IRRIGATION AND ITS IMPLICATIONS FOR SEEDLING GROWTH AND DEVELOPMENT

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Abstract - Irrigation is an integral cultural practice in forest nursery production. It is used to supplement rainfall to maintain adequate water for seedling growth, to manipulate the seedlings' thermal environment, to apply fertilizers and pesticides, and to harden seedlings for lifting. Irrigation primarily impacts the maintenance of turgor which drives cell enlargement. Cell enlargement occurs in a stepwise manner, directly dependent on water. Extrapolation to an entire seedling depends on compounding cellular growth over thousands of cell and the modifications imposed by the soil-plant-atmosphere continuum. Watering requirement for seedlings changes over the growing season due to varying water supply mechanisms and increasing needle surface area which affects water loss. The irrigation practices of 54 southern nurseries is summarized.

Additional Keywords: water potential, osmotic potential, turgor potential, tensiometer, southern pine.

Introduction

Irrigation in forest nurseries is one of the most important cultural practices and yet it is probably the least understood in terms of its effect on the biology of the crop. Kramer (1969) provided some insight into the complexity of irrigation in the statement: "Successful and efficient irrigation involves numerous problems requiring some knowledge of engineering, soil water relations, plant physiology, and the characteristics of the particular crop being irrigated." Since that time, there have been a number of articles published dealing specifically with various aspects of forest nursery irrigation. The topics are wide ranging from the design of a system (Day, 1984) and water distribution (Shearer, 1981) to more salient points of soil and plant water relations (Day, 1980; Joly, 1985; McDonald, 1984). The importance of irrigation, especially enhancing its efficiency, is going to increase in the future as water becomes scarce.

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The charge of this paper is to provide an introduction and basis for the following two papers which deal with the application of two types of irrigation systems to forest nurseries. Therefore, the paper will discuss the purpose of irrigation and present the results of a questionnaire about irrigation in southern forest nurseries.

Seedling Water Relations and Growth

The purpose of irrigation is primarily to supplement rainfall in order to minimize water stress and to provide a seedling water status that maintains growth. Irrigation is used to manipulate the seedlings' thermal environment and to apply chemicals such as fertilizers and pesticides. Irrigation scheduling has also been used successfully to manipulate seedling physiology by the controlled induction of mild water stress.

To understand why irrigation is needed, the functions of water in seedling physiology must be understood. Water has four major functions in plants (Kramer, 1969): 1) it is a constituent of protoplasm, making up about 50% of the fresh weight of a seedling and providing the necessary degree of hydration; 2) it is a solvent that allows the uptake and transport throughout a seedling of gases, nutrients and other solutes; 3) it is a reagent in a number of important chemical reactions including photosynthesis and hydrolysis, and; 4) it maintains cellular turgidity that is required for cell enlargement. Although irrigation water contributes to all of these functions in a seedling, the most important from a nursery perspective is the maintenance of turgidity.

Turgidity is a result of the interaction of several components of a cell's water potential. These components include solute potential, turgor potential and matrix potential, and together they determine a cell's overall water potential as illustrated in the equation:

$$\psi_w = \psi_s + \psi_t + \psi_m$$

where: ψ_w = water potential

ψ_s = solute potential

ψ_t = turgor potential

ψ_m = matrix potential

Solute potential is a function of the number of salutes present in a cell; the more solutes, the more negative the solute potential. Turgor potential is the positive pressure created by water flowing into a cell and pushing outward against the cell wall. Matrix potential is a result of the binding of water to the cell walls and is usually ignored because it is typically small and constant in comparison to the two other components.

