUBE1	TUBE2	WI	WF	WD	SEQ	SI	ST	N	INVP	C	RWC
225	2	1	1	3	27.0	1.6139	1.7230	7.86	6.24	1.89	6	0.6770	0.9609	8	0.037037	0.082387	87.2799
226	2	1	1	4	27.2	1.6389	1.7768	8.82	7.12	2.30	6	0.8631	1.0832	7	0.036765	0.088114	85.4108
227	2	1	1	1	32.7	1.6392	1.7751	9.96	8.44	2.50	7	0.9747	1.0829	7	0.030581	0.062443	86.0973
228	2	1	1	2	32.8	1.6947	1.7681	7.13	6.10	1.86	7	0.5583	0.6551	7	0.030488	0.053557	88.3898
229	2	1	1	3	32.0	1.6429	1.7427	7.86	6.24	1.89	7	0.7768	0.9609	8	0.031250	0.082387	85.6082
230	2	1	1	4	32.2	1.6042	1.7044	8.82	7.12	2.30	7	0.9633	1.0832	7	0.031056	0.088114	83.8740
231	2	1	1	1	37.7	1.5003	1.6085	9.96	8.44	2.50	8	1.0829	1.0829	7	0.026525	0.062443	84.6469
232	2	1	1	2	37.8	1.7132	1.8100	7.13	6.10	1.86	8	0.6551	0.6551	7	0.026455	0.053557	86.5530
233	2	1	1	3	37.0	1.5521	1.6480	7.86	6.24	1.89	8	0.8727	0.9609	8	0.027027	0.082387	84.0019
234	2	1	1	4	37.7	1.6596	1.7795	8.82	7.12	2.30	8	1.0832	1.0832	7	0.026525	0.088114	82.0351
235	2	1	1	3	42.0	1.7018	1.7900	7.86	6.24	1.89	9	0.9609	0.9609	8	0.023810	0.082387	82.5245
236	2	1	2	1	6.7	1.6950	1.8966	9.50	7.95	2.46	2	0.2016	0.7517	8	0.149254	0.099788	95.7189
237	2	1	2	2	7.5	1.7541	1.9204	9.00	7.41	2.44	2	0.1663	0.5684	7	0.133333	0.145943	95.2402
238	2	1	2	3	8.6	1.6485	1.7858	10.61	9.23	3.27	2	0.1373	0.6865	7	0.116279	0.099071	96.7797
239	2	1	2	4	8.5	1.6378	1.8972	11.22	9.52	3.18	2	0.2594	1.1906	7	0.117647	0.072771	95.8685
240	2	1	2	1	11.7	1.6566	1.7505	9.50	7.95	2.46	3	0.2955	0.7517	8	0.085470	0.099788	94.3851
241	2	1	2	2	12.5	1.6465	1.7641	9.00	7.41	2.44	3	0.2839	0.5684	7	0.080000	0.145943	93.4475
242	2	1	2	3	13.6	1.7188	1.8141	10.61	9.23	3.27	3	0.2326	0.6865	7	0.073529	0.099071	95.4813
243	2	1	2	4	13.5	1.6770	1.8339	11.22	9.52	3.18	3	0.4163	1.1906	7	0.074074	0.072771	93.9170
244	2	1	2	1	16.7	1.6202	1.7018	9.50	7.95	2.46	4	0.3771	0.7517	8	0.059880	0.099788	93.2260
245	2	1	2	2	17.5	1.6756	1.7549	9.00	7.41	2.44	4	0.3632	0.5684	7	0.057143	0.145943	92.2387
246	2	1	2	3	18.6	1.6806	1.7736	10.61	9.23	3.27	4	0.3256	0.6865	7	0.053763	0.099071	94.2143
247	2	1	2	4	18.5	1.4359	1.5592	11.22	9.52	3.18	4	0.5396	1.1906	7	0.054054	0.072771	92.3834
248	2	1	2	1	21.7	1.4130	1.4756	9.50	7.95	2.46	5	0.4397	0.7517	8	0.046083	0.099788	92.3368
249	2	1	2	2	22.5	1.6180	1.6583	9.00	7.41	2.44	5	0.4035	0.5684	7	0.044444	0.145943	91.6243
250	2	1	2	3	23.6	1.6524	1.7178	10.61	9.23	3.27	5	0.3910	0.6865	7	0.042373	0.099071	93.3233
251	2	1	2	4	23.5	1.6430	1.7863	11.22	9.52	3.18	5	0.6829	1.1906	7	0.042553	0.072771	90.6011
252	2	1	2	1	26.7	1.6237	1.6794	9.50	7.95	2.46	6	0.4954	0.7517	8	0.037453	0.099788	91.5456
253	2	1	2	2	27.5	1.7117	1.7825	9.00	7.41	2.44	6	0.4743	0.5684	7	0.036364	0.145943	90.5451
254	2	1	2	3	28.6	1.6144	1.7059	10.61	9.23	3.27	6	0.4825	0.6865	7	0.034965	0.099071	92.0767
255	2	1	2	4	28.5	1.6837	1.8315	11.22	9.52	3.18	6	0.8307	1.1906	7	0.035088	0.072771	88.7628
256	2	1	2	1	31.7	1.5211	1.6086	9.50	7.95	2.46	7	0.5829	0.7517	8	0.031546	0.099788	90.3027
257	2	1	2	2	32.5	1.7183	1.7641	9.00	7.41	2.44	7	0.5201	0.5684	7	0.030769	0.145943	89.8469
258	2	1	2	3	33.6	1.5883	1.6618	10.61	9.23	3.27	7	0.5560	0.6865	7	0.029762	0.099071	91.0753
259	2	1	2	4	33.5	1.5723	1.7517	11.22	9.52	3.18	7	1.0101	1.1906	7	0.029851	0.072771	86.5314
260	2	1	2	1	36.7	1.5800	1.6753	9.50	7.95	2.46	8	0.6782	0.7517	8	0.027248	0.099788	88.9490
261	2	1	2	2	37.5	1.6275	1.6758	9.00	7.41	2.44	8	0.5684	0.5684	7	0.026667	0.145943	89.1106
262	2	1	2	3	38.6	1.6828	1.8133	10.61	9.23	3.27	8	0.6865	0.6865	7	0.025907	0.099071	89.2974
263	2	1	2	4	38.5	1.5276	1.7081	11.22	9.52	3.18	8	1.1906	1.1906	7	0.025974	0.072771	84.2864
264	2	1	2	1	41.7	1.6269	1.7004	9.50	7.95	2.46	9	0.7517	0.7517	8	0.023981	0.099788	87.9050
265	2	1	3	1	8.6	1.6090	1.7800	10.99	9.29	3.23	2	0.1710	0.8290	7	0.116279	0.124429	96.1929
266	2	1	3	2	7.8	1.6030	1.7530	10.47	8.82	3.19	2	0.1500	0.4670	7	0.128205	0.169000	95.6181
267	2	1	3	1	13.6	1.7030	1.8600	10.99	9.29	3.23	3	0.3280	0.8290	7	0.073529	0.124429	94.1697
268	2	1	3	2	12.8	1.6180	1.7520	10.47	8.82	3.19	3	0.2840	0.4670	7	0.078125	0.169000	93.7775
269	2	1	3	1	18.6	1.5750	1.7110	10.99	9.29	3.23	4	0.4640	0.8290	7	0.053763	0.124429	92.4172
270	2	1	3	2	17.8	1.5080	1.5520	10.47	8.82	3.19	4	0.3280	0.4670	7	0.056180	0.169000	93.1731
271	2	1	3	1	23.6	1.6630	1.7290	10.99	9.29	3.23	5	0.5300	0.8290	7	0.042373	0.124429	91.5666
272	2	1	3	2	22.8	1.5510	1.5760	10.47	8.82	3.19	5	0.3530	0.4670	7	0.043860	0.169000	92.8297
273	2	1	3	1	28.6	1.5510	1.6610	10.99	9.29	3.23	6	0.6400	0.8290	7	0.034965	0.124429	90.1491
274	2	1	3	2	27.8	1.6400	1.6880	10.47	8.82	3.19	6	0.4010	0.4670	7	0.035971	0.169000	92.1703
275	2	1	3	1	33.6	1.6450	1.7300	10.99	9.29	3.23	7	0.7250	0.8290	7	0.029762	0.124429	89.0538
276	2	1	3	2	32.8	1.5890	1.6260	10.47	8.82	3.19	7	0.4380	0.4670	7	0.030488	0.169000	91.6621
277	2	1	3	1	38.6	1.5900	1.6940	10.99	9.29	3.23	8	0.8290	0.8290	7	0.025907	0.124429	87.7135
278	2	1	3	2	37.8	1.5460	1.5750	10.47	8.82	3.19	8	0.4670	0.4670	7	0.026455	0.169000	91.2637
279	2	1	4	1	6.8	1.6180	1.8420	7.57	6.52	2.52	2	0.2240	0.7570	8	0.147059	0.036625	94.8391
280	2	1	4	2	8.0	1.5970	1.8190	8.79	8.56	3.40	2	0.2220	0.7860	7	0.125000	0.063429	95.5332

