The Potential Use of Slow Release Fertilizers for Forest Tree Nursery Production in the Southeast U.S.

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Introduction

The southern U.S. produces over 1.2 billion tree seedlings per year (Moulton and Snellgrove 1997). The majority of these seedlings (95%) are bareroot loblolly (*Pin us taeda* L.) and slash (*Pin us elliottii* Eng1m.) pines (Carey and Kelley 1993) which are outplanted to a variety of sites throughout the region. One of the key elements in quality seedling production is the use of fertilizers to maintain proper seedling nutrition. Over 30 different kinds of fertilizers are used in southern tree nurseries including both liquid and granular formulations. On average, nurseries in the south will apply 141 kg/ha of nitrogen, 25 kg/ha of phosphorus, and 99 kg/ha of potassium along with much smaller applications of other essential plant nutrients (South and Zwolinski 1996). Because nurseries produce an annual biomass crop, a significant portion of fertilizer materials are removed at the time of harvest.

Not all applied fertilizer is taken up by the seedlings and harvested in the crop. A significant portion of these elements can be "lost" to the environment through leaching, volatilization, surface runoff, immobilization, and other pathways. Not only might this loss of fertilizer be considered an unnecessary expense, but it also has the potential to be an environmental contaminant that is best avoided. Nitrogen is of particular concern because of its high application rate, leaching potential, and use efficiencies. While application rates are normally 141 kg/ha, removal rates have been reported at 74 kg/ha for loblolly pine (Boyer and South 1985). When calculated on a nursery acre basis, it appears that around 50% of nitrogen applied as fertilizer in southern forest tree nurseries is not taken up by the seedlings.

A potential strategy to improve nitrogen use efficiencies is through the use of slow release fertilizers (also known as controlled release). Slow release fertilizers make nitrogen available by metering out small doses over time. The release rate can be somewhat controlled by formulation. In theory, this should be a more efficient use of fertilizer as it releases nitrogen at a rate closer to what the plant can take up. With increased efficiencies, proportionally more of the fertilizer ends up in the seedling with less lost to the environment. While slow release chemistries are commonly employed in containerized horticultural nurseries (Landels 1991), their use in bareroot forest tree nurseries is rare. The objective of this paper is to present the current situation as to slow release fertilizer use in the southeastern U.S. and discuss their potential for seedling production in the region.

Slow Release Fertilizers

There are two basic types of slow release nitrogen fertilizers; coated and non-coated. Coated materials have a urea core surrounded by a water-insoluble shell usually made of either sulfur or polymers. The fertilizer dissolution rate is related to the thickness and composition of the coating. Uncoated fertilizers, on the other hand, are products of a urea-formaldehyde or related reaction. The release pattern of these chemicals is determined by microbial or hydrolytic decomposition of the compounds which release the nitrogen. Below is a summary of the important characteristics of the major slow release materials (from Goertz 1991).

Coated Slow Release Fertilizers

1. **Sulfur Coated Urea (SCU).** Urea is used as a soluble nitrogen source core. The coating is made from molten sulfur, a wax sealant, and a flow conditioner. The wax sealant closes gaps or cracks in the sulfur covering, while the flow conditioner provides for particle separation and flow (wax coated granules can stick together). Total nitrogen content varies from 30 to 38%. The mechanism of nitrogen release is through micropores and cracks in the sulfur coating. The wax coating must be attacked by microbes. The release rate can be manipulated somewhat by increasing the coating thickness and quality. There are a number of SCUs on the market, with typical residual release times of 2 to 4 months.

2. **Polymer Coated (PCU).** Urea is used as a soluble nitrogen source core. The coating is made from one of several polymer materials: linseed oil, polyethylene, polypropylene, and various other organic polymers. Diffusion through the coating is the release mechanism and is strongly affected by temperature. The rate of nitrogen release can be manipulated by coating thickness and composition. Polymer coated products are newer chemistries than the sulfur coated ureas and are generally higher in price. Examples of PCUs on the market are Osmocote®, Nutricote®, and Meister®.

Noncoated Slow Release Fertilizers

1. **Urea-Formaldehyde Reaction Products (UF).** There are two general types of UF products, ureaform and methylene ureas, classified according to their chemical structure (polymer chain length) and water solubility characteristics. Nitrogen content ranges from 38 to 41%, which is released through microbial breakdown and hydrolysis. The environmental factors which control microbial activity also control UF decomposition and nitrogen release, including temperature, moisture, pH, and aeration. The type of fertilizer also affects the rate of release as the

longer chain molecules (also the less soluble) are more difficult to decompose and will release their nitrogen at a slower rate.

