Groundwater Contamination

This paper can be cited as:
South, D.B. 1994. Managing pesticides and nitrogen in southern pine nurseries and some ways to reduce the potential for groundwater contamination. Ala. Agr. Exp. Sta. Forestry School Series No. 14, 18 p.

Managing Pesticides and Nitrogen in Southern Pine Nurseries and Some Ways to Reduce the Potential for Groundwater Contamination

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ACKNOWLEDGEMENTS
The author expresses appreciation to Drs. Ken McNabb, Eric Vance and Harold Walker for their comments on earlier drafts. This work was funded in part by the Auburn University Southern Forest Nursery Cooperative and from the National Council for the Paper Industry for Air and Stream Improvement.

INTRODUCTION
In the southern United States, chemicals are an integral part of the management of bare-root nurseries. The rationale for using chemicals is based on economics as they can reduce hand labor, improve the use of valuable seed, and increase seedling performance. The cost of all chemicals associated with loblolly pine seedling production averages less than 0.2 cent per seedling. The cost of nitrogen (N) fertilizers (including usage for cover crops) is less than 0.01 cent per seedling. The most expensive chemical treatment (fumigation with methyl bromide and chloropicrin) costs about 0.15 cent per seedling. The total cost of producing a bare-root loblolly pine seedling is usually less than 2.5 cents, due in part to increased efficiencies provided by chemicals. In 1993, one nursery contracted to grow loblolly pine for as little as 1.8 cents per seedling (excluding seed cost).

The cost of southern pine seedling production can be tripled when nursery managers do not use pesticides and inorganic fertilizers. Hand labor requirements would increase dramatically, seed costs would likely double, and the average production goals per nursery would be lowered. A reduction in mean nursery production would require establishment of additional nurseries or a reduction in levels of artificial reforestation. Due to an increase in frequency of catastrophic losses, some of the money spent on preparing sites for outplanting would be wasted in years where there is an unexpected shortage of plantable seedlings. The standards for a plantable seedling would also likely be lowered (accepting smaller seedlings and some with evidence of disease). At some nurseries, oak trees would need to be eliminated from the surrounding area, perhaps 600 acres or more, in order to reduce the probability of infection from fusiform rust. An increase in mechanical cultivation would probably increase the consumption of gasoline and might increase the output of carbon dioxide. The latter are a few of the esoteric reasons for using chemicals in nursery management. However, there is little doubt that ceasing the use of chemicals would decrease the economic efficiency of tree nurseries in the South.

CONCERN FOR NITRATES IN GROUNDWATER

Although the use of chemicals has increased the efficiencies of crop production, the general population is increasingly concerned with potential environmental effects. Groundwater contamination is one of these concerns. For example, nitrates and pesticides (to a lesser extent) can be found in well water. Between 1988 and 1990, the Environmental Protection Agency (EPA) sampled approximately 1,300 wells for the presence of pesticides and nitrates. They found that nitrates was 5 to 13 times more likely to occur in drinking water wells than contamination from pesticides (U.S. EPA 1990).

On a region-wide basis, the production of forest tree seedlings appears to be inversely related to nitrate concentrations in drinking water wells. For example, Nebraska produced only 3.6 million seedlings in 1990 and had more than 30 percent of the drinking water wells with more than 3 mg/l of nitrate-N. In contrast, South Carolina produced more than 230 million seedlings and had a very low percentage of drinking water wells that exceeded 3 mg/l of nitrate-N (Table 1). The reason for this apparent correlation is in part due to the percentage of land covered by forests. States with a low population density and a high percentage of land in forests generally have low levels of nitrates in the drinking water. In contrast, states with a high population density or a high percentage of land in row crops tend to have high levels of nitrates in well water. The ratio of croplands to timberlands has even proven useful when modeling nitrates in watersheds (Osborne 1988). Therefore, regions that harvest plantations and replant nursery seedlings will have fewer problems with nitrates in groundwater than regions that convert to row crops or residental areas after timber harvesting.

