Using Polymer-coated Controlled-release Fertilizers in the Nursery and After Outplanting
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Controlled-release fertilizers (CRF) are the newest and most technically advanced way of supplying mineral nutrients to nursery crops. Compared to conventional fertilizers, their gradual pattern of nutrient release better meets plant needs, minimizes leaching, and therefore improves fertilizer use efficiency. In our review of the literature, we found many terms used interchangeably with controlled-release, such as slow-release, but in this article, we will simply refer to all of them as controlled-release fertilizers (CRF). CRF can be divided into 3 categories based on their coating and nutrient composition:

1. Uncoated, nitrogen-based fertilizers – This oldest class of CRF consists of chemically-bound urea and the release rate is determined by particle size, available water, and microbial decomposition (Goertz 1993). Ureaform and IBDU are examples of uncoated, nitrogen-based fertilizers. With the exception of Agriform® tablets, which have been used at outplanting, this class of CRF is rarely used in forest, conservation, and native plant nurseries.

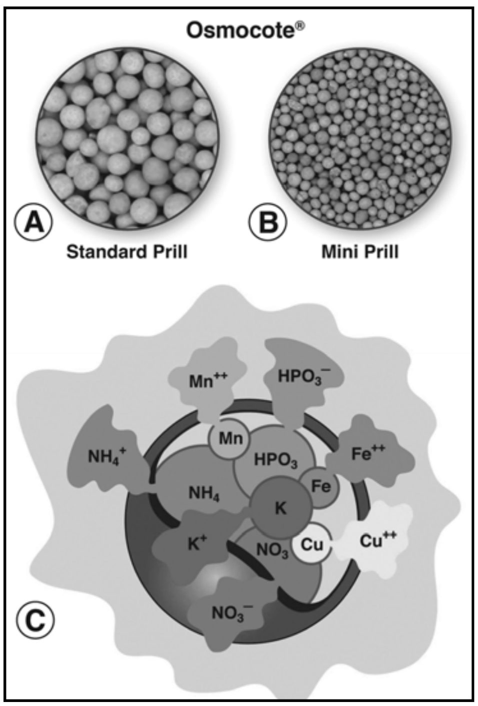

Figure 1 - The individual particles of polymer-coated controlled release fertilizers (PCRF) are called "prills" and consist of soluble fertilizers inside a thin plastic shell (A-B). After water penetrates the prills, soluble nutrient ions move outwards into the soil or growing medium along an osmotic gradient (C). (A and B courtesy of Scott-Sierra®.)

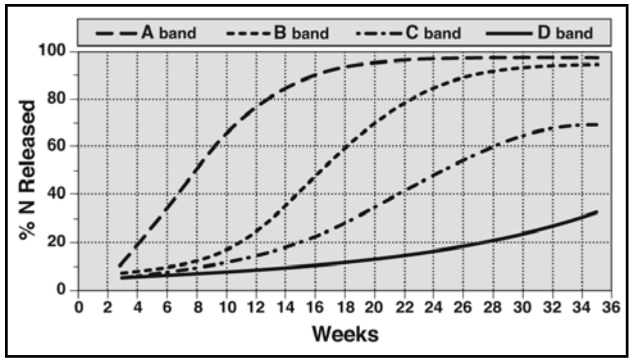

Figure 2 - Nutrient release patterns vary between fertilizer brands and formulations. For example, the nutrients in Osmocote® can be formulated in bands to release faster or slower during the growing season (modified from Hulme and Buchheit 2007).

2. Coated, nitrogen-based fertilizers – Sulfur-coated urea was one of the first CRF and nitrogen release is controlled by the thickness of the sulfur coating (Goertz 1993). Although still used in agriculture, sulfur-coated urea is rarely used in forest, conservation, and native plant nurseries.

3. Polymer-coated multi-nutrient fertilizers – Polymer-coated CRF (PCRF) are the newest and most technically sophisticated fertilizers being used in horticultural plant production, and consist of a core of soluble nutrients surrounded by a polymer coating. Each polymer-coated fertilizer particle is known as a prill" (Figure 1A-B), and nutrient release is precisely controlled by the chemical composition and thickness of the polymer coating. Compared to the previous categories that only supply nitrogen, PCRF supply all 3 "fertilizer elements" (nitrogen [N], phosphorus [P], and potassium [K]), and many formulations include calcium, magnesium, sulfur, and micronutrients. The defining characteristic of PCRF, however, is the sophisticated polymer coatings that gradually release nutrients over extended periods; release rates can be as short as 3 months or as long as 18 months.