2. **Urea-Other Aldehyde Reaction Products.** While the urea-formaldehyde reaction produces long chain polymers of varied length, the reaction of urea with isobutyraldehyde forms a single non-repeating nitrogen compound (IBDU) with a nitrogen content of 32%. Hydrolysis decomposes IBDU (not microbes) which is affected by both soil temperature and pH.

3. **Crotonylidene Diurea (CDU).** A urea-acetaldehyde reaction product with 32% nitrogen, CDU is released through both microbial and hydrolysis. It has very limited use domestically.

4. **Oxamide.** Oxamide is a single molecule compound with 32% nitrogen that is released through hydrolysis. It decomposes (releases nitrogen) through hydrolysis at a much slower rate than other non-coated formulations.

5. **Melamine.** A single molecule compound with 67% nitrogen that is released very slowly through hydrolysis and microbial decomposition. Nitrogen is release over a two year period after an initial lag period of two months.

Current Slow Release Utilization in Southern Bareroot Nurseries

Slow release chemicals have been tried on a trial basis by a few nurseries in the Southeast. The most common product has been a 21-7-14 formulation where the nitrogen source is principally a polymer coated urea. It is manufactured for a 270 day release, meaning that 80% of the nitrogen fertilizer will have been made available to plants within 9 months after application. It is recommended by the manufacturer for use on "nursery crops and forest seedling nurseries". Application rates range from 336 to 560 kg/ha (300 to 500 lbs/ac) which applies 70 to 118 kg/ha of nitrogen (63 to 105 lb/ac). The fertilizer cost for a one time application is about $554 to $924 per hectare ($225 to $375 per acre). By comparison, ammonium nitrate applied at 510 kg/ha would cost around $100/ha. Obviously, the feasibility of using such an expensive fertilizer amendment must be carefully scrutinized.

From the nursery manager's perspective, a potential advantage to slow release products is they eliminate the need for multiple top-dressing applications of nitrogen fertilizers during the summer growing season. Typically, nursery managers make five to six top-dressed applications to bareroot seedling beds with ammonium sulfate or ammonium nitrate. A 30 million seedling nursery might take a total of 24 man days to perform this operation. By making a single application before spring sowing, there is the potential savings of this labor as well as the tractor depreciation and fuel. Moreover, these are resources that may be used for other tasks. One nursery manager calculated a break-even point at about 560 kg/ha. Above this, the cost of the fertilizer is more than the labor and equipment costs. Below this number there may actually be a cost savings.

Even though slow release can be justified economically in some cases, the quality of the trees will be the final determinant of feasibility. To date, the crop response to the above formulation has been variable. While every nursery manager has produced a sellable crop with the slow release, their seedlings become off-color during late July and August and seem to lag slightly behind the standard top-dressing treatments in terms of size. In these cases, each manager has had to apply supplemental nitrogen fertilizers to get their crops to the desired condition of color and size. A similar experience was reported by one nursery manager using a nitrogen-only slow release compound. While each of these nurseries realized the potential benefits from the use of slow release chemicals, the actual results have been variable or disappointing to date.

Recent Research Efforts Using Slow Release Nitrogen Compounds

In an effort to better understand the suitability of slow release compounds for producing bareroot seedlings, the Auburn University Southern Forest Nursery Management Cooperative initiated two experiments testing several of these compounds. A trial was established in 1976 at a coastal plain nursery in southern Georgia, comparing three levels of top dressed ammonium nitrate to three equivalent levels of two different slow release formulations on the growth and development of slash pine. One of the SRFs was a polymer coated urea (PCU), while the other was a polymer coated-sulfur coated urea (PSCU). All three fertilizers were applied at 56, 112, and 224 kg/ha of elemental nitrogen. Both the SRFs were applied to the top of the bed in April and incorporated with a bed shaper prior to sowing. The ammonium nitrate was top dressed in five bi-weekly applications from early June to early August. Figure 1 presents the total seedling dry weight biomass accumulation over time for the three fertilizers at the standard nitrogen application rate of 112 kg/ha.

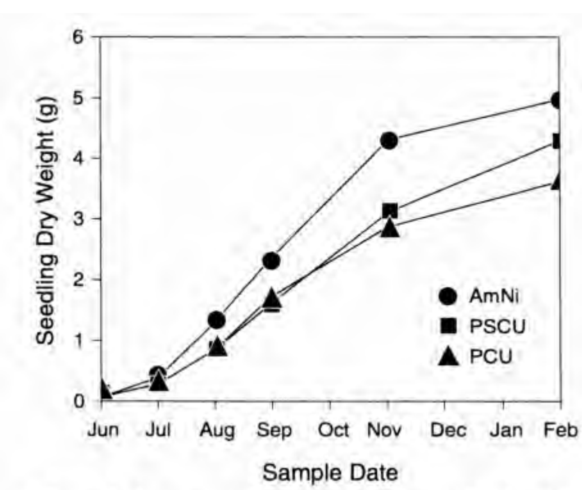

Figure 1. Average seedling biomass when fertilized with ammonium nitrate (AmNi), polymer coated-sulfur coated urea (PSCU), and a polymer coated urea (PCU).