Nitrogen use in the U.S.

Farmers use most of the N fertilizer in the United States. For example, approximately 23,000,000,000 pounds of N fertilizer were sold in 1985. Of this amount, it is estimated that 0.2% (45,000,000 pounds of ammonium nitrate, diammonium phosphate, urea, etc.) were used by the forest industry in the South for pine plantations and nurseries.

It has been estimated that forests in the United States contribute approximately 780,000,000 pounds of N each year as non-point sources of water pollution (Sands 1984). However, this amount is much higher than the 10,300,000 pounds of N applied to forests in the South (a 75 to 1 ratio). Apparently, much of the N in the EPA estimate comes from natural processes and little is due to inorganic fertilization. For example, N will sometimes flush from a watershed that has been clearcut (Krause 1982). Even so, the EPA has estimated that the forests' contribution to N pollution is one-sixth that of the natural background levels of N (U.S. EPA 1978). Nevertheless, some suggest farmers should plant trees in riparian zones to reduce the potential of nitrates contaminating groundwater (Licht 1992).

Nitrogen use by the forest industry

Nitrogen fertilizers are used by the forest industry to improve growth of pines both in pine plantations (Allen 1987) as well as in nurseries. In 1988, the area of pine plantations fertilized with N exceeded 66,000 acres (NCSFNC 1989). The amount applied in one application usually varies from 115 to 210 lbs N/acre. The amount of N applied to loblolly and slash pine plantations exceeded 10 million pounds in 1988. In contrast, the amount of N applied to 1.9 billion southern pine seedlings in 1988 is estimated to be 0.6 million pounds. A 1992 survey of southern pine nurseries reported that 168,000 pounds of nitrogen was used to produce 503 million seedlings. Therefore, the amount of N applied to southern pine plantations is more than 16 times that applied in southern pine nurseries.

The recovery of applied N in crop trees is higher in forest nurseries than in forests. In loblolly and slash pine nurseries, about 50% of the amount applied is utilized by the crop. Often 150 lbs N/acre are applied during the growing season and 75 to 80 lbs N/acre are removed at harvest (Boyer and South 1985). In comparison, less than 30% of fertilizer N applied to conifer stands is recovered in the above-ground tree biomass (Pritchett 1979; Ballard 1984). The efficiency can be 23 to 26% in 13- to 15-year-old slash pine plantations (Pritchett and Smith 1974; Mead and Pritchett 1975). The efficiency may only be 9 to 14% if the fertilizer is applied at time of outplanting (Baker et al. 1974).

Recovery of fertilizer N in the above-ground portions of grain crops seldom exceeds 50% and is often lower (U.S. Congress 1990). For example, when applying 134 to 178 lbs N/acre to corn, the efficiency may only be 35 to 40%. The efficiency is higher in conifer nurseries because nursery managers use frequent applications of N (five or six per year), higher plant densities, and harvest both roots and shoots.

Nitrogen use in tree nurseries

With regards to N fertilization, there are several differences between plantations and nurseries. In plantations, 115 to 210 lbs N/acre might be applied in a single application. However, in southern pine nurseries, 150 lbs N/acre might be applied in five or six applications over one growing season. Typically, 30 lbs N/acre would be applied every two weeks beginning the first week in June and ending around the middle of August. Sources predominantly used are ammonium nitrate and ammonium sulfate while southern pine plantations are treated mainly with urea and diammonium phosphate.

Nursery managers in other regions of the world apply 17% to 100% more N to conifer seedlings than in the southern U.S., where a common rate is 150 lbs N/acre/crop. For example, in Australia, slash pine is fertilized at 192 lbs N/acre (Donald 1991). Bare-root nurseries in the Pacific Northwest typically require twice as much N per seedling crop than do nurseries in the southern United States. It may take two years or more to produce a plantable seedling in the Northwest compared to one year in the South. In the Northwest, the amount applied during the first year may be 155 lbs N/acre (45 lbs N/acre applied pre-sowing and 110 lbs N/acre applied as top-dressing). In addition, approximately 160 lbs N/acre are applied as top-dressings during the second year (van den Driessche 1984). This average of 315 lbs N/acre/crop is about double the amout often applied to a crop of pine seedlings in the South.

