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SEEDLING NUTRITION MANAGEMENT AND FOREST YIELD IMPROVEMENT

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ABSTRACT

As resources become limiting, greater emphasis will be placed on nutritional management of forests to shorten rotations and improve marginal site productivity. With intensive forest management, prescriptions during early growth can be used to exploit favorable site, genotype, and operational interactions while conserving the environment. Fertilization decisions must be based on sound physiological principles weighed against economics and an understanding of end-use products. Production of properly fertilized nursery seedlings and maintenance of high forest productivity during early growth will produce tremendous yield benefits; benefits which cannot be recaptured once lost. Gains of more than 40 percent could be expected from improved nutrient management. Strategies and obstacles to implementation are discussed.

INTRODUCTION

The demand for wood and wood products is expected to increase well into the next century. However, the land base, energy and raw materials needed to accelerate forest growth will become more limiting. As demand for these resources grows, the United States will receive over time a proportionately smaller share of the world supply. The use of fertilizers has increased worldwide, and demand is expected to increase. It follows that: (1) fertilizers must be utilized in such a way as to ensure maximum response and (2) careful attention will have to be given to factors determining the return from these investments. In addition, strategic use of fertilization can exploit ongoing intensification of tree improvement programs, soil management and reforestation practices, thinning regimes, and pest control.

The obvious opportunity for intensive management through the use of fertilization is in forest nurseries. There have been several reviews of the nutritional status of forest nursery soils (Stoeckeler and Arneman 1960; van den Driessche 1980; Armson and Sadreika 1979). Among other topics, these papers discuss deficiency symptoms, nutrient utilization and mineral contents, which will not be discussed in this paper.

Three aspects of nutrition management will be addressed: (A) accelerating growth in the nursery, (B) preparing the seedling for transplanting and (C) accelerating growth following planting via nursery fertilization.

ACCELERATING NURSERY GROWTH

Nitrogen (N) is the element most commonly applied to nursery soils to increase seedling size. The impact of N fertilization on nursery seedling size has been demonstrated in numerous studies. Many of the major timber species have been evaluated at some point, including lodgepole pine (van den Driessche 1977), loblolly pine (Switzer and Nelson 1963), Douglas-fir (van den Driessche 1982) and white spruce (Armson and Sadreika 1979). The response of loblolly pine to nitrogen is fairly typical (fig. 1). Switzer and Nelson (1963) found the increase in seedling dry weight was linearly related to the amount of nitrogen applied per plant. These experiments were repeated over three years and superimposed over four growing densities. With an increase in dry weight, there was a concomitant increase in the

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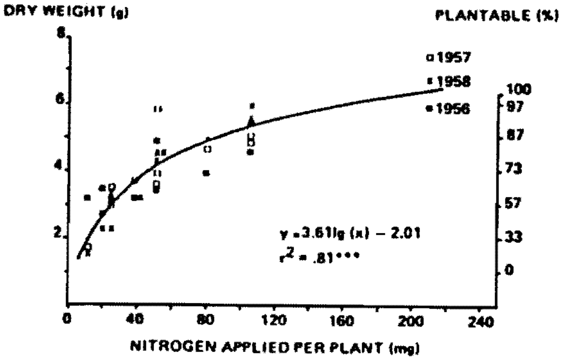

Figure 1.--Effect of nitrogen fertilization on loblolly pine seedling dry weight (Switzer and Nelson 1963).

proportion of seedlings reaching plantable size (i.e. root collar diameter $\geq$ 3mm). Maximum yield, in terms of the percentage plantable, could be achieved with an application of about 160 mg of N per plant.

The interaction between N fertilization and seedling growing density appears to be relatively straightforward: the lower the density or the greater the N per plant, the larger the seedling. In general, seedlings grown at high densities respond proportionately more to N fertilization than seedlings grown at lower densities (fig. 2). The responses to increased fertility levels are usually in the range of 1 to 2 g increase in seedling dry weight. The response to altered seedling density is much more dramatic for the species studied. The increase in seedling biomass is of the order of 5 g.

While total biomass production is a function of growing density, fertility and species, the optimum growing density does not appear to be influenced by these variables. The optimum growing density offers a trade off between maximizing seedling size and maximizing the number of plantable seedlings produced per unit area of the nursery bed. Mexal (1980a) recommended an optimum growing density of $200/m^2$ for loblolly pine. Similar densities have been recommended for Douglas-fir (Edgren 1977), red pine (Mullin 1981) and radiata pine (van Dorsser unpublished). Van den Driessche (1982) illustrated the relationship between growing density and fertilization for Douglas-fir (fig. 2B). Transformation of the data to examine the interaction between biomass production and growing area, indicates no apparent interaction between growing area and fertilization (fig. 3). The optimum growing area, regardless of fertility, appears to be between 50 cm^2 and 60 cm^2/seedling, which is a growing density of 180 to $200/m^2$. At growing areas greater than 60 cm^2, the growth curve changes due to incomplete site utilization. At growing areas less than 50 cm^2, competition increases and individual seedling weight decreases.

