

ECOPHYSIOLOGICAL RESPONSE OF DOUGLAS-FIR SEEDLINGS TO POLYMER-COATED FERTILIZERS

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Abstract

Application of polymer-coated controlled-release fertilizers (CRF) during outplanting has resulted in variable growth responses in the Pacific Northwest (PNW). Results have been linked to several factors, including soil moisture availability. Multiple experiments were designed to examine the influence of CRF on Douglas-fir seedling root architectural development and establishment. Placement of CRF as a uniform layer beneath transplanted seedlings restricted root penetration at progressively higher CRF rates and this was attributed to damaging rhizosphere osmotic concentrations. Dry summers on many sites in the PNW may compound this effect because moisture to leach excess fertilizer salts from the root zone is absent. Application of 2.1 oz (60 g) CRF to the planting hole on a droughty site in the Oregon Coast Range impaired seedling root development and increased plant moisture stress. For all treatments, new root growth was positively correlated with xylem water potential, emphasizing the need for vigorous root growth during establishment. Drought stress may limit photosynthetic capacity and force seedlings to expend stored carbohydrates, which may impair whole-plant growth. On drought-prone sites in the PNW, negative fertilizer responses may be avoided with conservative polymer-coated CRF application rates, utilizing CRF with moisture-dependent nutrient release characteristics, or avoiding field fertilization entirely.

Key Words

Nutrient leaching, fertilizer efficiency, plantations, forest regeneration, *Pseudotsuga menziesii*, electrical conductivity

INTRODUCTION

Field foresters in the Pacific Northwest (PNW) are no longer concerned with simply getting good survival following planting. The ability of newly-planted seedlings to rapidly establish within a new environment and grow vigorously during the first several years is of principle concern. Recently, there has been a great deal of interest in using controlled-release fertilizers (CRF) in both the nursery and field to enhance reforestation productivity (Haase and Rose 1997). Both positive and negative results associated with using CRF at outplanting can be identified in the literature. Attaining a positive seedling growth response with CRF appears to depend on a complex interaction of factors, including the technology associated with controlling nutrient

release, plant material (that is, species, stocktype, age, and so on), and planting environment. These fertilizers offer a means to improve reforestation success dramatically; but an inadequate understanding of the proper use of this technology may result in plantation failures.

This paper provides a synthesis of some relevant findings associated with recent research conducted by the Nursery Technology Cooperative (NTC) at Oregon State University with CRF and Douglas-fir (*Pseudotsuga menziesii* (Mirb.) Franco) seedlings. These results were presented in greater detail in Jacobs (2001). The objectives of this paper are to: 1) provide a brief overview of the technology associated with nutrient release in polymer-coated CRF; 2) discuss the influence of polymer-coated

CRF on Douglas-fir seedling root development; 3) explain the importance of soil electrical conductivity to root growth; 4) describe how changes in root growth associated with CRF may affect field performance; and 5) provide implications for reforestation programs in the PNW.

POLYMER-COATED CRF TECHNOLOGY

There are many different types of CRF on the market today. These fertilizers are generally distinguished from fertilizers with immediately-available forms of nutrients (for example, Peters[®] water soluble or urea) and from each other by their mode of nutrient release. Whereas immediately-available fertilizers release nearly all nutrients soon after application, nutrients from CRF are released slowly over a time period of up to 24 months following application. A primary advantage is that with a single application, seedlings may receive enhanced nutrient levels for up to 2 growing seasons. The slow-release nature of CRF better coincides with plant needs, reduces the potential for plant damage, and minimizes nutrient leaching as compared to conventional fertilizers (Hauck 1985; Donald 1991).

Polymer-coated CRF represent the culmination of many years of research in CRF technology and are considered the “state of the art” CRF for horticultural plant production. Product examples include Osmocote[®] (OM Scotts Co), Nutricote[®] (Chisso-Asahi Fertilizer Co), and Polyon[®] (Pursell Industries Inc). To manufacture this product, a water-insoluble polymer material (several different polymer types may be used) is applied as a coating to a water-soluble fertilizer nutrient core, creating a small, granular piece of material commonly referred to as a “prill”.