TABLE XI (Continued)

OBS	LOC	TRT	DATE	SEEDLING	P	TUBE1	TUBE2	WI	WF	WD	SEQ	SI	ST	N	INVP	C	RWC
281	2	1	4	3	7.2	1.7440	1.9490	8.69	7.46	2.80	2	0.2050	0.5810	7	0.138889	0.092714	94.9454
282	2	1	4	4	6.8	1.7610	1.9400	7.69	6.75	2.40	2	0.1790	0.7170	8	0.147059	0.027875	96.0893
283	2	1	4	1	11.8	1.6500	1.7310	7.57	6.52	2.52	3	0.3050	0.7570	8	0.084746	0.036625	93.2351
284	2	1	4	2	13.0	1.6350	1.7850	9.79	8.56	3.40	3	0.3720	0.7860	7	0.076923	0.063429	93.1858
285	2	1	4	3	12.2	1.7550	1.7810	8.69	7.46	2.80	3	0.2310	0.5810	7	0.081967	0.092714	94.5040
286	2	1	4	4	11.8	1.6550	1.7510	7.69	6.75	2.40	3	0.2750	0.7170	8	0.084746	0.027875	94.2746
287	2	1	4	1	16.8	1.6220	1.7210	7.57	6.52	2.52	4	0.4040	0.7570	8	0.059524	0.036625	91.2748
288	2	1	4	2	18.0	1.6190	1.7200	9.79	8.56	3.40	4	0.4730	0.7860	7	0.055556	0.063429	91.6052
289	2	1	4	3	17.2	1.6410	1.7200	8.69	7.46	2.80	4	0.3100	0.5810	7	0.058140	0.092714	93.1627
290	2	1	4	4	16.8	1.6080	1.6820	7.69	6.75	2.40	4	0.3490	0.7170	8	0.059524	0.027875	92.8757
291	2	1	4	1	21.8	1.6640	1.7380	7.57	6.52	2.52	5	0.4780	0.7570	8	0.045872	0.036625	89.8094
292	2	1	4	2	23.0	1.6500	1.7490	9.79	8.56	3.40	5	0.5720	0.7860	7	0.043478	0.063429	90.0559
293	2	1	4	3	22.2	1.7180	1.7780	8.69	7.46	2.80	5	0.3700	0.5810	7	0.045045	0.092714	92.1441
294	2	1	4	4	21.8	1.6230	1.6810	7.69	6.75	2.40	5	0.4070	0.7170	8	0.045872	0.027875	91.7793
295	2	1	4	1	26.8	1.5520	1.6250	7.57	6.52	2.52	6	0.5510	0.7570	8	0.037313	0.036625	88.3639
296	2	1	4	2	28.0	1.6480	1.7140	9.79	8.56	3.40	6	0.6380	0.7860	7	0.035714	0.063429	89.0230
297	2	1	4	3	27.2	1.6920	1.7550	8.69	7.46	2.80	6	0.4330	0.5810	7	0.036765	0.092714	91.0745
298	2	1	4	4	26.8	1.6570	1.7230	7.69	6.75	2.40	6	0.4730	0.7170	8	0.037313	0.027875	90.5317
299	2	1	4	1	31.8	1.6930	1.7580	7.57	6.52	2.52	7	0.6160	0.7570	8	0.031447	0.036625	87.0767
300	2	1	4	2	33.0	1.7700	1.8330	9.79	8.56	3.40	7	0.7010	0.7860	7	0.030303	0.063429	88.0371
301	2	1	4	3	32.2	1.7400	1.8070	8.69	7.46	2.80	7	0.5000	0.5810	7	0.031056	0.092714	89.9369
302	2	1	4	4	31.8	1.7580	1.8480	7.69	6.75	2.40	7	0.5630	0.7170	8	0.031447	0.027875	88.8303
303	2	1	4	1	36.8	1.5810	1.6500	7.57	6.52	2.52	8	0.6850	0.7570	8	0.027174	0.036625	85.7104
304	2	1	4	2	38.0	1.6350	1.7200	9.79	8.56	3.40	8	0.7860	0.7860	7	0.026316	0.063429	86.7069
305	2	1	4	3	37.2	1.6300	1.7110	8.69	7.46	2.80	8	0.5810	0.5810	7	0.026882	0.092714	88.5617
306	2	1	4	4	36.8	1.6940	1.7720	7.69	6.75	2.40	8	0.6410	0.7170	8	0.027174	0.027875	87.3559
307	2	1	4	1	41.8	1.6270	1.6990	7.57	6.52	2.52	9	0.7570	0.7570	8	0.023923	0.036625	84.2847
308	2	1	4	4	41.8	1.6220	1.6980	7.69	6.75	2.40	9	0.7170	0.7170	8	0.023923	0.027875	85.9192