Cell growth occurs in steps and is a result of changes in both turgor and solute potential. The process begins with a decrease in the solute potential, usually due to the synthesis of new solutes such as sugars, but the uptake of salts can also be important (Fig. la). As the solute potential decreases so does the cell's water potential which causes water to move into the cell (water moves from areas of high water potential, less negative, to low water potential, more negative). The water when it moves into the cell increases the pressure pushing outwards on the cell wall, i.e. turgor potential increases (Fig. lb). At this point the cell wall "loosens" due to chemicals such as auxin secreted into the cell wall. The positive turgor potential causes the cell to enlarge (Fig. lc) which increases the cell's volume and dilutes the solutes present (solute potential increases). The increased solute potential causes a decrease in turgor potential (Fig. id), slowing or stopping cell enlargement. At this point the cell wall becomes more rigid due to the re-establishment of chemical bonds that were disrupted during the loosening step. The process is then repeated, starting with a decrease in solute potential (Fig. la). Cell enlargement, thus, is the result of this stepwise process repeated many times until the cell wall becomes lignified. When water availability is low, cells cannot expand as much due to their inability to generate adequate turgor potential necessary for cell enlargement.

The above description for cell enlargement can be extrapolated to an entire seedling by compounding cell growth over thousands of cells in the meristematic regions of a seedling, i.e. shoot, needles and roots. Other water related factors, however, govern growth in a seedling including competition for water as it moves from the soil into the roots, through the xylem, into the needles and out of stomatal pores. About 90% of the water taken up by a seedling is "transient" in the seedling. It functions as a solvent and then is transpired into the atmosphere. The water status of a seedling at a given time can be determined by knowing its rate of supply, rate of loss and the amount of storage. This can be expressed by the following equation (Ritchie and Hinckley, 1975):

$$W = (U - T) + S$$

where: W = water status of the seedling
U = water uptake or supply from the soil
T = water lost by transpiration
S = water stored in seedling

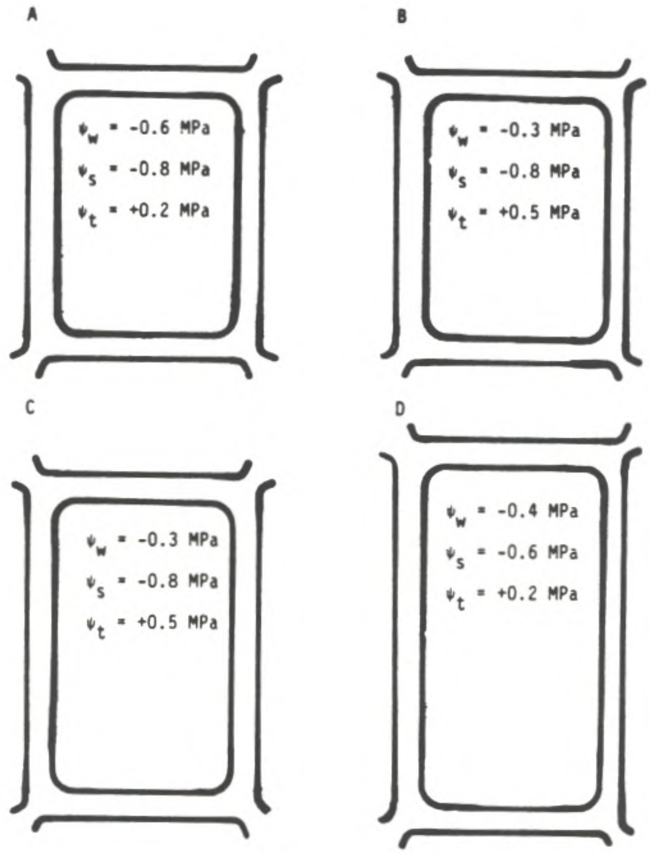

Fig. 1. The role of water in cell growth; A. Accumulation of solutes decreases the solute potential; B. Water flows into the cell due to the lowering of water potential resulting in the increase in turgor and water potential; C. The cell wall begins to "loosen" allowing the elongation of the cell; D. As the cell elongates, the volume increases allowing more water to flow into the cell which dilutes the solutes and causes a drop in solute and turgor potential.

