Variation in Nutrient Release of Polymer-Coated Fertilizers

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Abstract: Polymer-coated fertilizers (PCF) are used primarily in horticultural plant production. However, interest in using these fertilizers in forest tree nurseries has increased over the last decade. Compared to immediately-available forms of fertilizer and other controlled-release fertilizer types, PCF tend to release nutrients in a relatively consistent flow over time. This helps to improve efficiency of fertilizer use. Nutrient release from PCF is primarily dependent on media temperature; an estimated timeframe for nutrient release at a specific temperature is provided by the manufacturer. Although many different products fall into the general category of PCF, the actual polymer material used varies among products. This affects the degree to which nutrients are released over time. Additionally, timeframes for nutrient release are simply estimates provided by the manufacturer based on lab results, and actual release under operational conditions may deviate considerably from these estimates. There is also considerable variation in release of individual nutrient ions over time from PCF. For instance, many products release a large percentage of available nitrogen soon after application, while release of phosphorus is delayed. Because timing of nutrient release can be critical to successfully using PCF in forest tree nurseries, differences among products should be understood by nursery growers when incorporating various types of PCF into production.

Keywords: controlled-release fertilizer, seedling nutrition, electrical conductivity, nutrient leaching, Osmocote®, Nutricote®, Polyon®

Introduction

Polymer-coated fertilizers (PCF) have been in use within the horticultural industry for decades. These fertilizers represent the most technically advanced state of the art among controlled-release fertilizers (CRF) in controlling product longevity and efficiency of nutrient delivery for plant uptake (Goertz 1993), and PCF comprise the majority of CRF used in horticultural plant production (Bunt 1988; Goertz 1993; Huett and Gogel 2000). Compared to other types of CRF, these fertilizers tend to provide a more gradual and consistent nutrient release pattern with release rates ranging from about 3 months to nearly 2 years. Other types of CRF often provide only nitrogen, but PCF may be blended to provide a balance of all macro- and micronutrients. An advantage of PCF over conventional water soluble fertilizers (that is, fertigation) is that a single application of PCF can supply plants with extended nutrient availability, eliminating the need for labor costs associated with repeated fertilizer application.

Due to the costs of the polymer coating, PCF have traditionally been restricted to relatively high value applications. However, there has been increased interest in mixing PCF into container media in forest tree nurseries. This has become standard operation for a significant portion of seedlings grown by some private companies. Additionally, clients occasionally request that PCF be incorporated into the media of seedlings grown on contracts. In theory, the PCF should begin to release nutrients during nursery propagation, and products with a longer timeframe for nutrient release may continue to provide elevated levels of nutrients to seedlings following outplanting (Jacobs and others 2003a).

Nutrient release from prills of PCF (Figure 1) occurs by diffusion through a semi-permeable membrane. The mechanism of nutrient release is accomplished in 2 stages (Gambash and others 1990). Soon after application and exposure to moisture, water vapor infiltrates into the fertilizer prill and condenses on the soluble fertilizer salt, creating an internal osmotic pressure gradient. The elevated pressure within the prill then allows the fertilizer salts to leak into surrounding media. A

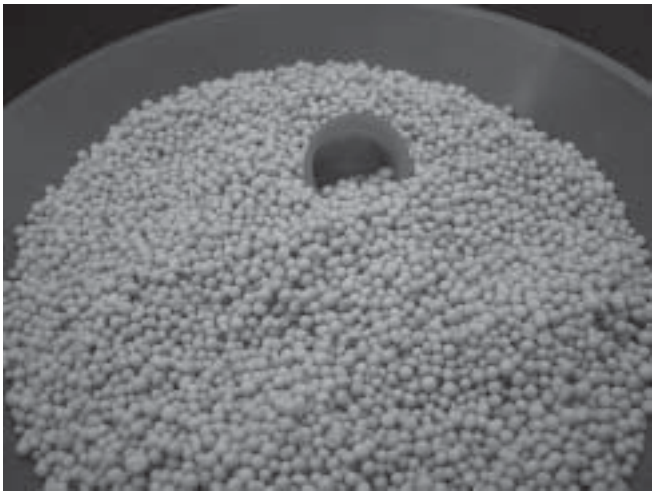

Figure 1—Prills of polymer-coated fertilizer.

given proportion of total nutrients (~20%) may never release from prills of PCF, because the pressure within the prill decreases as the majority of nutrients are released. Manufacturers are able to adjust release rates by changing the physical characteristics of the coating, either the coating thickness or chemical composition of the polymer itself (Goertz 1993).