Nitrogen harvested with a loblolly pine seedling crop
If one defines the desired weight and nutrient content for the "target seedling," then one can also calculate the amount of N removed by a crop of seedlings. For example, when growing 600,000 trees per acre, the amount of N removed would be 80 lbs N/acre (assuming each seedling contains 60 mg of N: 40 mg in foliage; 10 mg in stem; 10 mg in root). Since N fertilization in conifer nurseries is about 50% efficient, about 160 lbs N/acre would need to be applied in order to not lower the base level of N in the soil. If we only apply 75 lbs N/acre and removed 80 lbs N/acre, we would be relying on organic matter, N fixation, air pollution, and soil reserves to provide the extra N. This may actually work during the first few years, but the system would not be sustainable. After several harvests, succeeding seedling crops would begin to suffer. This may have occurred in the past when nursery managers produced several seedling crops without applying sufficient amounts of fertilizer. In order not to "mine" the soil, some researchers recommend applying 150 lbs N/acre to loblolly, slash, shortleaf and sand pine seedlings that are grown at a density of 20 to 23 seedlings per square foot. However, higher rates would be required with higher densities or when fertilizing with the objective of improving height growth in the field.

Nitrogen and cover-crops
Nitrogen is used in nurseries to promote the growth of both seedlings and cover-crops. Typically, about half of the seedbed area is sown to cover crops each year. Due to potential buildup of disease (Hamm and Hansen 1990) and insects (Dixon et al. 1991), legumes are not often used as cover-crops. Cover crops sown in the spring are usually monocots. These include a hybrid of sorghum and sudan grass, millet, and corn. Nnursery managers typically apply about 75 lbs N/acre to their cover crop unless they are adding woody materials (i.e. sawdust, bark, chips, etc.) as an organic amendment. In that case they usually add about 215 lbs N/acre. The most common rotation is two years of monocots to two years of seedlings. Therefore, some nursery managers apply about one lb N to a cover-crop for every two lbs N that is used on the seedling crop.

The rate of N fertilization used for pines will range widely depending upon species, soil texture and nursery manager. The rate can range from 21 lbs N/acre at some to 300 lbs N/acre at others (Larsen et al. 1988; Dierauf 1991). The amount applied often varies depending on the nursery manager's philosophy (in some cases researcher's philosophy). To a limited extent, N rates are based on results from nursery and field trials (Switzer and Nelson 1963; Duryea 1990; Blake and South 1990; Diearuf 1991).

Rationale for nitrogen fertilization in nurseries
There are several reasons why N is applied in nurseries. These include: (1) producing a healthy cover-crop to reduce soil erosion; (2) producing a healthy green-manure crop to improve soil organic matter; (3) reducing the cull percentage of the seedling crop and thereby increasing seed efficiency; (4) improving the root growth potential of the seedling crop; and (5) improving the performance potential of the seedling crop.

One way nursery managers could reduce the use of N would be to cease using N for cover-crops (used to prevent soil erosion) and green-manure crops (used to improve organic matter). Using N fertilizers only for the seedling crop could reduce total nursery consumption by approximately one third. However, biomass produced by the monocots would be reduced and this would decrease their utility. This could be overcome to some extent by applying organic amendments such as pine bark or composted sawdust.

Some suggest that legumes be used as cover-crops. However, use of beans as a cover-crop would increase the likelihood of increasing pathogens such as Fusarium and Macrophomina which can reduce seed efficiency (Hamm and Hansen 1990; Dixon et al. 1991). In addition, herbicides are sometimes used to control weeds in legume crops. However, alachlor can leach and has been detected in groundwater. Although legumes were once commonly used as cover-crops (Wakeley 1954), it is now realized that cover-crop selection is an important consideration for an effective integrated pest management program (Dixon et al. 1991).