309	2	2	1	1	7.2	1.6259	1.7360	7.29	6.37	1.90	2	0.1101	0.6248	7	0.138889	0.042171	97.1749
310	2	2	1	2	10.0	1.6343	1.7945	11.78	10.14	2.74	2	0.1602	1.0022	7	0.100000	0.091114	97.2200
311	2	2	1	3	7.2	1.6658	1.9442	12.58	10.45	3.23	2	0.2784	1.6177	8	0.138889	0.064038	96.3376
312	2	2	1	4	7.5	1.6270	1.8912	9.57	8.48	2.52	2	0.2642	1.2896	7	0.133333	-0.028514	96.6569
313	2	2	1	1	12.2	1.5747	1.6769	7.29	6.37	1.90	3	0.2123	0.6248	7	0.081967	0.042171	95.2788
314	2	2	1	2	15.0	1.5500	1.6381	11.78	10.14	2.74	3	0.2483	1.0022	7	0.066667	0.091114	96.2454
315	2	2	1	3	12.2	1.5393	1.7923	12.58	10.45	3.23	3	0.5314	1.6177	8	0.081967	0.064038	93.6317
316	2	2	1	4	12.5	1.5661	1.7283	9.57	8.48	2.52	3	0.4264	1.2896	7	0.080000	-0.028514	94.3562
317	2	2	1	1	17.2	1.5611	1.6419	7.29	6.37	1.90	4	0.2931	0.6248	7	0.058140	0.042171	93.7798
318	2	2	1	2	20.0	1.6408	1.8206	11.78	10.14	2.74	4	0.4281	1.0022	7	0.050000	0.091114	94.2565
319	2	2	1	3	17.2	1.6198	1.8292	12.58	10.45	3.23	4	0.7408	1.6177	8	0.058140	0.064038	91.3921
320	2	2	1	4	17.5	1.5411	1.7064	9.57	8.48	2.52	4	0.5917	1.2896	7	0.057143	-0.028514	92.0116
321	2	2	1	1	22.2	1.7367	1.8212	7.29	6.37	1.90	5	0.3776	0.6248	7	0.045045	0.042171	92.2120
322	2	2	1	2	25.0	1.7275	1.8900	11.78	10.14	2.74	5	0.5906	1.0022	7	0.040000	0.091114	92.4589
323	2	2	1	3	22.2	1.6077	1.7867	12.58	10.45	3.23	5	0.9198	1.6177	8	0.045045	0.064038	89.4777
324	2	2	1	4	22.5	1.6894	1.8726	9.57	8.48	2.52	5	0.7749	1.2896	7	0.044444	-0.028514	89.4130
325	2	2	1	1	27.2	1.6041	1.6883	7.29	6.37	1.90	6	0.4618	0.6248	7	0.036765	0.042171	90.6499
326	2	2	1	2	30.0	1.7084	1.8687	11.78	10.14	2.74	6	0.7509	1.0022	7	0.033333	0.091114	90.6857
327	2	2	1	3	27.2	1.7463	1.9172	12.58	10.45	3.23	6	1.0907	1.6177	8	0.036765	0.064038	87.6499
328	2	2	1	4	27.5	1.6931	1.8617	9.57	8.48	2.52	6	0.9435	1.2896	7	0.036364	-0.028514	87.0215
329	2	2	1	1	32.2	1.6351	1.7190	7.29	6.37	1.90	7	0.5457	0.6248	7	0.031056	0.042171	89.0933
330	2	2	1	2	35.0	1.5886	1.7350	11.78	10.14	2.74	7	0.8973	1.0022	7	0.028571	0.091114	89.0662
331	2	2	1	3	32.2	1.6538	1.8441	12.58	10.45	3.23	7	1.2810	1.6177	8	0.031056	0.064038	85.6146
332	2	2	1	4	32.5	1.6210	1.8117	9.57	8.48	2.52	7	1.1342	1.2896	7	0.030769	-0.028514	84.3165
333	2	2	1	1	37.2	1.7737	1.8528	7.29	6.37	1.90	8	0.6248	0.6248	7	0.026882	0.042171	87.6258
334	2	2	1	2	40.0	1.5480	1.6529	11.78	10.14	2.74	8	1.0022	1.0022	7	0.025000	0.091114	87.9058
335	2	2	1	3	37.2	1.5408	1.7057	12.58	10.45	3.23	8	1.4459	1.6177	8	0.026882	0.064038	83.8509
336	2	2	1	4	37.5	1.7186	1.8740	9.57	8.48	2.52	8	1.2896	1.2896	7	0.026667	-0.028514	82.1123