Nutrient release from PCRF prills occurs by diffusion through a semi-permeable membrane. The process occurs in 2 stages (Gambash and others 1990). First, when prills are exposed to moisture in the soil or growing medium, water vapor infiltrates into the prill and condenses on the soluble fertilizer salts, creating an increase in osmotic pressure. Second, this elevated pressure within the prill causes the fertilizer ions to diffuse outward into the surrounding medium (Figure 1C) .

Types of Polymer-Coated Controlled-Release Fertilizers

Several different brands of PCRF have been used in forest and conservation nurseries in North America, and they can be categorized by nutrient content, release pattern, and longevity (Jacobs and others 2005).

Osmocote® (Scott-Sierra, Marysville, OH) is one of the oldest PCRF and its coating is classified as a polymeric resin. The coating is applied in several layers, and the relative thickness determines the speed and pattern of nutrient release at 70 °F (21 °C). Osmocote fertilizers are available with release periods from as short as 3 to 4 months to as long as 14 to 16 months (Table 1). One recent innovation is called "patterned nutrient release", which uses specialized formulations called bands to offer specific release patterns (Figure 2). A wide variety of Osmocote PCRF is available for different crops and production cycles including a "miniprill" formulation (Figure 1B) for small volume containers and miniplugs (Scotts Horticulture 2008). Although more expensive, the smaller miniprills improved distribution between containers by 5-fold and reduced problems with uneven growth (Drahn 2007).

Apex® (J.R. Simplot, Boise, ID) uses the Polyon® Reactive Layers Coating (RLC™) process that applies 2 reactive monomers over the fertilizer core in a continuous coating drum, resulting in an ultrathin polyurethane membrane coating. The result is a PCRF that delivers nutrients through a solute concentration gradient permeation process that is unaffected by soil moisture, microbial activity, or pH levels. A variety of Apex formulations are available to meet the specific needs of conifers, woody plants, and native plants (Table 1). One formulation, Apex Native, is specially formulated for plants that are sensitive to high rates of P, and therefore aids in the colonization of mycorhizal fungi (Simplot 2008).

Multicote® and **Nutricote®** (Sun Gro Horticulture, Bellevue, WA) uses thermoplastic resin coatings blended with special release-controlling agents to determine the nutrient release rate and longevity. Sun Gro markets 2 brands of PCRF—Multicote® in the U.S. and Canada, and Nutricote®, which is only available in the western U.S. (Sun Gro Horticulture 2008). Multicote® is available in a wide variety of nutrient formulations with release rates from 4 to 16 months (Table 1).

Diffusion® (Green Valley Agricultural, Caledonia, MI) PCRF are customized for different temperature zones, and come in many nutrient formulations with longevities from 3 to 9 months (Green Valley Agricultural 2008).

Table 1 - Macro nutrient composition (N-P-K) and longevity of polymer-coated controlled release fertilizers commonly used in forest and native plant nurseries *

Longevity at 70 °F (21 °C)	Osmocote Classic®	Apex®	Multicote®	Diffusion ®
3 to 4 mos	14-14-14 19-6-12		15-7-15	17-6-17 18-6-18 22-2-3
5 to 6 mos			15-7-15	17-6-17 18-5-18 22-4-9
8 to 10 mos	13-13-13 19-6-12	13-13-13 16-8-16 18-6-12 19-8-12 21-2-11	15-7-15 17-7-14 20-6-12	17-6-17 18-4-18 22-4-8
12 to 14 mos	19-6-12	17-6-12	14-7-14 17-6-14 20-5-12	
14 to 16 mos	19-6-12	16-5-11	14-7-14 17-5-14 20-5-10	

* = modified from www.scottsprohort.com, www.simplot.com, www.sungro.com, www.diffusionfertilizer.com

Because CRF technology is continually evolving and fertilizer manufacturers are constantly improving the nutrient content and release characteristics of their products, we stress that growers should consult company internet sites for the latest information.

Advantages of Using Polymer-Coated Controlled-Release Fertilizers

Polymer-coated controlled release fertilizers offer several advantages to nurseries, especially those that grow small lots of many species or ecotypes:

Easy to adjust fertilization type and rate for different crops - With the wide variety of N-P-K formulations and nutrient release timings, growers can easily customize their fertilization programs. By incorporating different PCRF into the soil or batches of growing media, different species or ecotypes can receive the proper amount of fertilizer at the proper time.