Some pathologists recommend leaving areas fallow and not using any cover-crops (Sutherland 1991). However, fallow areas are often subject to excessive soil erosion in areas with heavy thundershowers. A major reason why nurseries use cover-crops in the South is to reduce soil erosion.

Inorganic N is applied to tree seedlings for economic reasons. If inorganic N fertilizers were not applied, nursery managers would use more expensive sources such as chicken manure, horse manure and cow manure. Although these sources are usually not expensive at the source, transportation costs usually make them more expensive on a $ per pound of N basis. One pound of N is contained in three pounds of ammonium nitrate or 145 pounds of horse manure (Pritchet 1979). The delivered cost of fertilizer can vary with year and location. However, at a delivered cost of $210 per US ton of ammonium nitrate, the cost of N would be about $0.32/pound of N.

Improved seed efficiency is one major economic reason for using N. Seed efficiency is defined as the number of plantable seedlings produced per pure live seed sown (South 1987). Losing one plantable seedling per square foot of bed will usually mean a loss in nursery income of $870 per acre (when seedlings sell for $30/thousand). In contrast, fertilizing with 150 lbs N/acre will cost approximately $48/acre. In effect, the break-even analysis indicates that one could afford to fertilize with N even if the loss in seedling production amounted to only 1,600 seedlings per acre. There is no doubt that ceasing to use N would result in a substantial loss in production of much more than 1,600 plantable seedlings per acre.

In one study (Duryea 1990), applying 100 lbs N/acre to slash pine seedbeds produced 13% culls. Applying an additional 50 lbs N/acre in August resulted in 10% culls (this was not a statistically significant reduction). However, if a single application of 50 lbs N/acre ($16/acre for ammonium nitrate and $10/acre application costs) could produce an additional 21,780 plantable seedlings/acre (3% increase in plantable seedlings), then the increase in crop value could amount to $653/acre. If a nursery had 30 acres in production, this could equate to an additional net income of $18,810. This level of economic return provides a strong incentive for nursery managers not to reduce the level of N fertilization.

Root growth potential (RGP) is an indication of the ability of seedlings to produce new roots after outplanting. It is often measured by counting the number of new roots produced under controlled conditions in either a greenhouse or in growth chambers. The application of N in the nursery has been shown to increase the RGP of pine seedlings (Donald 1988; Switzer 1962;

South et al. 1989). Chlorotic pine seedlings will usually have lower RGP values when compared to seedlings that are not deficient in N.

Researchers have debated how much N should be applied to a crop of loblolly pine seedlings. One reason for the debate is due to different management objectives. Some researchers have short-term objectives while others have long-term objectives. Those with long-term objectives believe the rate should be increased since the N content (mg N/seedling) can be positively correlated with field growth (Switzer and Nelson 1963; Landis 1985; Larsen et al. 1988; van den Driessche 1991). Published studies have demonstrated that field growth can be increased by applying additional N in the nursery (Switzer and Nelson 1967; van den Driessche 1991; Duryea 1990; Hinesley and Maki 1980). Five studies in Mississippi (Autry 1972) consistently demonstrated that average tree growth 14 to 16 years after planting can be increased by applying 300 lbs N/acre in the nursery instead of 150 lbs N/acre (Figure 2). These results are supported by studies with other pines. For longleaf pine (Hinesley and Maki 1980), applying an extra 150 to 300 lbs N/acre in the fall improved volume growth after eight years in the field. Duryea (1990) found that applying an additional 150 lbs N/acre in August increased average slash pine volume by 15% after three growing seasons.

