INCORPORATING CONTROLLED-RELEASE FERTILIZER TECHNOLOGY INTO OUTPLANTING

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Abstract

The application of controlled-release fertilizers (CRF) at the time of planting offers a means to improve the establishment of forest tree seedlings. As compared to conventional fertilizers, the gradual pattern of nutrient release from CRF may better coincide with plant needs, minimize leaching, and improve fertilizer use efficiency. Many different CRF types are available and products differ in both the technology by which nutrients are contained and the environmental stimulus for nutrient release. Coated CRF use a polymer or sulfur coating to encapsulate water-soluble nutrients; coating thickness and media temperature primarily control the rate of nutrient release. Uncoated nitrogen reaction products are relatively insoluble in water and nutrient release is generally controlled by water availability and/or microbial decomposition. Results from field trials in the Pacific Northwest (USA) indicate that attaining a positive response at outplanting with polymer-coated CRF is largely dependent on soil moisture availability. Continued release of fertilizer nutrients under hot and dry conditions may cause root damage and increase seedling susceptibility to drought. In the southeastern US, rainfall during summer may reduce the potential for this problem. On drought-prone sites, however, a conservative polymer-coated CRF application rate or the use of CRF with moisture-dependent forms of nutrient release is recommended.

Key Words

Nutrient leaching, fertilizer efficiency, plantations, forest regeneration, *Pseudotsuga menziesii*, *Pinus ponderosa*

INTRODUCTION

Controlled-release fertilizers (CRF) have traditionally been used in the horticultural industry to improve nutrition of nursery-grown plants. These fertilizers offer a potential means to improve forest regeneration efforts substantially, and interest in their application for plantation forestry has increased in recent years (Haase and Rose 1997). With a single application, CRF can supply seedlings with enhanced nutrition for as long as 2 years, providing a consistent and sustained flow of nutrients that may better coincide with plant development (Donald 1991) as compared to conventional forms of fertilizer with immediately-available forms of nutrient release. The gradual release of CRF may act to minimize nutrient leaching, reduce plant damage, and improve overall fertilizer use efficiency.

Many different types of CRF are currently marketed for use with forest tree seedlings. Controlled-release fertilizers primarily vary in terms of their nutrient formulations, estimated product longevities, and mechanisms of nutrient release. The ultimate goal of CRF manufacturers has been to develop a product that delivers nutrients at a rate matching plant demand, thus improving crop yield and minimizing the loss of nutrients due to leaching (Hauck 1985; Goertz 1993). To date, the use of CRF in field plantings has been primarily experimental. Attaining a positive seedling growth response from CRF following application at planting appears to depend on a complex interaction of factors including plant material, CRF type and application rate, soil characteristics, environmental growing conditions, and so on. Both positive and negative responses can be found in the literature.

The purpose of this paper is to: 1) provide an overview of CRF technology; 2) outline some products currently available on the market; 3) present an overview of recent research conducted by the Nursery Technology Cooperative at Oregon State University with CRF; and 4) briefly discuss possible implications of CRF to reforestation programs in the southern region.

OVERVIEW OF CRF TECHNOLOGY

Controlled-release fertilizers differ from conventional forms of fertilizer (for example, urea and water-soluble products) in that the majority of nutrients are not available immediately following application but released slowly over time. The vast array of different CRF types makes selecting a product for a specific planting application difficult. The purpose of this section is to provide a brief technical overview of some common forms of CRF that may be applicable to field plantings. Two primary distinctions between individual CRF products are the technology associated with encapsulating or binding fertilizer nutrients and the environmental mechanism by which these nutrients are released into the soil solution (table 1).

Coated Materials

Coated CRF products currently represent the most widely expanding form of CRF technology due to the flexibility in patterns of nutrient release and the capacity to release nutrients other than nitrogen (Goertz 1993). Coated CRF products usually involve

Table 1. Abbreviated list of different types of controlled-release fertilizers, mechanisms of nutrient release, and product examples.