TABLE XI (Continued)

OBS	LOC	TRT	DATE	SEEDLING	P	TUBE1	TUBE2	WI	WF	WD	SEQ	SI	ST	N	INVP	C	RWC
337	2	2	1	3	42.2	1.6285	1.8003	12.58	10.45	3.23	9	1.6177	1.6177	8	0.023697	0.0640375	82.0135
338	2	2	2	1	9.1	1.6377	1.8217	13.21	11.85	4.15	2	0.1840	0.9527	7	0.109890	0.0581857	97.3269
339	2	2	2	2	6.8	1.7328	1.9754	10.26	8.81	3.52	2	0.2426	0.9109	8	0.147059	0.0673875	95.4008
340	2	2	2	3	7.5	1.6114	1.7626	6.13	5.36	1.77	2	0.1512	0.5759	8	0.133333	0.0242625	95.9756
341	2	2	2	4	7.2	1.6435	1.8237	7.07	6.14	2.05	2	0.1802	0.6211	7	0.138889	0.0441286	95.5313
342	2	2	2	1	14.1	1.6448	1.7601	13.21	11.85	4.15	3	0.2993	0.9527	7	0.070922	0.0581857	96.0542
343	2	2	2	2	11.8	1.6512	1.7569	10.26	8.81	3.52	3	0.3483	0.9109	8	0.084746	0.0673875	93.8325
344	2	2	2	3	12.5	1.5947	1.6560	6.13	5.36	1.77	3	0.2125	0.5759	8	0.080000	0.0242625	94.5697
345	2	2	2	4	12.2	1.5648	1.6576	7.07	6.14	2.05	3	0.2730	0.6211	7	0.081967	0.0441286	93.6827
346	2	2	2	1	19.1	1.5230	1.6452	13.21	11.85	4.15	4	0.4215	0.9527	7	0.052356	0.0581857	94.7055
347	2	2	2	2	16.8	1.7036	1.7851	10.26	8.81	3.52	4	0.4298	0.9109	8	0.059524	0.0673875	92.6233
348	2	2	2	3	17.5	1.6550	1.7123	6.13	5.36	1.77	4	0.2698	0.5759	8	0.057143	0.0242625	93.2554
349	2	2	2	4	17.2	1.5410	1.6111	7.07	6.14	2.05	4	0.3431	0.6211	7	0.058140	0.0441286	92.2863
350	2	2	2	1	24.1	1.6792	1.8053	13.21	11.85	4.15	5	0.5476	0.9527	7	0.041494	0.0581857	93.3136
351	2	2	2	2	21.8	1.6230	1.7352	10.26	8.81	3.52	5	0.5420	0.9109	8	0.045872	0.0673875	90.9586
352	2	2	2	3	22.5	1.7009	1.7586	6.13	5.36	1.77	5	0.3275	0.5759	8	0.044444	0.0242625	91.9321
353	2	2	2	4	22.2	1.6921	1.7567	7.07	6.14	2.05	5	0.4077	0.6211	7	0.045045	0.0441286	90.9994
354	2	2	2	1	29.1	1.5730	1.7204	13.21	11.85	4.15	6	0.6950	0.9527	7	0.034364	0.0581857	91.6867
355	2	2	2	2	26.8	1.6077	1.7521	10.26	8.81	3.52	6	0.6864	0.9109	8	0.037313	0.0673875	88.8162
356	2	2	2	3	27.5	1.5921	1.6724	6.13	5.36	1.77	6	0.4078	0.5759	8	0.036364	0.0242625	90.0903
357	2	2	2	4	27.2	1.6738	1.7465	7.07	6.14	2.05	6	0.4804	0.6211	7	0.036765	0.0441286	89.5512
358	2	2	2	1	34.1	1.7473	1.8916	13.21	11.85	4.15	7	0.8393	0.9527	7	0.029326	0.0581857	90.0940
359	2	2	2	2	31.8	1.6450	1.6941	10.26	8.81	3.52	7	0.7355	0.9109	8	0.031447	0.0673875	88.0877
360	2	2	2	3	32.5	1.7159	1.7504	6.13	5.36	1.77	7	0.4423	0.5759	8	0.030769	0.0242625	89.2990
361	2	2	2	4	32.2	1.5382	1.6214	7.07	6.14	2.05	7	0.5636	0.6211	7	0.031056	0.0441286	87.8939
362	2	2	2	1	39.1	1.5985	1.7119	13.21	11.85	4.15	8	0.9527	0.9527	7	0.025575	0.0581857	88.8423
363	2	2	2	2	36.8	1.6538	1.7289	10.26	8.81	3.52	8	0.8106	0.9109	8	0.027174	0.0673875	86.9735
364	2	2	2	3	37.5	1.6220	1.6801	6.13	5.36	1.77	8	0.5004	0.5759	8	0.026667	0.0242625	87.9665