As many forest tree nurseries are beginning to integrate PCF into production, questions have arisen as to precise mechanisms of how these products release different nutrients and potential variation among products. Using PCF in container media has led to dramatic improvements in both quality of forest tree seedlings following nursery growth and field performance (Nursery Technology Cooperative at Oregon State University, unpublished data). However, some growers have experienced problems with excessive release of fertilizer nutrients into growing media from PCF, which may cause damage to plant roots (Jacobs and others 2003b). Additionally, release of nutrients (for example, ammonium) late in the growing season may promote undesired shoot growth during dormancy induction (Landis and others 1989). Growers must understand that when using PCF, precise control of nutrient supply to plants is reduced compared to conventional water soluble fertilizer inputs. Furthermore, it is important to keep in mind that PCF products currently available on the market were generally not designed specifically for use with forest tree seedlings, but rather for crops more commonly produced in the horticultural industry.

It is therefore important to be well aware of nutrient release characteristics of PCF and potential differences among comparable products. Thus, the objectives of this paper are to: (1) explain factors controlling the rate and pattern of nutrient release from PCF, (2) describe variation in release of individual nutrient ions from PCF, (3) compare differences in coating technology among varying products of PCF, and (4) synthesize the current literature regarding variation in nutrient release among different products of PCF.

Rate and Pattern of Nutrient Release

Two terms that are helpful when examining how PCF release nutrients are the rate and pattern of nutrient release. Rate refers to the total quantity of nutrients released over the entire time period; pattern refers to the periodic distribution of nutrient release at specified time intervals throughout the designated release period. Manufacturers of PCF generally strive to produce a product that begins to release nutrients soon after application and provides a consistent flow of nutrients through the duration of the designated release period. Hence, the rate would be delivered in a pattern of equal distribution over the release timeframe.

In forest tree nurseries, it might be preferable if nutrients were delivered in an exponentially increasing manner (Timmer 1997) to better match supply with plant demand. There is potential for this pattern of nutrient release to be achieved with products characterized by a release period of 5 to 6 months or more. However, the actual pattern of nutrient release of some PCF types may be to dispel a large portion of nutrients in the early stages of the designated release period when plant demand is low. For instance, in a study where Osmocote® and Nutricote® (3- to 4-month release) were tested, the most rapid nitrogen (N) and potassium (K) release occurred within the first 2 weeks after potting, resulting in significant nutrient leaching and poor efficiency of fertilizer use (Huett 1997a,b).

The major environmental factor controlling the pattern of nutrient release from PCF is media temperature (Kochba and others 1990). Soil moisture percentage within the range typically maintained in container seedling production has a relatively minor influence on nutrient release from PCF. Kochba and others (1990) reported no significant difference in patterns of nitrate released when soil moisture varied between 50 to 100% of field capacity (Figure 2). In contrast, nutrient release from PCF may increase dramatically as media temperatures rise (Kochba and others 1990; Huett and Gogel 2000) (Figure 3). Kochba and others (1990) studied nutrient release behavior of PCF and, in one instance,

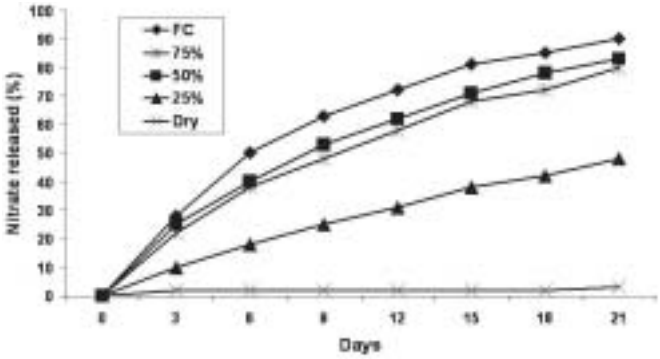

Figure 2—Release of nitrate from polymer-coated fertilizer based on media moisture content (adapted from Kochba and others 1990).