Nutrient release from polymer-coated CRF occurs first by the diffusion of water through the semi-permeable membrane (Goertz 1993). Water then condenses within the soluble fertilizer core and creates an internal osmotic pressure gradient that forces nutrients out into the soil solution. This process is accelerated with increasing media temperature. Beyond a certain range, soil water content has little influence on nutrient release (Kochba and others 1990). Manufacturers of CRF provide an estimated time for 95%+ nutrient release based on a standardized media temperature (typically 70 °F [21 °C]). Manufacturers vary time periods for nutrient release from CRF by altering the polymer coating thickness or coating composition. Time periods for nutrient release of CRF may range from 3 to 16 months, depending on product.

A series of research trials established during the 1950s illustrated the potential for improving Douglas-fir seedling plantation establishment using urea-formaldehyde (Austin and Strand 1960), at that time a new CRF technology. Since then, the majority of studies investigating the application of CRF to reforestation have utilized polymer-coated CRF. Results from many applied studies have been variable and Brockley (1988) suggested that future research should attempt to better understand the physiological mechanisms by which fertilizer applications affect the growth of planting stock.

INFLUENCE OF CRF ON ROOT ARCHITECTURAL DEVELOPMENT

In an effort to understand how locally-applied CRF may affect early root proliferation of Douglas-fir seedlings, a controlled greenhouse experiment was established. Three-month-old Douglas-fir seedlings grown in 2.4 in³ (39 cm³) containers were transplanted into 135 in³ (2200 cm³) pots. Prior to transplant, Osmocote Plus[®] 15-9-12 (5 to 6 month release) CRF was applied at 1 of 4 fertilizer rates (0, 0.3, 0.6, and 0.9 oz [0, 8, 16, and 24 g]) as a single uniform layer beneath the transplanted root system (fig. 1).

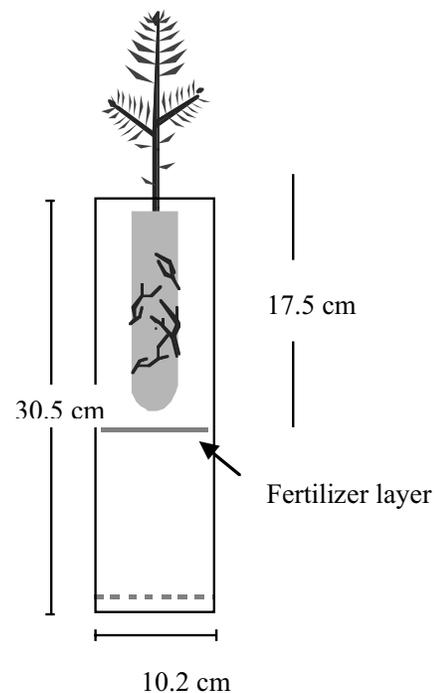


Figure 1. Placement of CRF treatments within pots as a single, uniform layer beneath the transplanted root system.

Seedlings were grown in a controlled environment greenhouse and well-watered throughout the duration of the experiment. Six months following transplant, seedlings were lifted from pots to examine root architectural development in relation to the localized positioning of the CRF layer. Root penetration into the soil zones beneath the CRF layer was severely restricted at the highest CRF rates (fig. 2). Overall mean seedling shoot and root production were greatest in the 0.3 oz (8 g) CRF treatment, but significantly less in the highest (0.9 oz [24 g]) CRF treatment. The negative influence on root penetration at the highest CRF rates and the corresponding reduction in whole-plant growth were attributed to detrimental changes in soil electrical conductivity (EC) associated with an excessive release of nutrients from the CRF.

SOIL ELECTRICAL CONDUCTIVITY

An important concept when applying fertilizers in any plant propagation operation is the resulting influence on soil EC. As fertilizer nutrients are released from CRF, the total salt level within the soil solution increases. Electrical conductivity provides a

measure of the total salt level of a solution and therefore gives an indication of the quantity of fertilizer salts dissolved in the solution (Landis and others 1989). Conifer seedlings range from sensitive to moderately sensitive to high salt concentrations (Tinus and McDonald 1979). High salt concentrations resulting from the release of excessive fertilizer salts into the soil solution may act to kill root apical meristems due to the buildup of toxic ion concentrations and detrimental changes in osmotic potential (Drew 1975).