365	2	2	2	4	37.2	1.6123	1.6698	7.07	6.14	2.05	8	0.6211	0.6211	7	0.026882	0.0441286	86.7484
366	2	2	2	2	41.8	1.7480	1.8483	10.26	8.81	3.52	9	0.9109	0.9109	8	0.023923	0.0673875	85.4853
367	2	2	2	3	42.5	1.6545	1.7300	6.13	5.36	1.77	9	0.5759	0.5759	8	0.023529	0.0242625	86.2348
368	2	2	3	1	8.0	1.5450	1.6490	5.49	4.60	1.43	2	0.1040	0.4890	7	0.125000	0.0572857	96.0274
369	2	2	3	2	8.0	1.6750	1.7920	6.76	5.52	2.04	2	0.1170	0.5260	8	0.125000	0.0892500	95.6303
370	2	2	3	1	13.0	1.5150	1.6250	5.49	4.60	1.43	3	0.2140	0.4890	7	0.076923	0.0572857	93.3181
371	2	2	3	2	13.0	1.6330	1.6880	6.76	5.52	2.04	3	0.1720	0.5260	8	0.076923	0.0892500	94.4650
372	2	2	3	1	18.0	1.6290	1.7300	5.49	4.60	1.43	4	0.3150	0.4890	7	0.055556	0.0572857	90.8304
373	2	2	3	2	18.0	1.5840	1.6120	6.76	5.52	2.04	4	0.2000	0.5260	8	0.055556	0.0892500	93.8718
374	2	2	3	1	23.0	1.5610	1.6110	5.49	4.60	1.43	5	0.3650	0.4890	7	0.043478	0.0572857	89.5989
375	2	2	3	2	23.0	1.6830	1.7250	6.76	5.52	2.04	5	0.2420	0.5260	8	0.043478	0.0892500	92.9820
376	2	2	3	1	28.0	1.6200	1.6690	5.49	4.60	1.43	6	0.4140	0.4890	7	0.035714	0.0572857	88.3920
377	2	2	3	2	28.0	1.5700	1.6410	6.76	5.52	2.04	6	0.3130	0.5260	8	0.035714	0.0892500	91.4778
378	2	2	3	1	33.0	1.6110	1.6420	5.49	4.60	1.43	7	0.4450	0.4890	7	0.030303	0.0572857	87.6284
379	2	2	3	2	33.0	1.6660	1.7300	6.76	5.52	2.04	7	0.3770	0.5260	8	0.030303	0.0892500	90.1218
380	2	2	3	1	38.0	1.6350	1.6790	5.49	4.60	1.43	8	0.4890	0.4890	7	0.026316	0.0572857	86.5447
381	2	2	3	2	38.0	1.6810	1.7300	6.76	5.52	2.04	8	0.4260	0.5260	8	0.026316	0.0892500	89.0837
382	2	2	3	2	43.0	1.6000	1.7000	6.76	5.52	2.04	9	0.5260	0.5260	8	0.023256	0.0892500	86.9650
383	2	2	4	1	6.8	1.7710	1.9800	8.16	6.60	2.76	2	0.2090	1.0770	8	0.147059	0.0603750	95.0116
384	2	2	4	2	8.3	1.5300	1.7330	10.78	10.00	3.95	2	0.2030	0.6690	7	0.120482	0.0158571	96.7956
385	2	2	4	3	7.5	1.7190	1.8600	6.64	5.79	2.27	2	0.1410	0.5280	8	0.133333	0.0402500	95.8524
386	2	2	4	4	7.2	1.7150	1.8950	10.47	8.89	3.58	2	0.1800	0.8230	8	0.138889	0.0946250	96.0142
387	2	2	4	1	11.8	1.4500	1.5990	8.16	6.60	2.76	3	0.3580	1.0770	8	0.084746	0.0603750	92.2523
388	2	2	4	2	13.3	1.6140	1.7170	10.78	10.00	3.95	3	0.3060	0.6690	7	0.075188	0.0158571	95.2876
389	2	2	4	3	12.5	1.7020	1.7910	6.64	5.79	2.27	3	0.2300	0.5280	8	0.080000	0.0402500	93.8158
390	2	2	4	4	12.2	1.6880	1.8360	10.47	8.89	3.58	3	0.3280	0.8230	8	0.081967	0.0946250	93.8661
391	2	2	4	1	16.8	1.6360	1.7490	8.16	6.60	2.76	4	0.4710	1.0770	8	0.059524	0.0603750	90.1597
392	2	2	4	2	18.3	1.6120	1.6900	10.78	10.00	3.95	4	0.3840	0.6690	7	0.054645	0.0158571	94.1456

TABLE XI (Continued)