Some researchers ignore data demonstrating growth gains and make recommendations based on short-term objectives. For some, the objective is to keep seedlings short so that top-pruning is not required. Therefore, they recommend applying about 75 to 80 lbs N/acre to a crop of pine seedlings. However, Duryea (1990) concluded that cutting back on N in the nursery may not be a beneficial way to control height since top pruning was a non-detrimental method of controlling height and produced a uniform crop of seedlings. Duryea found that seedlings with reduced foliar N contents grew less during the year after transplanting. This debate among researchers will likely continue until they agree that long-term performance is more important than the short-term appearance of pine seedlings.

Nitrate-N levels in irrigation water

During the 1980's, the Auburn University Southern Forest Nursery Management Cooperative sampled irrigation water from 42 tree nurseries in the South. Twenty-six samples came from wells and 15 came from surface waters (lakes, rivers, etc.). Water was analyzed by the Auburn University Soils Laboratory for nitrate-N. The nitrate-N levels in samples from wells ranged from 0.14 to 0.66 mg/l (refers to the nitrogen content of nitrate). For surface water samples, the range was from 0.19 to 0.47 mg/l. None of the samples exceeded 3 mg/l of nitrate-N (Figure 3). Most wells used for irrigation at nurseries are deep wells. The EPA estimates that 1.2% of community water wells and 2.4% of rural domestic wells have nitrate-N contents exceeding 10 mg/l.

Water samples collected from 11 Forest Service nurseries (most in the West) showed a wide range of nitrate-N levels in the vadose zone, which is the soil above the groundwater but below the surface soil. A majority of samples were between 0 and 50 mg/l (Landis et al. 1992).

CONCERN FOR PESTICIDES IN GROUNDWATER

The EPA National Pesticide Survey of 1,300 drinking water wells found low levels of nitrate common in well water, but presence of pesticides was much less common. For example, no pesticide residues were detected for more than 65 compounds. Some nursery pesticides not detected in the survey included acifluorfen, carbaryl, carbofuran, chlorothalonil, diazinon, diphenamid, EPTC, fenamiphos, hexazinone, methiocarb, metolachlor, napropamide, prometryn, pronamide, triademefon, and trifluralin. However, residues from 14 pesticides were detected. With respect to Maximum Contaminant Levels (EPA standards for public water systems), 0.8% of the community water wells had pesticide contamination that exceeded the Maximum Contaminant Level and 0.6% of rural domestic wells had levels that exceeded this value.

DCPA (acid metabolites) and atrazine were the two most commonly detected pesticides in well water samples from the EPA survey. Also found were the herbicides - dinoseb, prometon, simazine, alachlor, bentazon; the insecticides - lindane, chlordane, 4-nitrophenol (a breakdown product of parathion); the fungicides - hexachlorobenzene, ethylene thiourea (a breakdown product of EBDC fungicides); and the nematicides - ethylene dibromide and dibromochloropropane. Most of these pesticides are not used in southern pine nurseries. However, a few managers use mancozeb (an EBDC fungicide) and some use atrazine which is occasionally used to control weeds in cover crops. DCPA has been used in Federal tree nurseries in Washington and Oregon (Landis and Campbell 1989). Although the parent compound is considered to have a low leaching potential (Landis et al. 1992), the acid metabolites can leach into groundwater.

Soil fumigation

Methyl-bromide and chloropicrin are the most commonly used pesticides in conifer nurseries and currently account for 95% (by weight) of the pesticides used in southern tree nurseries (Table 4). These fumigants are used to kill weed seed, soil-borne pathogens, nematodes, and insects. Mixtures containing 2% chloropicrin are commonly used to control perennial weeds (e.g. nutsedge), nematodes and easy-to-kill fungi. Mixtures containing 33% chloropicrin are used when difficult-to-control disease fungi occur.