Diurnal variation in atmospheric demand for water (which is function of air temperature and humidity) causes changes in seedling water status. During the day atmospheric demand is high (because of high temperature and low humidity) so transpiration is greater than water uptake and the stored water reduced, resulting in water stress or deficit (Fig. 2, line 1). Through proper irrigation scheduling this daily deficit is minimized and growth continues during the time uptake is equal to or greater than transpiration and the stored water is replenished, i.e. during the evening, night and early morning. If irrigation water is not properly supplied, then water deficit will increase over time, depleting the stored water, and shortening the time period during which growth can occur (Fig. 2, lines 2). When soil water becomes unavailable, there is little or no water available in the plant to move into the cells and turgor potential drops to zero (Fig. 2, line 3). At zero turgor, the non-lignified tissues of a seedling wilts. Ultimately, if the water deficits continue, death will ensue.

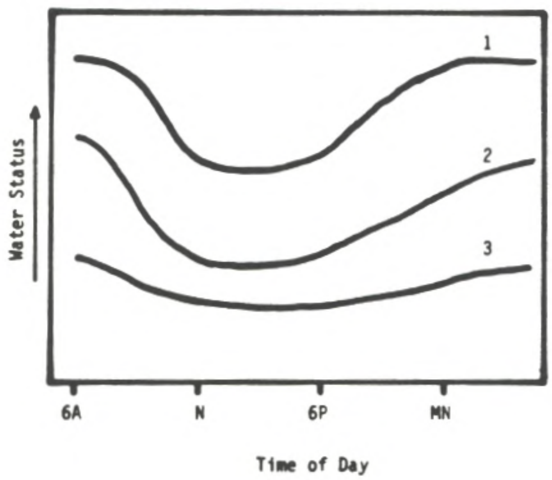

Fig. 2. The diurnal variation of the water status of a seedling. Line 1, adequate soil moisture; Line 2, soil water starts to become limiting; Line 3, soil water nearly depleted.

This, unfortunately is only a partial explanation. Other factors that influence a seedling's water status include root growth into new areas of the soil, foliage surface area which is related to water loss, and competition from neighboring seedlings. As a seedling grows it increases both in root and needle surface area, and the amount of "transient" water that moves through the seedling increases. Seedling density will affect competition for water; soil water can be quickly depleted under high density.

Over a growing season, the water requirement in terms of irrigation and rainfall for a seedling changes (Fig. 3). After sowing and during germination, the requirement is high, but as root growth begins, a seedling's water needs are met through exploration of new soil regions that have high available soil water. Thus, in terms of applied water (irrigation and rainfall), the requirement is decreased. This continues until competition amoung adjacent seedlings begins to deplete soil water, usually coinciding with lignification, secondary needle production and "canopy closure". Beyond this point competition for water becomes severe requiring more water to be applied. The water requirement, however, does not return to earlier levels for several reasons: First, the weather at this point begins to moderate, i.e. lower temperatures and higher humidities; second, the days become increasingly shorter,

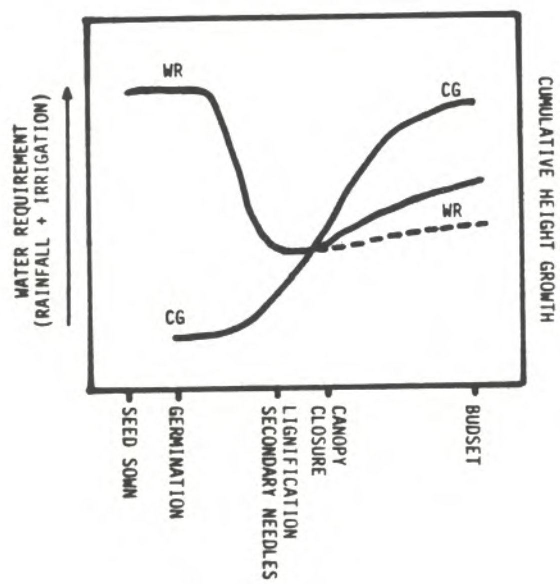

Fig. 3. The changes in water requirement over a growing season as related to seedling height growth. Dashed line represents an open grown seedling; the solid line a seedling grown at a normal density.

providing a longer recovery period for a seedling's water status, and; third, water is withheld purposely to induce hardening and budset.