Better fertilizer use efficiency - Placing the fertilizer directly in the root zone is much more efficient than liquid fertilization that is lost when sprayed on benches or walkways, runs off the foliage, or drips through openings in containers. This is particularly true with broad-leaved species that shed a high percentage of applied fertigation. PCRF are ideal for open compounds in rainy climates where applying liquid fertilization to already wet plugs is very inefficient.

Less fertilizer pollution in wastewater - Fertilizers in nursery runoff, especially N and P, lead to eutrophication in ditches and ponds. These excess nutrients promote the growth of moss and algae on the surface of soils, growing medium, and floors. Weeds are stimulated by non-target nutrients, and moist, nutrient rich environments are ideal for nursery pests such as fungus gnats.

No rinsing required after fertilization - After fertigation, the concentrated fertilizer solutions need to be rinsed off plant foliage to prevent burning (Drahn 2007). This extra irrigation can cause more nutrients to leach from the medium and keeps humidity high in the growing area, which can create disease problems during cloudy, cool weather.

Nutrients present at root initiation - When rooting cuttings, incorporating PCRF into the rooting medium ensures that nutrients will be available as soon as roots form. This is preferable to fertigation that can keep the medium too damp and discourage root formation (Drahn 2007).

Fertilizer reserves for after sale or outplanting - Using long-term PCRF in growing media ensures that plugs will be delivered to the customer with a nutrient reserve (Drahn 2007). For forestry applications, the benefit of this reserve depends on moisture condition on the outplanting site. For example, incorporation of Apex 14 to16 month PCRF in the plugs of Douglas-fir (*Pseudotsuga menziesii*) seedlings produced significant growth benefits for 2 to 3 years after outplanting on wet sites. However, on a drier site, initial survival of fertilized Douglas-fir and ponderosa pine (*Pinus ponderosa*) seedlings was significantly less than nonfertilized controls and growth after 2 years was the same with or without PCRF (Jacobs and others 2003b).

Cultural Advantages when Using Polymer-Coated Controlled-Release Fertilizers

Application method - For the larger volume containers used in ornamental nurseries, PCRF are applied in 2 ways: incorporation into the growing medium at the time of sowing, and top-dressings during the growing season. Incorporation into growing media is by far the most common way of using PCRF in the smaller containers used in forest, conservation, and native plant nurseries. Growers should be mindful of 2 concerns when incorporating PCRF into growing media. The first concern is to ensure that the small prills are even distributed so that each container has the same number. This becomes very problematic with small volume miniplugs, which is why Scotts developed Osmocote® Miniprill formulations (Figure 1B). Counting the number of prills per container or volume of growing media is extremely tedious, but some soil and plant testing laboratories (www.mmilabs.com or www.qal.us) will perform this service on a fee basis (Pilon and Passchier 2007). The second concern is mechanical damage to the prills that can occur when they are mixed with the growing medium. Overmixing in cement mixers or other mechanical mixers may rupture the polymer-coating and cause an immediate release of fertilizer salts that will not only damage the mixer but, more importantly, may kill young germinating seedlings or newly-struck cuttings. Having PCRF incorporated with a ribbon-type mixer is the best way to make sure that the prills are evenly distributed and not damaged during the process. Prill damage can be monitored by taking electrical conductivity measurements of a sample of the growing medium before sowing. This type of testing is discussed in detail in a subsequent section.

During outplanting, PCRF may be placed under or near plants (Jacobs and others 2003b). Some researchers recommend placing PCRF in the bottom of the planting hole, which ensures that released nutrients will be easily accessible to the plant (Gleason and others 1990). Other applications include applying the PCRF in a dibbled hole alongside the plant or broadcasting it around its base. To minimize the possibility of fertilizer burn to roots and prevent the nutrients from being "stolen" by competing vegetation, the side application makes the most sense.

Variable nutrient release - Laboratory testing in sand columns has shown that the major environmental factor controlling the pattern and longevity of nutrient release from PCRF is the temperature of the soil or growing medium. Most PCRF are based on a standard 70 ºF (21 ºC) benchmark and nutrient release increases or decreases as soil or growing medium temperatures change. Laboratory tests also show that soil moisture has a relatively minor influence on nutrient release within the range typically maintained in container seedling production (Kochba and others 1990). In actual practice, however, nutrients will continue to move outward from the prill as long as an osmotic gradient exists. As the nutrient ions are taken-up by plant roots or leach downward with irrigation, the osmotic gradient becomes higher and more nutrient ions are released (Huett and Gogel 2000). Leaching tests have shown that a certain proportion of total nutrients (10 to 20%) may never release from the PCRF prills because the internal osmotic pressure within the prill decreases as most nutrients are released (Jacobs 2005).