In 1945, weeds, disease and soil-borne insects caused a high degree of seedling mortality because nursery managers were not using pesticides, consequently. To produce one plantable seedling, it was often the case that three good seeds were sown (resulting in a seed efficiency of 33%). Production levels were limited and a total of about 50 million seedlings were grown in the South in 1945. It was initially believed that methyl bromide fumigation was too expensive but nursery managers soon learned that fumigation reduced weeding times and produced more plantable seedlings. As a result, seed efficiencies increased to 66% after the 1950's. By 1975, approximately 77% of the nurseries in the South were using methyl bromide/chloropicrin on an operational basis. By 1987, almost all nurseries were using these fumigants. A single nursery today can produce in excess of 50 million seedlings. By integrating several pest control practices and cultural techniques, seed efficiency now is often greater than 80%. These fumigants are now considered the backbone of a nursery manager's pest management program.

Although mixtures of methyl bromide and chloropicrin are restricted use pesticides (because of their toxic properties), they usually do not persist in the soil for long periods of time. In fact, tree seed can be sown within a day or two after the plastic tarp has been removed and the soil has been sufficiently aerated. After the tarp has been removed, any gas which remains generally moves up into the atmosphere, not down into groundwater. As a result, groundwater contamination by methyl bromide and chloropicrin have not yet been detected in the United States (Parsons and Witt 1989).

There is concern that man-made sources of methyl bromide could act to deplete the ozone layer. Since this fumigant will be removed from the marketplace, alternatives such as 100% chloropicrin will become more common. Without the use of methyl bromide, some nursery managers may decide to control nutsedge tubers with herbicides like alachlor, atrazine, and bentazon. Unlike methyl bromide, these herbicides have been detected in domestic wells. There is little doubt that use of other pesticides will increase when methyl bromide is withdrawn from the market.

Although fumigation may costs $1,100/acre, the practice commonly increases crop value. This increase can result simply from an increase in seed efficiency (even when chronic levels of pathogens are not present). In other words, fumigation often results in increasing the number of plantable seedlings enough to pay for itself. An increase of 37,000 plantable seedlings per acre is usually enough to pay for fumigation (Table 2). For a density of 740,000 seedlings per acre, this would equate to a 5% increase in plantable seedling production for a 1:1 rotation (where soil is fumigated prior to sowing each pine crop). For a 2:2 rotation, an increase of 2.5% a year would be required (where soil is fumigated once for two consecutive pine crops).

Herbicide use in nurseries

Southern tree nurseries use a relatively small percentage of herbicides applied annually in the United States (Table 3). The total amount of herbicides used in 1989 amounted to 394 million pounds (US Congress 1990). From a survey of southern tree nurseries (43% of total production surveyed), it is estimated that 7,300 pounds of herbicides were used in 1992 (Table 4). This means that southern tree nurseries use less than 0.002 percent of the herbicides used in the United States. Typically forest nurseries in the South use about 1.8 pounds active ingredient (a.i.) per acre to control weeds while farmers often use 3 pounds to control weeds in corn. Nursery managers commonly use oxyfluorfen, glyphosate and lactofen. These herbicides have high soil sorption coefficients (Table 4) and are not considered to have a high potential for leaching (Landis et al. 1992). Their relative leaching potential index is greater than 2,000 (Hornsby 1992). Those that do have a high potential for leaching include atrazine and fomesafen (sodium salt) but it is estimated that southern pine nurseries used less than 220 pounds of these herbicides in 1992. Atrazine use was in cover-crop areas while most of the fomesafen was used in pine seedbeds in Georgia.

Weed management

Weed management is potentially one of the most expensive steps in the production of tree seedlings. In the past, cost of handweeding could exceed 25% of the total production costs (Boyer and South 1984). Prior to 1947, southern pine nurseries were weeded almost entirely by hand or in combination with mechanical cultivation (Wakeley 1954). Weed populations were high and the time required to handweed often exceeded 1,000 hr/acre/yr. During the 1950's, methyl bromide use was evaluated at several nurseries. At nurseries with high weed populations, fumigation reduced handweeding times by 50 to 66% (South and Gjerstad 1980). Today, nursery managers employ efficient weed management systems and several have reduced handweeding costs to less than 1% of production costs.