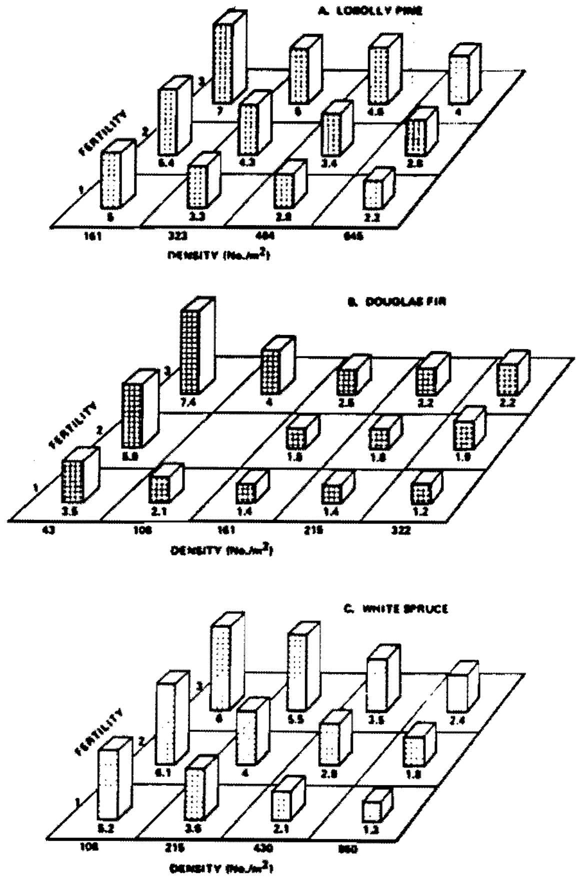

Figure 2.--Growing density (No./M^2) and fertility effect dry weight (g) of (A) loblolly pine (Switzer and Nelson 1963), (B) Douglas-fir (van den Driessche 1982), and (C) white spruce (Armson and Sadrieka 1979).

Fertility levels in the nursery often have little impact on survival following outplanting. However, height growth has been correlated with fertility level for a variety of species (Switzer and Nelson 1963, van den Driessche 1982). Due to the impact of initial seedling biomass on early performance, nursery cultural practices can have long-term impacts on total yield (Wakeley 1971). Autry (1972) reported a significant correlation between seedling biomass at planting and individual tree volume at age 14 using plantations established in the studies of Switzer and Nelson 1963 (Fig. 4). Seedling biomass at time of planting accounted for 66% of the variation in tree volume at age 14. Volume was increased 38% across the range of seedling sizes at time of planting. Similar responses may be expected for all the major timber species.

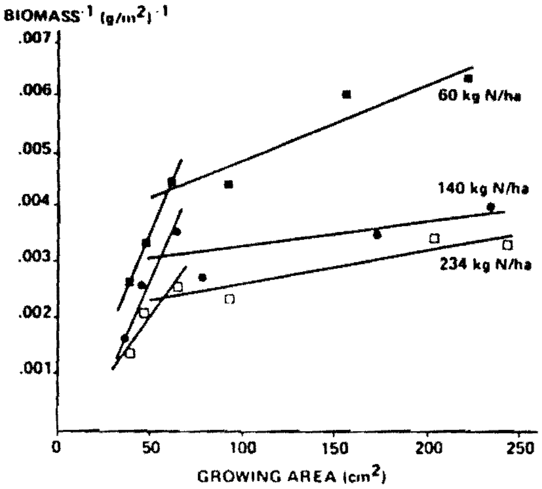

Figure 3.--Interactive effects of growing area and fertility on biomass production $(g\ m^{-2})^{-1}$ (redrawn from van den Driessche 1982).

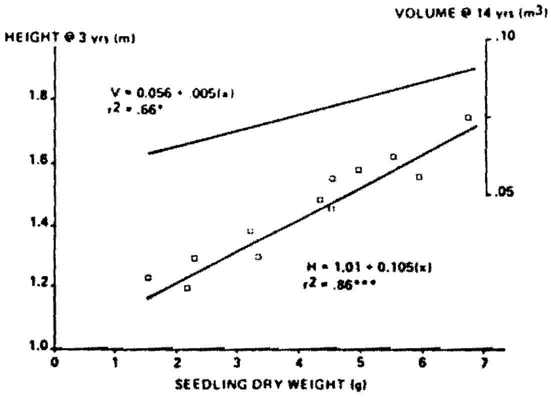

Figure 4.--Relationship between initial seedling dry weight and height after three years and individual tree volume after 14 years in the field (redrawn from Autry 1972, and Switzer and Nelson 1963).