Considering the importance of EC levels in plant propagation, surprisingly little research has been reported concerning ideal EC ranges to promote growth of forest tree seedlings. Phillion and Bunting (1983) recommended EC ranges between 1200 and 2500 $\mu\text{S}/\text{cm}$ for seedlings of spruce (*Picea*) species. Timmer and Parton (1982) recommended similar EC ranges for black spruce (*Picea pungens* Engelm.) seedlings. They illustrated that as EC levels increased to roughly 1800 $\mu\text{S}/\text{cm}$, seedling growth increased. Beyond this range, however, growth gradually decreased until reaching mortality at EC levels above approximately 4000 $\mu\text{S}/\text{cm}$.

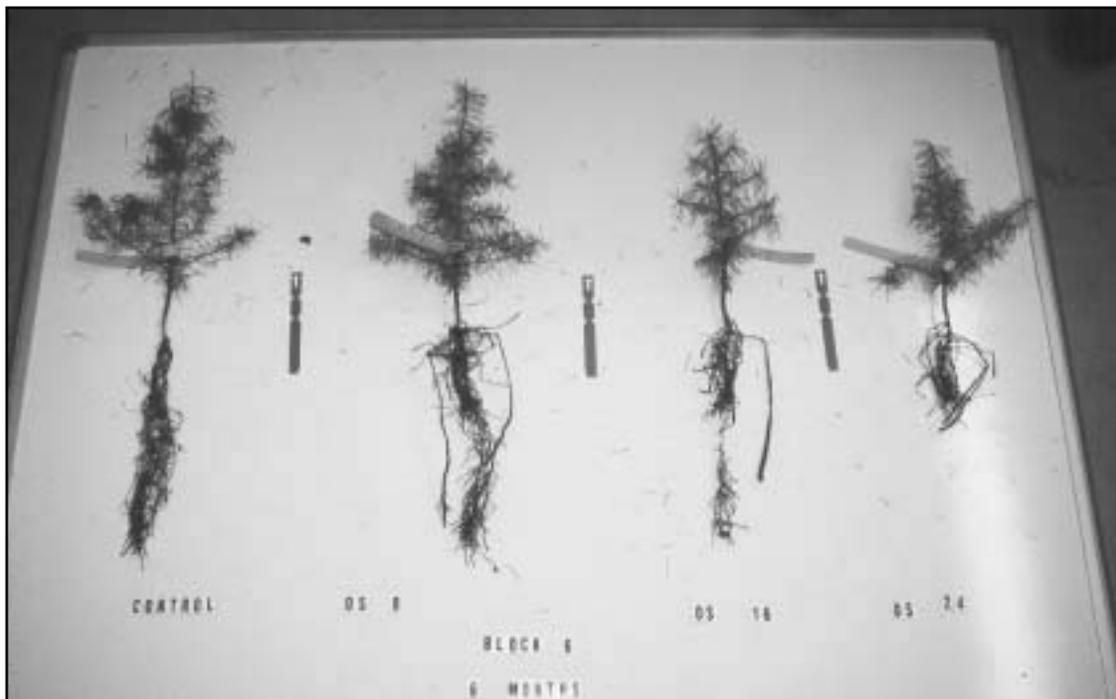


Figure 2. Example seedlings 6 months following transplant showing decreased root penetration into lower soil zones with increasing CRF rate (from left to right).

Poor seedling root growth documented for Douglas-fir seedlings at the highest CRF rates was attributed to excessive EC levels at the point of CRF application. The associated decrease in osmotic potential of the soil solution reached a point where elongating root apical meristems were desiccated and became non-functional. Thus, although CRF release fertilizer salts slowly over time, EC may still reach damaging levels and impair seedling root and whole-plant growth. This effect may be compounded in containerized seedling production when fertigation is also applied.