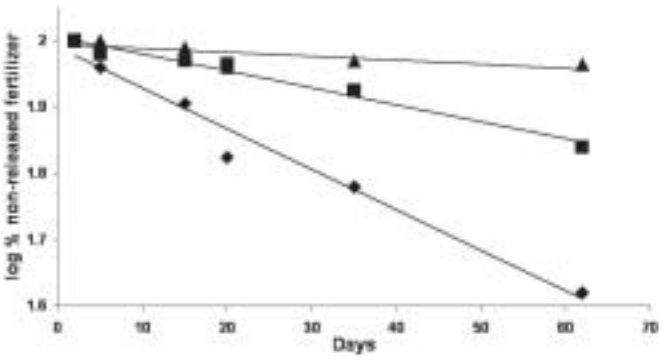

Figure 3—Release of nutrients from polymer-coated fertilizer based on media temperature (adapted from Kochba and others 1990).

reported a doubling of nutrient release when temperatures were increased by 10 °C (18 °F). Release rate of N, P, and K in a variety of Osmocote®, Polyon®, and Nutricote® fertilizers increased by 13 to 19% with a 10 °C (18 °F) rise in temperature (Huett and Gogel 2000).

Manufacturers provide estimates for duration of nutrient release from products of PCF. These estimates are generally based on controlled laboratory trials where total fertilizer released (by weight) is determined under constant temperature conditions, typically ranging from 21 (most common) to 25 °C (70 to 77 °F) (Goertz 1993). Actual rates of nutrient release under operational conditions may vary considerably from these estimates (Bunt 1988), as greenhouse temperatures may fluctuate dramatically both diurnally and seasonally. Thus, it is unlikely that PCF will conform closely in operation to estimates provided by manufacturers. In fact, release may be much slower (cool temperatures) or faster (warm temperatures) than expected. This suggests that growers should consistently monitor electrical conductivity (either of leachate or media) and supplement with fertigation or leach as necessary.

Variation in Release of Individual Nutrient Ions

In any fertilization program, it is important to understand the concept of nutrient balancing. This concept simply emphasizes that more important than absolute quantities of nutrients in the media is the balance of the supply of one nutrient to another. Ingestad (1977) proposed an optimum ratio of 100:50:15:5:5 for nitrogen (N) relative to potassium (K), phosphorus (P), calcium, and magnesium. This ratio seems to hold constant over a range of plant species. When nutrient ratios become imbalanced, plant development is likely to be limited by the nutrient in shortest supply.

Because container propagation of forest tree seedlings generally incorporates a peat-vermiculite media with low inherent fertility, most nutrients under these cultivation systems are supplied through external fertilizer inputs (Landis and others 1989). Fertigation with water-soluble fertilizers generally provides an adequate balance of both macro- and micronutrients. Because PCF also tend to contain a measured balance of most or all plant essential mineral nutrients, growers generally assume that a properly balanced nutrient ratio would be provided by PCF. However, there appears to be considerable variation in release of individual nutrient ions from PCF.

A field study examining release of individual nutrient ions from different Polyon® products with a range of estimated times for nutrient release found that ammonium (NH_4) and nitrate (NO_3) released 85 to 91% and 71 to 85%, respectively, of available nutrients during an approximately 15-month period (Nursery Technology Cooperative at Oregon State University, unpublished data). However, release of phosphate (P_2O_5) was found to be only 19 to 37% of original composition during the release period. Ranking of macronutrient release was $NO_3 > NH_4 > K >$ sulfur > magnesium > P. Release of micronutrients (that is, iron, manganese, zinc, and molybdenum) decreased very little from initial contents. Similarly, it was reported that P released at 60 to 80% of the N and K rate in Nutricote® and Osmocote® (Handreck 1997); and Huett and Gogel (2000) found the time-to-release in order of N > K > P.

The apparent lag in release of P as compared to other macronutrients from PCF could cause potential for concern if this created an imbalance in plant nutrient ratios. It is likely that mechanisms for inefficient release of P may be related to the tendency of P to adsorb to other mineral nutrients (for example, iron and aluminum) to form insoluble metal phosphates. This can be of particular relevance at extreme (that is, high or low) pH values, which may sometimes be induced locally through rhizosphere acidification following root uptake of NH_4. Release of P may be further reduced by its very low soil mobility. Thus, it is possible that much of the P contained within prills of PCF is either bound chemically or does not move beyond the immediate vicinity of the prill. This implies that P should be in greater quantity in PCF than N. However, most formulations of PCF have a 3 to 1 or greater ratio of N to P in the formulation. There is potential that this imbalance could limit seedling morphological and physiological development due to a low P to N ratio, though few published accounts have specifically addressed this issue. Furthermore, it has been suggested that for (at least) growth of forest tree seedlings, response is largely driven by fertilizer N content, with specific formulations of other mineral nutrients having little additional influence (van den Driessche 1997).