When the leaching patterns of 3 brands of PCRF were tested in sand columns (Huett and Gogel 2000), the time to 90% nutrient release varied among products (Figure 3A**)**. The nutrient release rate was also different for N, P, and K, which can affect crop development. The slower release of P could be problematic because young plants have a high requirement for P early in the growing season. This was confirmed in another leaching trial which concluded that, when PCRF are used, another supplemental source of fertilizer P may be required for early in the growing season (Handreck 1997)

Sand column research is one thing, but nutrient release patterns in soil or growing media could be radically different because of differential adsorption of mineral nutrients on cation exchange sites. The Nursery Technology Cooperative at Oregon State University buried plastic mesh bags containing PCRF in forest soil and monitored the release of mineral nutrients for more than a year (Haase and others 2007). Like the sand column studies, they found that the different macronutrients had different release rates with N being released the fastest and P the slowest (Figure 3B). The release rate of micronutrients was almost nil and the prill content of iron, manganese, zinc, and molybdenum had decreased very

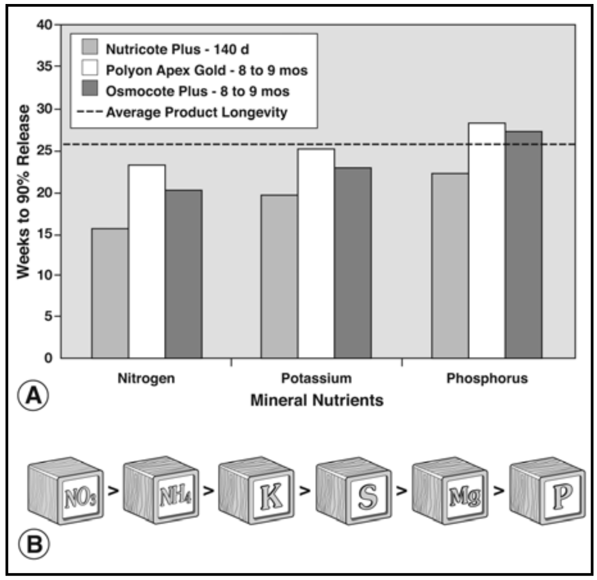

Figure 3 - The nutrient release rates were different for 3 brands of polymer-coated controlled- release fertilizers but, in each, phosphorus was released much slower than nitrogen or potassium (A). When the fertilizers were buried in soil, nitrogen ions were released fastest and phosphorus was again the slowest (B). (A - modified from Huett and Gogel 2000, and B - modified from Haase and others 2007).

little from their initial levels. They hypothesized that P was inactivated by forming insoluble compounds with the metal micronutrients which remained in the prill membrane.

The possibility of the slow release of P affecting plant uptake was confirmed when Douglas-fir seedlings were fertilized with 3 rates of Osmocote; the foliar N concentration increased with fertilization but foliar P decreased (Jacobs and others 2003a). As mentioned earlier, this can be compensated for by incorporating another source of P fertilizer such as concentrated superphoshate (Handreck 1997) or, for container stock, injecting phosphoric acid into the irrigation system. Of course, the ultimate way to determine if mineral nutrients are being used by plants is to have foliar samples analyzed throughout the growing season (Landis and others 2005).

Premature nutrient release causes fertilizer "burn" - Research has shown that when PCRF prills are surrounded by a slightly moist medium they begin nutrient release, which accelerates under warm conditions. Therefore, PCRF should not be incorporated into growing media more than about 2 weeks before it is used. Otherwise, salts can build-up and cause fertilizer burn when seeds begin to germinate or cuttings begin to root

Table 2 - Comparison of various techniques of measuring electrical conductivity *

EC Technique	EC Readings (µS/cm)				Containers	Soil	PCRF
Saturated Media Extract	1,000	2,000	3,000	4,000	All but Miniplugs	Yes	Yes **
1:2 Dilution	300	700	1,200	1,600	All but Miniplugs	Yes	No
Pour-Through	1,500	2,800	4,200	5,500	All but Miniplugs & Very Large Sizes	No	Yes
Plug Squeeze	1,300	2,700	4,100	5,600	Jiffy, Cone-tainers, Rootrain-ers, Miniplugs	No	No
Direct Sensor	700	1,300	1,800	2,400	All but Miniplugs	Yes	Yes