Category	Mechanism of Nutrient Release	Examples of Products
Coated Materials		
Sulfur-Coated	Cracks and imperfections in sulfur coating allow water vapor transfer through coating to reach soluble urea, osmotic pressure builds to further disrupt coating and urea released. Disruption of coating accelerated at high temperatures and in drier soils. Quality and quantity of sulfur coating determines release rate.	Lesco®
Polymer-Coated		
Polymeric-resin	Water vapor transfer through tiny pores in coating creates internal osmotic pressure that acts to distend semi-permeable and flexible membrane, which enlarges pores and allows dissolution of solution. Higher temperatures cause membrane to swell more rapidly. Thickness of coating determines nutrient release.	Osmocote® Sierra® High N®
Polyurethane	Unique method of coating known as “reactive layer coating” produces very thin membrane coating. Nutrient release occurs by osmotic diffusion through coating. Coating tends to resist swelling characterized by polymeric-resin products and may result in somewhat less temperature-dependent release.	Polyon®
Thermoplastic resin	Coating highly impermeable to water and coating thickness nearly the same for all products. Nutrient release controlled by added level of ethylene-vinyl acetate and surfactants which modify permeability characteristics. Results in a slightly less temperature-dependent release.	Nutricote® (polyolefin)
Uncoated Materials		
Ureaform	Product composed of methylene urea polymers. Broken down by soil microbes (primarily) and hydrolysis. Release rate extended by increasing polymer chain length. Environmental factors affecting microbial activity (soil temperature, moisture, pH, aeration, etc.) influence rate of release.	Nitroform®
IBDU	Product of urea and isobutylidene diurea. Nitrogen released through hydrolysis (accelerated at low pH and high temperatures). Rate of release primarily affected by particle size and amount of water available.	Woodace®

the encapsulation of soluble fertilizer nutrients within a water-insoluble coating, creating a 2 to 3 mm granule commonly referred to as a "prill". The variability and unevenness of an individual prill makes attaining a complete and uniform coating difficult. This often results in areas of uneven coverage that detract from the ability to accurately meter nutrient release. Many different types of coatings have been used experimentally and it is likely that the "ideal" material has yet to be discovered. Some materials release nutrients too rapidly while others never effectively release nutrients. Two common CRF coatings used commercially are sulfur and polymer.

Sulfur coated—Sulfur was one of the first materials used as a coating for CRF due to its low cost and value as a secondary nutrient (Goertz 1993). Sulfur-coated urea (SCU) is often marketed for use in the turf grass industry. Following the coating of urea particles with sulfur, a wax sealant may be used to close sulfur pores. Nutrients are released from SCU by water penetration through micropores or inconsistencies in the sulfur coating. Urea inside the prill dissolves and is rapidly released into the soil solution. The release rate of SCU is controlled by modifying the quality and thickness of the sulfur coating. Environmental conditions, such as high temperatures and exposure to relatively dry soils, act to further degrade the coating and accelerate nutrient release (Allen 1984). A disadvantage to SCU is the potential for urea to be released at a rapid initial rate and then quickly taper off, which may contribute to plant damage and reduce fertilizer efficiency. An advantage is the lower cost. Lesco® is an example of a SCU on the market.

Polymer coated—Polymer-coated CRF are considered the most technically-advanced form of CRF due to the considerable ability to control product longevity and subsequent efficiency of nutrient delivery. In most horticultural systems, polymer-coated CRF have replaced SCU because they provide a more gradual and consistent pattern of nutrient release (Goertz 1993). Nutrient release of most polymer-coated CRF is determined by the diffusion of water through the semi-permeable membrane (Goertz 1993). This process is accelerated at progressively higher soil temperatures, with soil water content providing little influence on release (Kochba and others 1990). Thus, manufacturers of polymer-coated CRF generally provide estimates for 90%+ nutrient release based on an average media temperature (typically 70 °F [21 °C]). The general term polymer refers to a compound of high molecular weight derived from many smaller molecules of low molecular weight. Thus, many specific coating materials fit into the general class of "polymer-coated CRF". These may include polymeric resin, polyurethane, and thermoplastic resins.

Polymeric resin—Polymeric resin-coated CRF are primarily produced by Scotts Company and include market brands such as Osmocote® and Sierra®. The resin coating is applied in several layers and nutrient release is controlled by regulating the thickness of the coating. Product longevities range from 3 to16 months. Water vapor transfer through microscopic pores in the coating reaches the soluble fertilizer and creates an internal osmotic pressure that acts to expand the flexible coating. This causes the pores to enlarge and nutrients are then released into the soil solution (Hauck 1985). High soil temperatures accelerate expansion of the coating and subsequently increase the rate of nutrient release. Depending on coating thickness and media temperature, polymeric resin-coated CRF may produce an excessive initial flush of nutrients. Osmocote® has been shown to release nitrogen at a more rapid initial rate than comparable polymer-coated CRF (Huett and Gogel 2000).

Polyurethane—An example of a polyurethane-coated CRF is Polyon® (Pursell Industries Inc), which uses a coating technology known as reactive layer coating (RLC) to polymerize 2 reactive monomers, forming a very thin membrane coating (Goertz 1993). Nutrients are released by osmotic diffusion and release is controlled by adjusting the thickness of the coating. The RLC technology results in a coating material that is more resistant to swelling than polymeric-resin CRF and the original coating thickness tends to be maintained. Although temperature is still the primary environmental factor governing release, this technology results in a less temperature-dependent release than polymeric-resin coated fertilizers, which may promote a more gradual pattern of nutrient release.