Irrigation is useful for altering a seedlings' thermal environment. Although not important in southern nursery production, irrigating during a late freeze in the spring or an early one in the fall is common practice. The freezing of the irrigation water increases air temperature through the release of the heat of crystallization as well as providing insulation for susceptible tissue. Of more importance in the south is the use of irrigation to cool seedlings, especially young, succulent germinants. The irrigation water serves two purposes: 1) the immediate reduction in temperature due to the temperature of the water and; 2) prolonged cooling as the applied water evaporates. A 30 minute midday irrigation was found to reduce soil temperature by 20° F (Stoeckeler and Slabaugh, 1965).

Induction of dormancy in seedlings can be enhanced through the scheduling of irrigation (Zaerr et al. 1981). The physiological changes that occur during repeated, mild water deficit appears to parallel changes that occur during hardening (Johnson et al. 1985; McDonald, 1984; McNabb, 1985). One explanation for the success of water stressing is that the solute potential is decreased through a process termed osmotic adjustment. The accumulation of solutes in cells makes them more frost resistant and imparts a capability to take up water at low water potential.

Questionnaire Results

The results of the questionnaire provided additional information about irrigation practices in the south; a total of 54 nurseries responded to the questionnaire. Although some practices were wide ranging without any concensus, a number of the them appear to be routinely followed. A summary of the responses to selected questions follows.

Gauging when to irrigate is done predominately by visual and tactile (90.7%) and is combined with soil tensiometer in some nurseries (42.6%). Only a few nurseries use other methods; pressure bomb (3.8%); water budget or soil moisture meter (1.9% each); one nursery (1.9'/.) reported that wilting of indicator plants growing along riser lines were used to help determine irrigation scheduling. According to McDonald (1984) the visual and tactile method is the least precise and subjective of all scheduling techniques. He suggested that it shoed be used in combination with one of the other mechanical techniques such as tensiometers. The discussion above also argues for the use of measure of seedling water status such as the pressure chamber.

Nearly two thirds (61.1'/.) of the responding nurseries said that they supplemented rainfall with irrigation, usually attempting to apply a total amount of rain plus irrigation (inches per week) of: 0.25 - 3.1%; 0.75 - 6.2%; 1.0 - 62.5%; 1.5 - 18.8%; 2.0 - 6.2% and; 3 - 3.1%. In light of the information presented in Fig. 3, fixing a constant amount of water to be applied weekly during the growing season probably results in overwatering. Monitoring seedling water status would rectify the problem.

In the area of needs for irrigation scheduling, 87% of respondents indicated a need for both instruments and guides. However, those voting no to the questions were more emphatic about instruments (22.2%) than guides (9.3%).

Sixty-three percent of the nurseries use irrigation to cool their seedlings with the majority irrigating when the air temperature reached 90° F and they usually irrigated for 30 minutes.

All (98.2%) but one nursery indicated that irrigation scheduling was used in the fall to induce water stress for hardening. However, there was some disagreement as to which species were hardened; exceptions included Virginia, sand, longleaf and white pine, and baldcypress. The majority of the nurseries begin restricting irrigation either in August (32%) or September (53%). Irrigation is usually withheld until lifting (83%).

One other opportunity for manipulating a seedling's water status is during lifting and processing, prior to shipping to the planting site. Over 85% of the nurseries indicated that they in some form added water to their seedlings before shipping. The means by which this is accomplished, however, varied widely. In order of number of responses (most to least) the procedures were: 1) spray water on seedling; 2) kaolin clay dip; 3) wet peat moss or a water gel slurry; 4) submerged seedlings after packing; 5) wet hydromulch in seedling package.

With water becoming a limited resource, forest nurseries will need to improve their irrigation efficiency through judicious scheduling. This type of irrigation scheduling will require a better understanding of seedling water relations and a refinement of the techniques available for monitoring seedling water status.

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