* modified from Fisher and others 2006 ** = vacuum extraction, not squeezing

(Huett and Gogel 2000). Another potential problem is release of salts when container plants with incorporated PCRF are kept under long-term refrigerated storage. Even though the temperatures are very low, the root plugs are moist and fertilizer salt levels can reach damaging levels, which has been observed during operational cold storage and during a research trial. Ponderosa pine container seedlings were grown with moderate release (12 to 14 mo) or slow release (16 to 20 mo) PCRF and then harvested and stored under refrigeration at 33 $^{\circ}$F (0.5 $^{\circ}$C) for about 4 months. When a sample of the stored seedlings were subjected to a root growth capacity test, the roots in many of the plugs were completely killed (Fan and others 2004). This type of damage would be hard to detect without the root tests, and affected seedlings could be transplanted or outplanted without any awareness of the problem. Obviously, more research into this potential problem is needed.

Monitoring nutrient levels with PCRF - The best way to avoid problems with PCRF or any fertilizer is through regular monitoring. All mineral nutrients are taken-up from the solution in the soil or growing medium as fertilizer salts. Therefore, the relative concentration of fertilizer salts can be measured with an electrical conductivity (EC) meter. For PCRF, this allows the grower to monitor precisely when fertilizer is being released from the prills, and Bilderback (2008) recommends that the EC should remain in the range of 200 to 500 µS/cm. It's a good idea to measure EC at least once a month, especially with small containers, and more often during hot and dry periods. The ideal situation is to plot EC readings over the course of the growing season to keep track of trends, especially of any accumulation of salts due to insufficient leaching (Figure 4A).

EC can be measured by several different techniques, but the saturated media extract remains the standard (Landis and Dumroese 2006). Note this restriction on monitoring EC in growing media with incorporated PCRF: any compression or squeezing of the amended medium will force extra nutrients out of the prills and provide erroneous results (Table 2). Catching leachate under the container or using the pour-through technique are good ways to keep track of EC trends for an entire block (Figure 4B**)** but the readings are just an average of conditions in the various cells. Using a direct sensor is quick and effective in larger containers (Figure 4C) but the probes are too large for use in miniplugs. With sensors, it's critical to always measure EC at the same moisture content, such as an hour after irrigation (Scoggins and van Iersel 2006).

Using Polymer-Coated Controlled-Release Fertilizers in Bareroot Nurseries

By far, the most work has been done with PCRF in container plants but this type of fertilization also has application in field soils. In a Wisconsin bareroot nursery, crops of red pine (*Pinus resinosa*), jack pine (*Pinus*

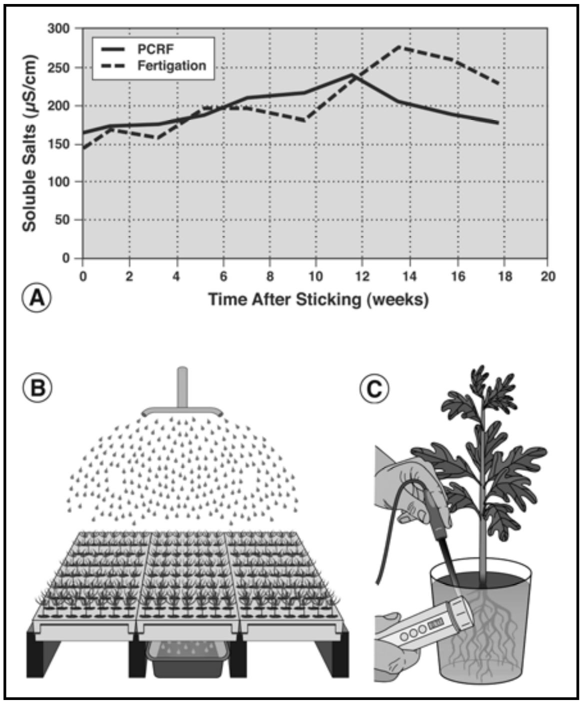

Figure 4 - Measuring the electrical conductivity of the soil or growing medium is the best way to monitor the effectiveness of polymer-coated controlled-release fertilizers (A). Because extra fertilizer can be squeezed out of the prills, catching leachate (B) or using the pour-through technique is best for smaller-volume containers. In larger containers and soil, EC can be measured directly with new sensors as long as the measurements are always taken at the same moisture content (C).