Thermoplastic resin—Thermoplastic resins, such as polyolefins, poly (vinylidene chrloride), and copolymers are also used as coating materials within the polymer-coated CRF grouping. An example is Nutricote®. Because these coatings are highly impermeable to water, nutrient release is controlled by added release agents, such as ethylene-vinyl acetate and surfactants, which act to modify permeability characteristics (Goertz 1993). Similar to other polymer-coated fertilizers, nutrients are released by diffusion through the coating. However, the added level of release agents determines the rate of nutrient diffusion rather than coating thickness.

High soil temperatures accelerate nutrient release, though the coating technology is designed to minimize this effect in order to provide a gradual and consistent pattern of release.

Uncoated Organic Materials

Several different nitrogen reaction products are produced for use as CRF. These involve reacting low-cost urea with one of several aldehdyes to form a compound that is sparingly soluble in water (Hauck 1985). These compounds then slowly release nitrogen into the soil solution by chemical and/or biological activity. A disadvantage as compared to polymer-coated fertilizers is that independently, these products release only nitrogen, and supplemental products may be needed to provide additional macro- and micronutrients. A potential advantage is that nutrient release is controlled by factors other than soil temperature; soil moisture being the most notable. Two common examples of uncoated organic CRF are urea-formaldehyde (ureaform) and isobutylidene diurea (IBDU).

Ureaform—Ureaform is a form of slow-release nitrogen technology dating back to the 1950s and is the product of the reaction of urea and formaldehyde in the presence of a catalyst. An example is Nitroform®, produced by Nu-Gro Technologies, Inc. The urea-formaldehyde reaction produces methylene urea polymers of varying molecular weights and chain lengths (Goertz 1993). The chain length is the technological mechanism by which nutrient release is controlled; a longer chain length is less water soluble and requires more time to break down. Microbial decomposition is the primary mechanism by which ureaform is converted to plant available forms of nitrogen in the soil. Thus, the numerous environmental conditions that regulate microbial activity (for example, soil moisture, temperature, pH, aeration, and so on) also control the rate of nutrient release.

IBDU—Another nitrogen reaction product is IBDU, which is the condensation product of urea and isobutyraldehyde. Commercially, Woodace® uses IBDU as a nitrogen source. This compound is relatively insoluble (< 0.1%) in water and a commercial product may contain roughly 31% nitrogen (Hauck 1985). As compared to ureaform, water is the primary mechanism for nutrient release as nitrogen from IBDU becomes available to plants strictly through hydrolysis. In the presence of water, the compound hydrolyzes to urea and isobutyraldehyde and this process is accelerated at low pH and high temperatures (Goertz 1993). Smaller particles tend to hydrolyze faster.

CURRENT TRENDS IN FOREST REGENERATION CRF RESEARCH

Recent interest in the potential for CRF to improve the establishment of outplanted seedlings has stimulated research in this area. The Nursery Technology Cooperative (NTC) in the Department of Forest Science at Oregon State University has been actively conducting CRF outplanting research in recent years. The purpose of this section is to present a brief overview of some recent findings from these studies.

There are 2 primary methods for incorporating CRF into outplanting. The first method is to apply CRF to seedlings at the time of planting. Researchers have advocated applying CRF to the bottom of the planting hole in field plantings to facilitate efficient nutrient uptake (Carlson 1981; Carlson and Preisig 1981; Gleason and others 1990). This placement positions the fertilizer in close proximity to the root zone where nutrients can be rapidly extracted (fig. 1). Other CRF placement options include dibbling to the side of the root system, placing directly on the roots within the planting hole, and broadcast application at the base of the seedling. The ideal placement of CRF at outplanting is still a matter of debate.

A second and relatively new approach involves incorporating CRF directly into the growing media of containerized seedlings (fig. 2). The CRF is uniformly mixed at a specific rate into soil media

Figure 1. Application of controlled-release fertilizer at outplanting. Fertilizer is typically measured by volume and then applied to the bottom of the planting hole prior to seedling planting.

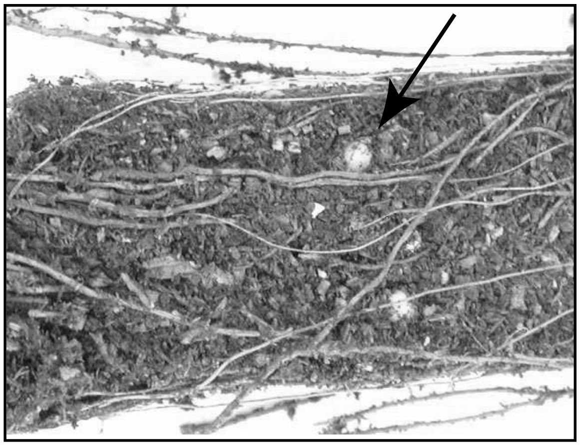

Figure 2. Controlled-release fertilizer incorporated into the media of a containerized seedling. Fertilizer is uniformly mixed into media prior to application to containers.

prior to seed germination and seedling roots grow into the CRF media while in the greenhouse. When using CRF with a relatively long product life (for example, 12 to 14 months), seedlings should experience 2 growing seasons of added nutrition. Roots begin to extract CRF nutrients in the greenhouse and these nutrients may continue to release following transplant to the field.