OBS	LOC	TRT	DATE	SEEDLING	P	TUBE1	TUBE2	WI	WF	WD	SEQ	SI	ST	N	INVP	C	RWC
393	2	2	4	3	17.5	1.438	1.505	6.64	5.79	2.27	4	0.297	0.528	8	0.0571429	0.0402500	92.2826
394	2	2	4	4	17.2	1.656	1.746	10.47	8.89	3.58	4	0.418	0.823	8	0.0581395	0.0946250	92.5599
395	2	2	4	1	21.8	1.688	1.802	8.16	6.60	2.76	5	0.585	1.077	8	0.0458716	0.0603750	88.0486
396	2	2	4	2	23.3	1.591	1.650	10.78	10.00	3.95	5	0.443	0.669	7	0.0429185	0.0158571	93.2817
397	2	2	4	3	22.5	1.765	1.835	6.64	5.79	2.27	5	0.367	0.528	8	0.0444444	0.0402500	90.6808
398	2	2	4	4	22.2	1.522	1.620	10.47	8.89	3.58	5	0.516	0.823	8	0.0450450	0.0946250	91.1375
399	2	2	4	1	26.8	1.632	1.738	8.16	6.60	2.76	6	0.691	1.077	8	0.0373134	0.0603750	86.0856
400	2	2	4	2	28.3	1.660	1.721	10.78	10.00	3.95	6	0.504	0.669	7	0.0353357	0.0158571	92.3886
401	2	2	4	3	27.5	1.651	1.695	6.64	5.79	2.27	6	0.411	0.528	8	0.0363636	0.0402500	89.6739
402	2	2	4	4	27.2	1.638	1.710	10.47	8.89	3.58	6	0.588	0.823	8	0.0367647	0.0946250	90.0925
403	2	2	4	1	31.8	1.619	1.745	8.16	6.60	2.76	7	0.817	1.077	8	0.0314465	0.0603750	83.7523
404	2	2	4	2	33.3	1.749	1.810	10.78	10.00	3.95	7	0.565	0.669	7	0.0300300	0.0158571	91.4955
405	2	2	4	3	32.5	1.599	1.644	6.64	5.79	2.27	7	0.456	0.528	8	0.0307692	0.0402500	88.6442
406	2	2	4	4	32.2	1.542	1.579	10.47	8.89	3.58	7	0.625	0.823	8	0.0310559	0.0946250	89.5555
407	2	2	4	1	36.8	1.535	1.655	8.16	6.60	2.76	8	0.937	1.077	8	0.0271739	0.0603750	81.5301
408	2	2	4	2	38.3	1.658	1.762	10.78	10.00	3.95	8	0.669	0.669	7	0.0261097	0.0158571	89.9728
409	2	2	4	3	37.5	1.595	1.634	6.64	5.79	2.27	8	0.495	0.528	8	0.0266667	0.0402500	87.7517
410	2	2	4	4	37.2	1.529	1.613	10.47	8.89	3.58	8	0.709	0.823	8	0.0268817	0.0946250	88.3364
411	2	2	4	1	41.8	1.629	1.769	8.16	6.60	2.76	9	1.077	1.077	8	0.0239234	0.0603750	78.9375
412	2	2	4	3	42.5	1.619	1.652	6.64	5.79	2.27	9	0.528	0.528	8	0.0235294	0.0402500	86.9966
413	2	2	4	4	42.2	1.615	1.729	10.47	8.89	3.58	9	0.823	0.823	8	0.0236967	0.0946250	86.6818

TABLE XII

MEAN VALUES OF THE INVERSE PRESSURE

N	Date	North Carolina Treatment		Oklahoma Treatment	
		Well-Watered	Stressed	Well-Watered	Stressed
4	September	0.06989	0.07691	0.07837	0.07171
4	October	0.08557	0.07786	0.07527	0.07479
2	November	0.08513	0.07028	0.10808	0.08384
4	January	0.11228	0.07715	0.08668	0.07862

LSD .05 ($n_1 = n_2 = 4$) = 0.01914.

LSD .05 ($n_1 = n_2 = 2$) = 0.02707.

Unit of measurement of inverse pressure is bar.

For comparing inverse pressure between the well-watered treatment and water-stressed treatment for the same location and on the same date.

TABLE XIII

STATISTICAL ANALYSES OF THE OSMOTIC POTENTIAL AT FULL TURGOR

DEPENDENT VARIABLE: INVP

SOURCE	DF	SUM OF SQUARES	MEAN SQUARE	F VALUE	PR > F	R-SQUARE	C.V.
MODEL	15	0.00720803	0.00048054	2.68	0.0066	0.501066	16.4680
ERROR	40	0.00717737	0.00017943		STD DEV		INVP MEAN
CORRECTED TOTAL	55	0.01438539			0.01339530		0.08134124

SOURCE	DF	TYPE I SS	F VALUE	PR > F	DF	TYPE IV SS	F VALUE	PR > F
LOC	1	0.00007287	0.41	0.5276	1	0.00000105	0.01	0.9395
TRT	1	0.00142232	7.93	0.0075	1	0.00162404	9.05	0.0045
LOC*TRT	1	0.00007231	0.40	0.5292	1	0.00002515	0.14	0.7101
DATE	3	0.00205629	3.82	0.0169	3	0.00205629	3.82	0.0169
LOC*DATE	3	0.00136590	2.54	0.0702	3	0.00136590	2.54	0.0702
TRT*DATE	3	0.00127408	2.37	0.0852	3	0.00127408	2.37	0.0852
LOC*TRT*DATE	3	0.00094365	1.75	0.1717	3	0.00094365	1.75	0.1717