banksiana), white spruce (*Picea glauca*), and other conifers are grown on a 2-year schedule. Initial trials with top-dressing Polyon® PCRF had 2 main drawbacks: 1) prills became sticky and didn't flow well through a typical drop-type fertilizer spreader; and 2) heavy rains washed the prills from the raised seedbeds into the tractor paths. Switching fertilizer brands to Diffusion® (Wilbur-Ellis Company, San Francisco, CA) solved the first problem because the coating did not gum up the fertilizer spreader. A shallow incorporation of the fertilizer into the seedbeds just before sowing and covering the seedbeds with hydromulch solved the problem of the prills washing away. PCRF applications later in the first year and during the second growing season did not wash or blow away because they were held in place by the rows of plants. In a comparison with standard fertilization, PCRF produced satisfactory plants, reduced nitrate leaching, and was more cost effective. Even though PCRF was triple the cost of conventional fertilizer, less frequent applications saved appreciable labor and equipment expenses (Vande Hey 2007).

When porous cup lysimeters were installed in pine seedbeds at 3.3 ft (1 m) spacing below the soil surface, nitrate-nitrogen leaching was significantly less with PCRF in the first and second growing seasons compared to standard fertilization (Dobrahner and others 2007).

In an Oregon bareroot nursery, nitrate leaching and soil compaction were serious concerns so subsurface banding of polymer-encapsulated sulfur-coated urea was compared to the standard fertilizer top-dressing. The CRF was banded below the soil surface and between the seed rows with a specially-modified seeder (Figure 5A). This allowed roots of seedlings to grow toward the N source and uptake the nutrient without burning (Figure 5B). Subsurface banding eliminated 3 tractor trips per season, which reduced soil compaction in the seedbeds. Because the N was gradually released during the growing season, concerns about nitrate leaching were reduced. As with the Wisconsin nursery, a cost comparison showed that the CRF was less expensive to use because of reductions in application costs, yet seedlings were larger with fewer culls (Steinfeld and Feigner 2004).

Summary

Of the 3 types of controlled-release fertilizers, polymer-coated products are most commonly used in forest, conservation, and native plant nurseries. Depending on the type of coating and temperature of the medium, these fertilizers release their nutrients over periods from 3 to 18 months. For growers, PCRF afford many advantages, including ease of adjusting fertilizer rate for many crops,

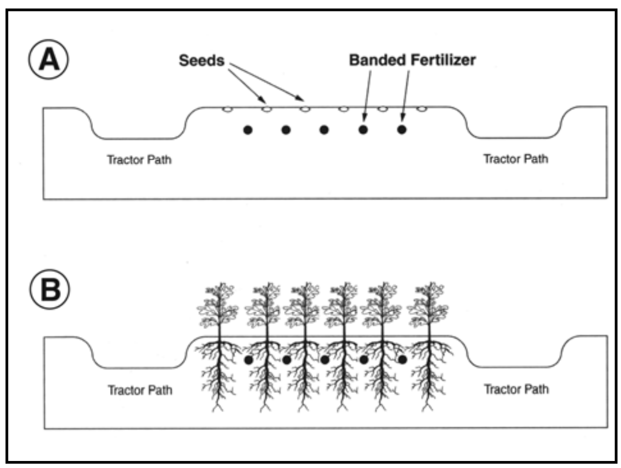

Figure 5 - Polymer-encapsulated urea fertilizer was banded at the time of sowing 3 to 4 inches (7.5 to 10 cm) below the soil and between the seed rows (A). This allowed the seedling roots to access the released nutrients during the growing season without concern about fertilizer burn (B). (From Steinfeld and Feigner 2004).

better fertilizer use efficiency, and less concern about potential groundwater pollution. In addition, nutrients are more available for germinating seeds or new roots forming on cuttings, and PCRF create fertilizer reserves to be used by the plants after outplanting. In order to achieve uniform and healthy plant growth, it is important to mix PCRF uniformly and without damaging their coatings. The various PCRF products release nutrients differently, but diligent monitoring of electrical conductivity can be used to avoid problems with salt accumulation, or to indicate when supplemental fertigation may be required. Although mainly used in container nurseries, PCRF has been used in bareroot nurseries to produce quality seedlings with less expense.

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