Polymer Coating Technology

Many different PCF are marketed for use in container production of forest tree seedlings. Perhaps the most common 3 product types are Nutricote®, Osmocote®, and Polyon® and this section focuses on them. Though all classified under the general category of PCF, the actual coating technology varies among these products. The following section briefly describes coating technology of these products as presented in Goertz (1993).

Nutricote® (Chisso-Asahi Fertilizer Company, Ltd, Tokyo, Japan) employs thermoplastic resins (polyolefin, poly [vinylidene chloride], and copolymers) as coating materials. Thermoplastic resins are highly impermeable to water. Thus, release controlling agents (ethylene-vinyl acetate and surfactants) are added to the coating to attain desired diffusion character. Coating thickness is the same for all

products, and the amount of added release controlling agents determines nutrient release rate. Manufacturers have attempted to minimize the effect of temperature on patterns of nutrient release by dispersing mineral fillers into the coating.

The coating technology in Osmocote® (OM Scotts Company, Marysville, OH) was developed in the 1960s, and this coating is classified as a polymeric resin. The coating process involves coating a soluble fertilizer core with a thermoset copolymer of dicyclopentadiene and a glycerol ester (linseed oil) dissolved in an aliphatic hydrocarbon solvent. The coating is applied in several layers, and coating thickness controls the pattern of nutrient release. Product longevities currently range from as little as 3 to 4 months to as long as 14 to 16 months.

As of 1988, Polyon® (Pursell Industries, Inc., Sylacauga, AL) employs a reactive layer coating (RLC) process which polymerizes 2 reactive monomers as applied to the fertilizer substrate in a continuous coating drum, forming an ultrathin polyurethane membrane coating. Apparently, the efficiency of the RLC process allows for somewhat lower production costs than many other PCF.

Variation in Nutrient Release Among PCF

Despite equivalent estimated times for nutrient release, different product types of PCF may have highly variable temporal patterns of nutrient release. Patterns of nutrient release among different products have been reported from laboratory experiments conducted under controlled temperatures (Lamont and others 1987; Cabrera 1997; Huett and Gogel 2000). Cabrera (1997) studied nutrient release behavior of 7 different PCF (each with an 8- to 9-month release period) over a 180-day experimental period. Osmocote® 24N:4P_2O_5:8K_2O (High-N) and Polyon® 25N:4P_2O_5:12K_2O exhibited a nutrient leaching pattern that closely followed changes in mean ambient daily temperatures, while Nutricote® 18N:6P_2O_5:8K_2O showed a more stable leaching pattern over a wider range of temperatures (Figure 4). The ability of the Nutricote® product to buffer against fluctuations in temperature may be partly a function of variation in coating technology, as described above.

Nutrient longevities (to 90% nutrient recovery) of Nutricote®, Osmocote®, and Polyon® were also studied under controlled conditions by Huett and Gogel (2000) at either 30 or 40 °C (86 to 104 °F) media temperature. They found that longevities of all formulations were considerably shorter than release periods designated by manufacturers. When examining 8- to 9-month longevity products, the general ranking of weeks to 90% recovery of N, K, or P was Nutricote® > Polyon® > Osmocote® regardless of media temperature (Figure 5).

Based on results described above from Cabrera (1997) and Huett and Gogel (2000), the tendency would be to assume that among products with comparable designated release periods, Nutricote® would release over a longer timeframe and be more resistant to fluctuations in media temperature than Polyon® or Osmocote®. However, this does not appear to always necessarily hold true. Huett and Gogel (2000) reported that when comparing Polyon® and Osmocote® (each with a 5- to 6-month release) with 140-day Nutricote®, longevity of N, P, and K was substantially less for Nutricote® than the other 2 products (Figure 6). Longevity of Polyon® was again greater than for Osmocote® (Figure 6).