Techniques for monitoring EC levels in containerized operations are presented in Tinus and McDonald (1979). A portable EC meter can be purchased for under US\$ 200. Levels may be consistently monitored during the growing season and irrigation water applied to leach excessive fertilizer salts from the growing media as conditions warrant. The ability to monitor and adjust EC levels is a distinct advantage that container nursery growers have to successfully use CRF. When CRF are applied at outplanting, foresters must still consider the potential for detrimental changes in soil EC levels associated with the release of fertilizer salts, but have no opportunity to adjust these levels to prevent plant damage.

APPLICATION OF CRF AT OUTPLANTING

To determine if the same type of restriction in root penetration noted in the controlled experiment occurred when Douglas-fir seedlings were fertilized with CRF at outplanting, an experiment was established on a recently clearcut site in the Oregon Coast Range. This site is characterized by wet, mild winters and hot, dry summers. Douglas-fir seedlings (1+1) were either non-fertilized or fertilized with 2.1 oz (60 g) 19-6-12 (~6-month release) Polyon® (JR Simplot Co) CRF in the bottom of the planting hole. Seedlings were excavated after one growing season in the field.

Fertilized seedlings had significantly less root volume growth during the first growing season than non-fertilized seedlings; in some cases, mean root volume growth for fertilized seedlings was actually negative. Fertilized seedlings were also smaller aboveground as compared to non-fertilized seedlings following excavation. No rainfall was recorded on this site from early July until the end of September. Because nutrient release of polymer-coated CRF is primarily controlled by temperature, fertilizer salts continued to release into the soil solution during

summer. Thus, poor root growth of seedlings fertilized at this relatively high rate (2.1 oz [60 g]) was again attributed to detrimental changes in soil EC levels.

A significant portion of roots, particularly fine roots, are lost when bareroot seedlings are lifted from the nursery (Nambiar 1980). Small seedlings have little capacity to store water. Thus, survival and growth is largely dependent on the rapid extension of roots, which reestablish root-soil contact and absorb water to reduce transpirational water loss (Ritchie and Dunlap 1980; Burdett and others 1983; Sands 1984). Drought stress immediately following outplanting may contribute to transplant shock and result in poor seedling growth or mortality.

Fertilized seedlings became significantly more water stressed than non-fertilized seedlings during the summer. Significant positive linear correlations between root volume growth and pre-dawn xylem water potential (that is, good root growth correlated well with resistance to water stress) were established in July, August, and September. This re-emphasizes the importance of promoting adequate root growth following planting.

IMPLICATIONS TO PNW REFORESTATION PROGRAMS

Under ideal conditions, reforestation productivity may be dramatically enhanced with the application of polymer-coated CRF at outplanting. Positive results seem to be most common on sites with adequate summer soil moisture, where doubling of stem volume compared to controls has been reported (Nursery Technology Cooperative 2001).

Extreme care must be taken, however, when utilizing polymer-coated CRF on drought-prone sites. As soils dry in summer and plants enter dormancy, nutrients from CRF continue to release into the root zone. High soil temperatures accelerate nutrient release. Without precipitation to leach excess fertilizer nutrients from within the rhizosphere, EC may reach levels which detrimentally affect root growth. This, in turn, limits the ability of seedlings to resist drought stress. This may contribute to transplant shock and ultimately result in failed plantation establishment.

There is clearly a balance that must be maintained between providing adequate levels of nutrients and maintaining safe EC levels. Under greenhouse conditions, EC levels can (and should) be consistently monitored and irrigation applied when necessary. In the field, foresters should consider the anticipated drought level of the site when deciding on a fertilizer

prescription. Conservative CRF application rates, the use of CRF with moisture-dependent nutrient release characteristics (for example, IBDU, ureaform), or avoiding field fertilization entirely will help to prevent negative results on drought-prone sites. Forestry applications are a relatively new market for CRF products. Manufacturers of CRF must continue to refine CRF nutrient release technology to provide a product in which nutrient release closely coincides with the developmental requirements of forest tree seedlings.

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