TESTS OF HYPOTHESES USING THE TYPE IV MS FOR LOC*TRT*DATE AS AN ERROR TERM

SOURCE	DF	TYPE IV SS	F VALUE	PR > F
LOC	1	0.00000105	0.00	0.9576
TRT	1	0.00162404	5.16	0.1077
LOC*TRT	1	0.00002515	0.08	0.7958
DATE	3	0.00205629	2.18	0.2694
LOC*DATE	3	0.00136590	1.45	0.3843
TRT*DATE	3	0.00127408	1.35	0.4055
LOC*TRT*DATE	3	0.00094365	1.00	0.5000

TABLE XIV

STATISTICAL ANALYSES OF ROOT REGENERATION POTENTIAL
WITHIN WARM TEMPERATURE CHAMBER

DEPENDENT VARIABLE: NROOTS

SOURCE	DF	SUM OF SQUARES	MEAN SQUARE	F VALUE	PR > F	R-SQUARE	C.V.
MODEL	16	21637.27777778	1352.32986111	11.69	0.0001	0.772728	30.4915
ERROR	55	6363.88888889	115.70707071		ROOT MSE		NROOTS MEAN
CORRECTED TOTAL	71	28001.16666667			10.75672212		35.27777778

SOURCE	DF	ANOVA SS	F VALUE	PR > F
BLOCK	5	1169.84259259	2.02	0.0890
LOC	1	2259.41358025	19.53	0.0001
TRT	1	245.68055556	2.12	0.1508
LOC*TRT	1	1.68055556	0.01	0.9045
DATE	2	12207.02777778	52.75	0.0001
LOC*DATE	2	4529.24382716	19.57	0.0001
TRT*DATE	2	1190.36111111	5.14	0.0090
LOC*TRT*DATE	2	34.02777778	0.15	0.8636

TABLE XV

STATISTICAL ANALYSES OF ROOT REGENERATION POTENTIAL WITHIN COLD TEMPERATURE CHAMBER

DEPENDENT VARIABLE: NROOTS

SOURCE	DF	SUM OF SQUARES	MEAN SQUARE	F VALUE	PR > F	R-SQUARE	C.V.
MODEL	16	294.41358025	18.40084877	6.34	0.0001	0.648449	77.2227
ERROR	55	159.61381173	2.90206930		ROOT MSE		NROOTS MEAN
CORRECTED TOTAL	71	454.02739198			1.70354610		2.20601852

SOURCE	DF	ANOVA SS	F VALUE	PR > F
BLOCK	5	28.41859568	1.96	0.0986
LOC	1	8.56520062	2.95	0.0914
TRT	1	38.28125000	13.19	0.0006
LOC*TRT	1	14.67013889	5.06	0.0286
DATE	2	162.70910494	28.03	0.0001
LOC*DATE	2	7.19984568	1.24	0.2972
TRT*DATE	2	8.52083333	1.47	0.2393
LOC*TRT*DATE	2	26.04861111	4.49	0.0157

TABLE XVI

STATISTICAL ANALYSES OF ROOT REGENERATION POTENTIAL

DEPENDENT VARIABLE: NROOTS

SOURCE	DF	SUM OF SQUARES	MEAN SQUARE	F VALUE	PR > F	R-SQUARE	C.V.
MODEL	33	61306.37673611	1857.76899200	31.33	0.0001	0.903826	41.0895
ERROR	110	6523.50270062	59.30457001		ROOT MSE		NROOTS MEAN
CORRECTED TOTAL	143	67829.87943673			7.70094605		18.74189815

SOURCE	DF	ANOVA SS	F VALUE	PR > F
CHMBR	1	39374.68537809	663.94	0.0001
BLOCK(CHMBR)	10	1198.26118827	2.02	0.0377
LOC	1	994.87673611	16.78	0.0001
TRT	1	45.00173611	0.76	0.3856
LOC*TRT	1	3.21006944	0.05	0.8165
DATE	2	7580.68557099	63.91	0.0001
LOC*DATE	2	2087.67013889	17.60	0.0001
TRT*DATE	2	580.33680556	4.89	0.0092
LOC*TRT*DATE	2	21.25347222	0.18	0.8362
CHMBR*LOC	1	1273.10204475	21.47	0.0001
CHMBR*TRT	1	238.96006944	4.03	0.0472
CHMBR*LOC*TRT	1	13.14062500	0.22	0.6388
CHMBR*DATE	2	4789.05131173	40.38	0.0001
CHMBR*LOC*DATE	2	2448.77353395	20.65	0.0001
CHMBR*TRT*DATE	2	618.54513889	5.21	0.0069
CHMBR*LOC*TRT*DATE	2	38.82291667	0.33	0.7216

TESTS OF HYPOTHESES USING THE ANOVA MS FOR BLOCK(CHMBR) AS AN ERROR TERM

SOURCE	DF	ANOVA SS	F VALUE	PR > F
CHMBR	1	39374.68537809	328.60	0.0001

TESTS OF HYPOTHESES USING THE ANOVA MS FOR LOC*TRT*DATE AS AN ERROR TERM

SOURCE	DF	ANOVA SS	F VALUE	PR > F
LOC	1	994.87673611	93.62	0.0105
TRT	1	45.00173611	4.23	0.1759
LOC*TRT	1	3.21006944	0.30	0.6378
DATE	2	7580.68557099	356.68	0.0028
LOC*DATE	2	2087.67013889	98.23	0.0101
TRT*DATE	2	580.33680556	27.31	0.0353
LOC*TRT*DATE	2	21.25347222	1.00	0.5000

TABLE XVII

SUMMARY OF STATISTICAL ANALYSES ON ROOT REGENERATION POTENTIAL

Chamber		OSL				Error		NC		OK	
Temp.	Days	LOC	TRT	LOC*TRT	df	MS	LSD .05	S	W	S	W
COLD	15	1.00	.03	.43	15	.26	.622	.50	.17	.67	.0
	25	.49	.03	.71	39	7.25	2.444	3.6	1.5	2.8	1.2
	35	.02	.001	.0001	63	6.95	1.757	7.1	2.4	3.0	3.5
WARM	15	.12	.34	.68	15	75.82	10.716	22.3	24.3	15.0	20.0
	25	.06	.11	.63	39	166.53	10.653	31.9	27.6	40.8	32.8
	35	.0001	.06	.94	63	921.91	20.242	28.8	43.1	61.7	74.9

Note: Means in the same column and temperature that are connected by a vertical line are not significantly different at the .05 level.