Reports of nutrient release among comparable products of PCF are helpful in predicting how forest seedlings might respond to application of these products in container media. However, it should be noted that documented release patterns under controlled conditions often show poor correlation with operational plant growth, likely due to interactions between the fertilizer and growing system (Bunt 1988).

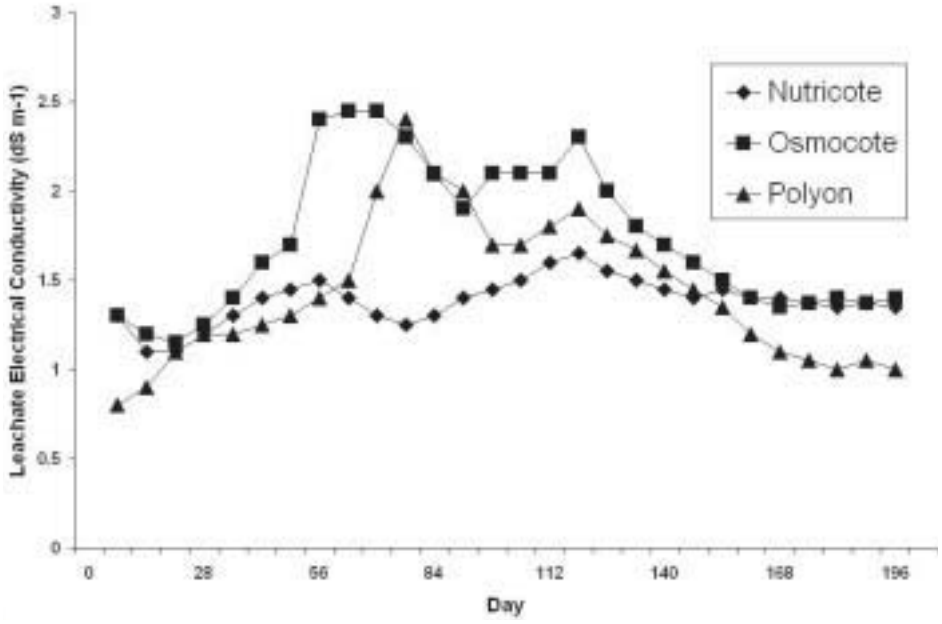

Figure 4—Variation over time in nutrient release (measured by electrical conductivity) from 3 different polymer-coated fertilizer products (adapted from Cabrera 1997).