Weed control techniques have improved dramatically since 1947. To document the changes in weed management practices, a questionnaire was sent to nursery managers in 1988. A total of 39 nurseries responded to the questionnaire. Four nurseries did not keep a record of handweeding times and therefore their data are not included. Some nurseries did not report the cost of methyl bromide fumigation and therefore a cost of $1000/acre was assumed. Cost of a herbicide application (one tractor-trip) was assumed to be $5/acre.

All nurseries surveyed were using methyl bromide fumigation in combination with oxyfluorfen (Table 5). Many nurseries were also using sethoxydim to control grasses. Fall fumigation was used by 13 nurseries, and spring fumigation was used at 10 nurseries. Managers at 16 nurseries fumigate some of their land in the fall and some in the spring. The median handweeding time was 10 hr/acre/yr. Only 4 nurseries reported handweeding times greater than 35 hr/acre/yr. The nursery with 100 hr/acre/yr produces mainly 2-0 white pine and uses only 2 applications of oxyfluorfen per crop. The nursery with 77 hr/acre/yr had a high population of sicklepod, morningglory, and nutsedge. Research by the Auburn University Southern Forest Nursery Management Cooperative determined that frequent postemergence applications of oxyfluorfen (at 0.125 lb a.i./acre) have proven more effective than two or three applications at 0.5 lb a.i./acre (Blake and South 1987). This research resulted in an improvement in weed control without increasing the total amount of herbicide used per year. Nurseries that apply only two applications of oxyfluorfen per crop are likely to have higher handweeding costs. For these reasons, the number of herbicide applications per pine crop usually exceeds 10 per year (Table 5).

The use of herbicides sometimes becomes a political issue as evidenced by the U.S. District Court Order of 1984 that temporarily banned the use of herbicides on National Forest lands in Washington and Oregon. The consequences of ceasing the use of herbicides in a nursery weed management program can be documented by observing the effect this ban had on weed management costs at the J. Herbert Stone Nursery (Figure 4). Even with the use of methyl bromide/chloropicrin fumigation and mechanical cultivation, handweeding cost in one-year-old seedbeds was five times greater than the total weed management costs prior to the ban in 1983. In addition, seed efficiency at the Wind-River Nursery was reduced to the point where 25% more seed was required to produce the same number of plantable seedlings. In contrast, seed efficiency can often be greater than 80% with the use of effective herbicides and soil fumigation (South 1991a). Ceasing the use of herbicides in forest nurseries not only increases the cost of seedling production, but also reduces the number of seedlings available for reforestation.

Insecticides

Most (85%) of the insecticides used in the United States are applied to corn, cotton and soybeans (US Congress 1990). The total amount of insecticides used in 1989 amounted to 61 million pounds. Tobacco farmers often use 3.8 pounds (a.i.) of insecticide per acre while nursery managers use less than half that rate (Table 3). Southern pine nurseries used a very small percentage of this amount (approximately 0.01%). From a survey of southern pine nurseries, it is estimated that 6,000 pounds of insecticides were used in 1992 (Table 4). Insecticides used included chlorpyrifos, esfenvalerate, and acephate. These insecticides are not considered to have a high potential for leaching into groundwater. However, dimethoate and diazinon are considered to have a medium potential for leaching (Landis et al. 1992).

Insect and mite management

Pests that can be troublesome for nursery managers include sucking insects and mites (southern red mite, scale insects, aphids, fire ants, tarnished plant bugs); defoliating insects (pine webworm, redheaded pine sawfly); stem feeders (Nantucket pine tip moth); and root feeders (white grubs, mole crickets, armyworms, cutworms, lesser cornstalk borer). Nursery managers usually apply non-chemical methods to try and prevent high populations from occurring (Dixon et al. 1991), and where deemed necessary, apply chemicals to control high populations (Bacon and South 1989).