TABLE XVIII

STATISTICAL ANALYSES OF THE SEEDLINGS HEIGHT WITHIN WARM TEMPERATURE CHAMBER

DEPENDENT VARIABLE: HEIGHT

SOURCE	DF	SUM OF SQUARES	MEAN SQUARE	F VALUE	PR > F	R-SQUARE	C.V.
MODEL	16	97624.68672840	6101.54292052	8.88	0.0001	0.720865	10.6502
ERROR	55	37802.42283950	687.31677890		ROOT MSE		HEIGHT MEAN
CORRECTED TOTAL	71	135427.10956790			26.21672708		246.16203704

SOURCE	DF	ANOVA SS	F VALUE	PR > F
BLOCK	5	5121.73456790	1.49	0.2071
LOC	1	5287.34722222	7.69	0.0076
TRT	1	8163.58024691	11.88	0.0011
LOC*TRT	1	1458.00000000	2.12	0.1509
DATE	2	75703.44753086	55.07	0.0001
LOC*DATE	2	277.86111111	0.20	0.8176
TRT*DATE	2	1495.71604938	1.09	0.3440
LOC*TRT*DATE	2	117.00000000	0.09	0.9185

TABLE XIX

STATISTICAL ANALYSES OF THE SEEDLINGS HEIGHT WITHIN COLD TEMPERATURE CHAMBER

DEPENDENT VARIABLE: HEIGHT

SOURCE	DF	SUM OF SQUARES	MEAN SQUARE	F VALUE	PR > F	R-SQUARE	C.V.
MODEL	16	17165.40740741	1072.83796296	1.38	0.1847	0.286898	13.7301
ERROR	55	42665.64467592	775.73899411		ROOT MSE		HEIGHT MEAN
CORRECTED TOTAL	71	59831.05208333			27.85209138		202.85416667

SOURCE	DF	ANOVA SS	F VALUE	PR > F
BLOCK	5	2032.41550926	0.52	0.7591
LOC	1	8959.39853395	11.55	0.0013
TRT	1	1735.58680556	2.24	0.1404
LOC*TRT	1	123.15779321	0.16	0.6918
DATE	2	3591.43750000	2.31	0.1083
LOC*DATE	2	411.94984568	0.27	0.7678
TRT*DATE	2	283.54861111	0.18	0.8335
LOC*TRT*DATE	2	27.91280864	0.02	0.9822

TABLE XX

STATISTICAL ANALYSES OF THE SEEDLINGS HEIGHT

DEPENDENT VARIABLE: HEIGHT

SOURCE	DF	SUM OF SQUARES	MEAN SQUARE	F VALUE	PR > F	R-SQUARE	C.V.
MODEL	33	182310.67303241	5524.56584947	7.55	0.0001	0.693780	12.0471
ERROR	110	80468.06751543	731.52788650		ROOT MSE		HEIGHT MEAN
CORRECTED TOTAL	143	262778.74054784			27.04677220		224.50810185

SOURCE	DF	ANOVA SS	F VALUE	PR > F
CHMBR	1	67520.57889660	92.30	0.0001
BLOCK(CHMBR)	10	7154.15007716	0.98	0.4668
LOC	1	14006.06500772	19.15	0.0001
TRT	1	1185.46315586	1.62	0.2057
LOC*TRT	1	1214.32889661	1.66	0.2003
DATE	2	55613.16473766	38.01	0.0001
LOC*DATE	2	558.01195988	0.38	0.6838
TRT*DATE	2	1097.71103395	0.75	0.4746
LOC*TRT*DATE	2	54.12307098	0.04	0.9637
CHMBR*LOC	1	240.68074846	0.33	0.5674
CHMBR*TRT	1	8713.70389660	11.91	0.0008
CHMBR*LOC*TRT	1	366.82889661	0.50	0.4804
CHMBR*DATE	2	23681.72029321	16.19	0.0001
CHMBR*LOC*DATE	2	131.79899691	0.09	0.9139
CHMBR*TRT*DATE	2	681.55362654	0.47	0.6288
CHMBR*LOC*TRT*DATE	2	90.78973765	0.06	0.9399

TESTS OF HYPOTHESES USING THE ANOVA MS FOR BLOCK(CHMBR) AS AN ERROR TERM

SOURCE	DF	ANOVA SS	F VALUE	PR > F
CHMBR	1	67520.57889660	94.38	0.0001

TESTS OF HYPOTHESES USING THE ANOVA MS FOR LOC*TRT*DATE AS AN ERROR TERM

SOURCE	DF	ANOVA SS	F VALUE	PR > F
LOC	1	14006.06500772	517.56	0.0019
TRT	1	1185.46315586	43.81	0.0221
LOC*TRT	1	1214.32889661	44.87	0.0216
DATE	2	55613.16473766	1027.53	0.0010
LOC*DATE	2	558.01195988	10.31	0.0884
TRT*DATE	2	1097.71103395	20.28	0.0470
LOC*TRT*DATE	2	54.12307098	1.00	0.5000

VITA 2

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Master of Science

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