The majority of NTC research thus far has involved polymer-coated CRF. Results have been somewhat variable and, observationally, results seem to differ based on soil moisture availability. Perhaps the most striking positive results thus far were observed on a site near Toledo, Oregon (Nursery Technology Cooperative 2001). This site is located adjacent to the Oregon coast and receives over 120 inches (305 cm) of rainfall per year. Douglas-fir (*Pseudotsuga menziesii* (Mirb.) Franco) seedlings were grown in containers with treatments consisting of various CRF products mixed into the growing media. Fertilized seedlings had up to double the height growth of unfertilized control seedlings during the first year following planting and continued to have significantly greater growth than controls during the second and third growing seasons. One CRF treatment resulted in more than double the mean stem volume of controls after three growing seasons.

Results on drier sites have been less positive. On a site at the Warm Springs Indian Reservation in central Oregon, a negative influence of fertilization with CRF applied to the planting hole was observed. Survival of fertilized Douglas-fir and ponderosa pine (*Pinus ponderosa* Dougl. ex Laws.) seedlings was reduced compared to unfertilized controls and no differences in growth were apparent after 2 seasons (Nursery Technology Cooperative 2000). An additional field study was designed to investigate the effects of various methods of CRF placement (that is, bottom of planting hole, dibble, on roots, and broadcast) on Douglas-fir establishment on a drought-prone site in the Oregon Coast Range. Results suggested that performance decreased with increasing proximity of CRF to seedling roots, particularly at higher CRF rates (Alzugaray 2002).

Speculation that the use of polymer-coated CRF on drier sites may negatively affect root growth and make seedlings more susceptible to drought stress stimulated several experiments designed to investigate the influence of CRF on root architectural development (Jacobs 2001). In a controlled study, CRF was applied as a single layer beneath the root system of transplanted Douglas-fir seedlings. At progressively higher CRF rates, root penetration below the soil layer was severely restricted; this was attributed to detrimental changes in soil osmotic potential following CRF nutrient release. A subsequent study on a drought-prone site in the Oregon Coast Range found that at a relatively high rate (2.1 oz [60 g]) of CRF applied to the planting hole, fertilized seedlings became significantly more drought stressed than controls during the first summer following planting. Fertilized seedlings also had very poor root growth. Analysis of fertilizer nutrient release over time (based on changes in dry weight) indicated that nutrients continued to release when soils dried during summer and plants entered dormancy. This resulted in changes in rhizosphere osmotic potential that, along with poor root growth, were attributed to the drought stress incurred.

Several lessons have been learned thus far from research with CRF at outplanting. Polymer-coated CRF work very well in a nursery environment due to the ability to control water availability. In the field, polymer-coated fertilizers continue to release nutrients as soils dry. On drier sites in the Pacific Northwest, this may present a problem during the summer dry season because water to leach excess nutrients from the root zone is unavailable. Detrimental changes in rhizosphere osmotic potential may be intensified at progressively higher CRF rates. It is possible that products with moisture-dependent nutrient release characteristics (for example, ureaform and IBDU) will minimize the potential for damage, and research into this area is currently being conducted by the NTC.

IMPLICATIONS FOR THE SOUTHERN REGION

Literature reviews on the use of CRF at outplanting in the southern region produced few examples from which to draw inference. Based on results from recent NTC studies, it is clearly important to match the level of field fertilization with polymer-coated CRF to the anticipated degree of moisture stress on the site. Compared to many sites in the Pacific Northwest, a distinct advantage in the southern region is the occurrence of precipitation during summer. This may act to periodically leach excess fertilizer salts from the root zone, minimizing potential for root damage and susceptibility to drought stress. However, high soil temperatures in the southern region may result in rapid CRF nutrient release during dry periods.

It is best to err on the side of conservative polymer-coated CRF application rates, particularly on drought-prone sites. Continued evolution of polymer-coated CRF technology to produce a nutrient release mechanism that is less dependent on soil temperature may improve seedling response to fertilization on moisture-limited sites. Consideration should also be given to applying fertilizer 1 to 2 years following planting when seedling root systems have established. The use of uncoated organic CRF with mechanisms of nutrient release that are largely dependent on moisture availability may be a better source of CRF on dry sites. On sites where drought is extreme, however, it may be necessary to avoid field fertilization entirely.

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