It is evident the slow release fertilizers were not able to produce a seedling with biomass comparable to the ammonium nitrate. At the beginning of the lifting season in November, the standard ammonium nitrate treatment (112 kg/ha for this nursery) produced seedlings with an average biomass of 4.3g, while seedlings grown using the slow release formulations at the same level of elemental nitrogen were 2.9g and 3.1g for the PCU and PSCU fertilizers, respectively. The ammonium nitrate produced significantly larger seedlings (a=.01). The difference in growth was also reflected in average root collar diameters and the number of seedlings with diameters of less than 3 mm (Table 1). The standard ammonium nitrate fertilizer consistently produced a larger number of

TABLE 1. Average diameter at the root collar and percent of slash pine seedlings with diameters below 3 mm (cull) by fertilizer type and level for a November sample.

	Ammonium Nitrate		Poly Coated-Sulfur Coated Urea		Sulfur Coated Urea	
	DRC (mm)	No. cull (%)	DRC (mm)	No. cull (%)	DRC (mm)	No. cull (%)
56 kg/ha N	3.7	22	3.2	36	3.7	22
112 kg/ha N	4.4	6	3.9	10	3.8	17
224 kg/ha N	4.8	3	3.9	16	4.1	10

TABLE 2. Nitrogen use ratios for slash pine seedlings fertilized with ammonium nitrate, polymer coated urea, and polymer coated-sulfur coated urea.

	Rate of Fertilization (kg/ha)		
	56	112	224
Ammonium Nitrate	1.75	1.34	.63
Polymer Coated Urea	1.41	.92	.47
Polymer Coated-Sulfur Coated Urea	1.63	.74	. 44

plantable seedlings and fewer culls than the same level of nitrogen fertilization using the slow release formulations.

Table 2 presents nitrogen use ratios for the various fertilizers and levels. Nitrogen use ratios are calculated by dividing the total amount of nitrogen in the seedling crop by the amount of fertilizer nitrogen applied (application was made only to the beds). A ratio of 1.00 would indicate the same amount of nitrogen applied was taken off by the crop, implying better nitrogen utilization efficiency. A ratio below 1.00 indicates that nitrogen remained in the environment, while a ratio above 1.00 indicates the seedling crop derived nitrogen from a source other than the fertilizer. This can be residual organic or fertilizer nitrogen left from the previous year or atmospheric inputs. The slow release formulations did not consistently have ratios closer to 1.00 than the ammonium nitrate top dressing. For example, at the 224 kg/ha N application rate, the deviation of the nitrogen use ratio from 1.00 for each treatment is .53, .56, and .37 for the polymer coated, polymer coated-sulfur coated, and ammonium nitrate, respectively. It might be noted, however, that the treatment having the Nitrogen use ratio closest to 1.00 is the polymer coated urea at the 112 kg/ha rate.

Because of what could be considered inadequate morphological development resulting from the use of the polymer and polymer coated-sulfur coated ureas, an additional study was initiated in 1997 to compare the suitability of several slow release formulations. A randomized complete block was used to test eight fertilizer treatments at a coastal plain nursery in Alabama. Table 3 presents the fertilizers, characteristics, and average height, diameter, and biomass in early August (4 months after sowing). At this point in seedling development, the slow release formulations appear to be at least equal to and several are clearly superior to the ammonium nitrate treatment. The complete polymer coated formulations (Nos. 6, 7, & 8) are doing well, although all the treatments were given equal amounts of P and K through supplemental applications of triple super phosphate and potassium chloride when the experiment was initiated. Based on previous experience, ammonium nitrate should be ahead of the slow release formulations at this time of the year. It will be interesting to follow seedling development to lifting season and quantify any differences between treatments.

TABLE 3. Average loblolly pine seedling height, diameter at root collar, and total dry weight at 4 months after sowing for eight fertilizer treatments.