TRANSPLANTING

Once seedlings have achieved target size, fertilization is usually stopped and irrigation frequency is decreased to induce seedling dormancy. Frequently, after height growth has ceased, potassium chloride (KCL) may be applied to promote cold-hardiness. There is ample data to demonstrate that K has little, if any, effect on cold-hardiness (Pellett and Cater 1981). Likewise, there is probably minimum impact of so-called luxuriant fertilization on subsequent cold-hardiness. More importantly, a balanced nutritional regime is required for maximum cold-hardiness (Timmis 1974). While K is not required for cold-hardiness, it is probably required for outplanting success through regulation of plant water status (Bradbury and Malcolm 1977, Christersson 1973). Potassium is highly mobile in soil and deficiency levels can develop in sandy soils at season end. Also, K regulates stomatal control and the drought hardiness of transplanted seedlings. Low K levels in foliage may result in loss of stomatal control during seedling establishment and irreversible wilting. Fall fertilization with KCL in the fall should continue in nursery programs, but for entirely different reasons.

ACCELERATING FIELD GROWTH

Fall fertilization has received little attention, especially in recent years. Woody plants, especially conifers, continue biomass accretion during the dormant season (Perry, 1971). Growth of many coniferous root systems will continue as long as soil temperatures are above 5°C. Fertilization with low levels of N after budset can increase biomass accretion and subsequent performance following outplanting. The opportunity for exploiting this phenomenon without adversely impacting seedling height is important. Hinesley and Maki (1981) demonstrated that field performance of longleaf pine (Pinus palustris Mill.) was significantly improved by fall fertilization in the nursery. Survival, percentage of longleaf pine seedlings emerging from the grass stage and height at 8 years following outplanting were significantly improved by fertilization before lifting. Similar growth and survival responses have been shown for Douglas-fir (Anderson and Gessle 1966) and Sitka spruce (Benzian et al. 1974).

Van den Driessche (1979) showed a positive response to N fertilization for Douglas-fir. Growth was positively correlated with foliage N content and maximum survival occurred when foliage nitrogen content was 2%. They found little correlation between nitrogen content and cold-hardiness of the stock. They recommended application of 50 to 75 kg N/ha the first year, and 100 to 150 kg N/ha the second year. Fall fertilization was not discussed but clearly provides an opportunity for regulating nitrogen content without contributing to seedling gigantism (Switzer and Nelson 1963).

FUTURE DEVELOPMENTS

In addition to biomass, the balance between the vegetative mass of the top and the root system must be considered. It is often assumed that fertilization decreases the root:shoot ratio, and creates an imbalance that might adversely impact field performance. However, data by Switzer and Nelson (1963) on loblolly pine and van den Driessche (1982) on Douglas-fir, Sitka spruce and lodgepole pine indicate fertilization has minimal deleterious impact on root:shoot ratios. Van den Driessche had to quadruple the nitrogen fertilization to show a significant decrease in root:shoot ratio. While the absolute ratio may remain unaltered by fertilization, changes in root morphology have been observed. Increased fertilization of southern pines tends to create a carrot type root system with thick primary laterals supporting few secondary and mycorrhizal roots. These factors can alter seedling performance (Lopushinski and Beebe 1976).

Because fertilization has little or no negative impact on seedling balance, nurserymen must use other means to control root:shoot ratio. Most obvious is the alteration of seedbed density (Harms and Langdon 1977). Undercutting (Tanaka et al. 1976) and water stress also could reallocate the carbon budget from shoot to roots and may be used alone or in combination to achieve balance. Matching fertilizer rate to the plant's needs could result in increased growth and improved balance (Ingestad 1978).

Seedling response to fertilization, especially to nitrogen, can be influenced by many factors, some of which have been discussed. One important factor is the impact of fumigation and subsequent response of mycorrhizal fungi. Adequate mycorrhizal inoculum can have an important impact, not only on seedling size and yield in the nursery (Marks et al. 1978), but also on outplanting performance (Marx, et al. 1977, Theodorou and Bowen 1970). The importance of mycorrhizal inoculation is obvious, but the mode of synergism is unclear because field performance may derive from: (1) seedling response in the nursery rather than plantation (Mexal 1980b), or (2) transfer of mycorrhizal fungi to the planting site (Shoulders and Jorgensen 1969). More work is needed to resolve this issue. Foliar fertilization may improve seedling nutrition without a concomitant decline in mycorrhizal infection (Dixon et al. 1979).

Clearly, it is possible to more fully exploit the immediate and lasting influences of nursery fertilization to achieve greater forest productivity. However, this will require a fuller understanding of the diverse factors governing fertilization interactions and the biological and soil determinants of root regeneration potential, transplant mycorrhization and hardiness. Research must focus on the specific nutritional needs of tree seedlings over time. This will lead to optimal growth and more judicious use of industry-derived resources.

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