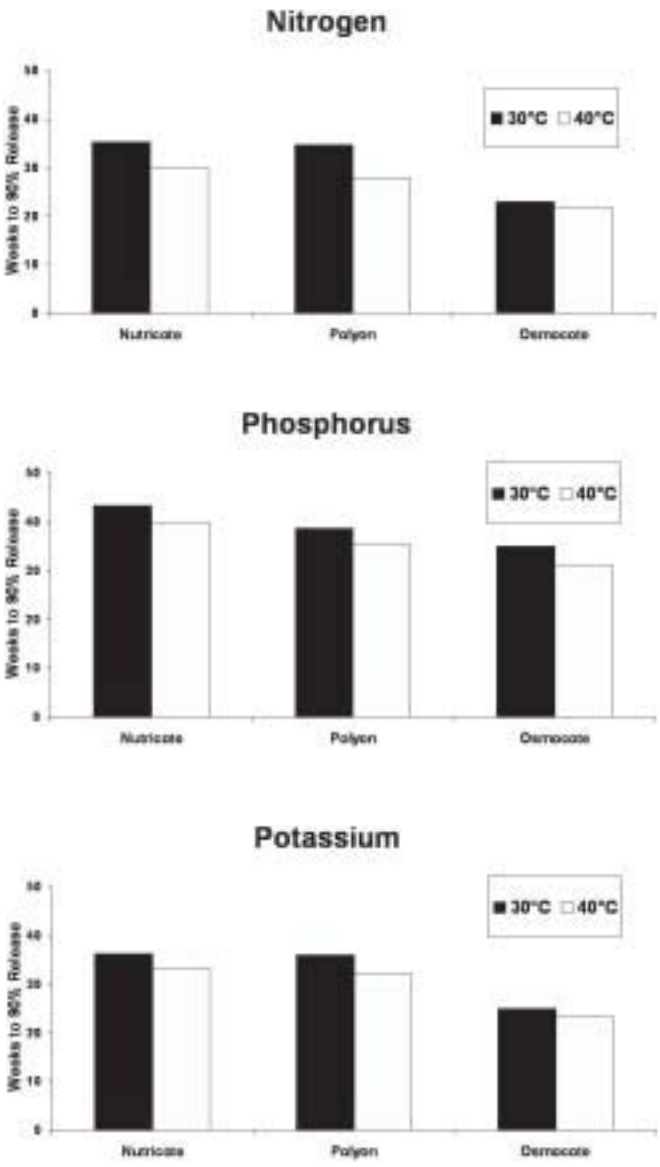

Figure 5—Weeks to 90% fertilizer nutrient recovery from 3 different polymer-coated fertilizer products, each with an estimated 8- to 9-month release timeframe, at either 30 or 40 °C media temperature (adapted from Huett and Gogel 2000).

Though increasing in recent years, relatively few research studies have examined how variation in nutrient release among comparable PCF products affects forest seedling development over time. Lack of this knowledge limits the ability of growers in forest tree nurseries to adjust fertilizer prescriptions to optimize plant growth and minimize potential for seedling damage. It is logical to assume that the variation in nutrient release among PCF products described above would lead to differences in forest seedling development over time. Jacobs and others (2005) compared similar formulations of Osmocote® and Polyon® (each with a 5- to 6-month release period) and found that Douglas-fir seedlings grown with Osmocote® exhibited greater caliper growth and had higher foliar concentrations of N (though lower P) after

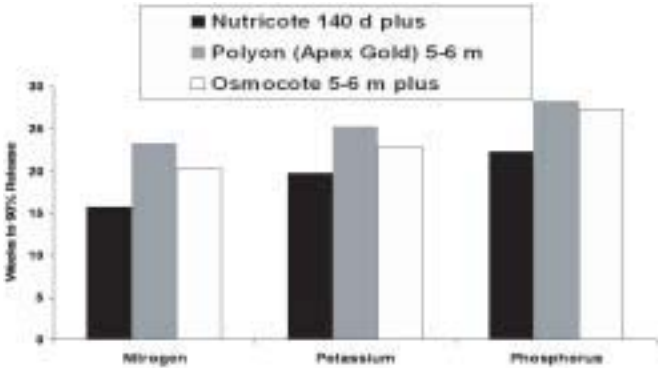

Figure 6—Weeks to 90% fertilizer nutrient recovery from 3 different polymer-coated fertilizer products, each with an approximately 5- to 6-month release timeframe (adapted from Huett and Gogel 2000).

4 months than seedlings grown with Polyon®, although differences were similar at 9 months.

Conclusions

Considerable interest in using PCF in container production of forest tree seedlings has been stimulated by periodic reports of large improvements in initial field growth for seedlings receiving PCF in container media (for example, Nursery Technology Cooperative at Oregon State University, unpublished data). As expectations for reforestation productivity continue to rise, it is likely that interest in using PCF for this purpose will only increase in the future.

It is critical that growers of forest tree seedlings realize that when using PCF, precision of nutrient supply is reduced compared to conventional fertigation. Plant nutrient supply from PCF is largely determined by media temperature, and cool greenhouse temperatures may promote low nutrient release, while sudden increases in temperatures can cause rapid nutrient flushes into media.

Timeframes for nutrient release provided by manufacturers are somewhat crude estimates, and not readily transferable to operation. Release of different individual nutrient elements from PCF varies both in rate and pattern. Patterns of nutrient release also tend to deviate considerably among comparable PCF products.

Variation in nutrient release from PCF should be understood by growers to formulate fertilizer prescriptions that optimize nutrient uptake, minimize leaching, and prevent crop damage. Growers should consistently monitor electrical conductivity levels and supplement with fertigation or leach as needed to ensure optimum nutrient supply.

It is likely that knowledge of crop nutrient requirements over specific developmental stages is as important as knowing the pattern and intensity of nutrient release from PCF. In an attempt to match nutrient supply with seedling demand, prescriptions for incorporating PCF should consider fluctuations in species nutrient requirements when selecting a product. Growers who wish to incorporate PCF into production should carefully monitor seedling development as affected by different products of PCF to identify a

fertilizer system that will optimize seedling growth of certain species under a specific nursery cultural regime. New research should be designed to better understand how different products of PCF affect seedling development of important commercial forest tree species, and these results should be effectively transferred to operation.

Acknowledgments

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