FERTILIZER	FORMULATION	HT (cm)	DRC (mm)	TDW (g)
1. Ammonium Nitrate	33% nitrogen	28.4'	2.7b	1.22d
2. Urea	45% nitrogen	29.7a	3.0a	1.35bcd
3. Liquid	12-0-12 (6% uncoated slow release, 6% urea)	29.0a	2.8ab	1.20d
4. Resin Coated Urea	40% nitrogen	30.0a	2.9ab	1.05e
5. Polymer Coated Urea	40% nitrogen	29.6a	2.9ab	1.27cd
6. Polymer Coated Urea	13-13-13 (180 day N release)[2]	31.4a	3.0a	1.47ab
7. Polymer Coated Urea	18-6-8 (270 day N release)[2]	30.0a	2.9ab	1.55a
8. Polymer Coated Urea	21-7-14 (270 day N release)[2]	30.8a	2.9a	1.42abc

1. Different letters within a column indicate significant differences at the 0.05 level.
2. A portion of the P and K in these compounds are in slow release forms.

Potential Use of Slow Release Fertilizers

The current practice of top dressing with ammonium nitrate and ammonium sulfate has consistently produced seedlings of suitable quality at a reasonable price. In order for slow release formulations to develop as a cost feasible substitute, they will have to reliably produce seedlings of acceptable quality. To this point we have not been able to demonstrate this reliability. The most serious problem appears to be the timing of nitrogen release. One of the advantages of top-dressed ammonium nitrate and ammonium sulfate is that the nursery manager has some level of control of the nitrogen application over time. This is not true with slow release formulations as nitrogen availability depends upon the specific environmental factors that cause release. The polymer and resin coated ureas, for example, depend upon a diffusion process for nitrogen release which is highly temperature dependent (Lamont et al. 1987, Harbaugh and Wilfret 1982, Hashimoto and Mullins 1979) The fertilizer industry usually bases its release curves on standard temperatures of 20 to 25 degrees centigrade (68 - 77° F) (Goertz 1991). Clearly, the soil temperatures in bareroot forest tree nurseries in the South are higher than this. In addition, other formulations, such as the sulfur coated ureas and the uncoated ureas are released to a great extent through microbial degradation which is subject to many environmental influences. The inability to effectively control the amount of nitrogen released to seedlings is a factor to be considered when evaluating the feasibility of slow release formulations.

Another issue that must be considered is the effect of seedling morphology and nitrogen content upon outplanting performance. The positive effect of seedling size and nitrogen content on seedling performance after outplanting is well documented (Mexal and South 1991, Larsen et al. 1988, South et al.

1985). Some plantation programs in the South are regenerating with large caliper seedlings produced at spacings of 15 seedlings per square foot in the nursery (normal spacings are 20 to 25 seedlings per square foot). High nitrogen fertilization is necessary to produce these "morphologically improved" seedlings. Nursery managers may need to increase their nitrogen application rates in addition to the wider spacings in order to achieve the desired increase in seedling size. There is a decision, therefore, to sacrifice nitrogen use efficiency in the nursery to produce larger caliper seedlings. Results to date, however, have indicated that it would be difficult to produce large seedlings using only slow release formulations. The suitability of slow release formulations for southern pine seedling culture is questionable when the nursery management goal is to grow either large or high nitrogen content seedlings.

Nevertheless, increased nitrogen use efficiencies may be a goal of some nurseries, particularly where nitrate contamination of ground water is a concern. This is an issue that will probably increase in importance in the future. Yet, their is no guarantee that slow release formulations actually reduce nitrogen leaching (Yeager and Cashion 1995, Cox 1993). If the use of slow release compounds can be shown to result in less nitrogen contaminated leachate, this may become a strong incentive for their use. While the price differential is substantial between the traditional nitrogen compounds and slow release formulations (slow release formulations are generally ten times more expensive on a weight basis), the relative importance of fertilizer costs to the price of seedlings is very small. Even when using slow release chemicals, the cost of nitrogen would amount to less than 0.4% of seedling costs (based on $2.2/kg fertilizer and $30/M seedlings sale price). If environmental concerns are sufficient to justify the pursuit of higher nitrogen use efficiencies, then the burden of added fertilizers costs will not have a large impact on seedling prices. In addition, there are the potential savings of reduced labor and machine costs for single fertilizer applications.

In the final analysis, our current understanding of the feasibility of slow release formulations for southern pine nursery culture is very rudimentary. We still need to document whether these fertilizers actually do increase nitrogen use efficiencies. Steadily available nutrient sources should theoretically provide adequate nutrient supply with less waste, yet this needs to be proven. Moreover, we do not know which type of release mechanisms will perform the best for our soil, moisture, and temperature conditions. There are many slow release formulations available with a variety of release mechanisms and price. Trials are needed to pursue a match between southern nursery conditions and slow release formulations. The Auburn University Southern Forest Nursery Management Cooperative believes these are justifiable research topics and plans to pursue them and other fertility related questions in the future.

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