In the past many seedlings were lost due to insects when chemical methods were either ineffective or not used. Nursery managers in Florida and in the Carolinas lost 25 to 40% of their crop due to white grubs feeding on the roots of pine seedlings (Wakeley 1954). If nursery managers stopped using fumigants and insecticides, there is no doubt that, at some nurseries, white grubs would once again cause significant seedling losses.

From the 1950's through to about the end of the 1970's, a mixture of xylene and mineral spirits was applied to pine seedlings two or three times a week for weed control. The frequent use of these chemicals also resulted in suppressing various above-ground insect pests. In general, tip moths and mites were not a problem until after the spraying of mineral spirits ceased in the fall. Since mineral spirits are essentially no longer used, injury from these pests and others have become more frequent. In particular, injury from two plant bugs has greatly increased (South 1991b; South et al. 1993). Prior to the initiation of an insecticidal program, some nursery managers were culling 10% of their crop due to injury from these insects. For a 30 million tree nursery, this resulted in a loss of $90,000 which is equal to 3 million seedlings. Since insecticides are relatively inexpensive (about $9/acre for the chemical plus application), it only requires saving about 300 seedlings/acre to justify applying insecticides (Table 3). At some nurseries, this is equivalent to only 3 linear feet of nurserybed. This is the economic justification used by nursery managers who are willing to apply insecticides to protect their crop.

Fungicides

About 80% of the fungicides in the United States were applied to peanuts (US Congress 1990). On average, a peanut farmer might treat with 3.6 pounds (a.i.). Although the total amount of fungicides used in 1989 amounted to 7.8 million pounds, southern pine nurseries used only a small percentage (approximately 0.13%). From a survey of southern pine nurseries, it is estimated that 10,300 pounds of fungicides were used in 1992 (Table 4). On average, a nursery manager may treat with only 2.6 pounds of fungicides per acre. Commonly used fungicides were captan, chlorothalonil and triadimefon. These fungicides are not considered to have a high potential for leaching into groundwater. However, a breakdown product of mancozeb (ethylene thiourea) has been found in well water and benomyl and metalaxyl are considered to have a high potential for leaching (Landis et al. 1992).

Disease management
In the past, many seedlings were lost due to disease when fumigation and fungicides were not used. There are many studies that show large increases in seedling production when chemicals are used to prevent diseases such as damping-off (Boyd 1971, Clifford 1963, Foster 1961, Hill 1955, Hodges 1962, Shoulders et al. 1965, Sutherland and Adams 1965).

In addition to chemicals, nursery managers use various non-chemical methods to reduce the likelihood of disease problems. Some nursery managers attempt to keep the soil more acidic than pH 5.5 to aid in reducing the chances of damping-off. Although tile drainage is expensive, it is used by some managers to remove water from the nursery and improve soil aeration (this reduces the likelihood of microaerophilic pathogens). Many managers avoid the use of legumes as cover crops in order to lower the potential risk from disease. Nurseries are often placed on sandy (>75% sand content), well drained sites (diseases are more likely on fine-textured soils that are wet due to poor drainage and a lack of macro-pores). If nursery managers ceased using fumigants and fungicides, there is no doubt that significant losses would result due to damping-off and infection by fusiform rust.

In 1975, a nursery manager would apply carbamate 28 times or more to control fusiform rust (a total of 28 lbs ai/acre/crop). By 1986, only four applications of triadimefon were needed for rust control (totaling two lbs ai/acre/crop). Nursery managers began to treat seed with triadimefon after research indicated it eliminated the need for the first postemergence application. In 1986, researchers again recommended using less fungicide and this cut the rate of triadimefon in half. By 1989, some nurseries would apply only a seed dressing and two applications of triadimefon (a total of 0.63 lb a.i./acre/yr). Researchers have made great strides in the South in greatly reducing the number of pounds of fungicides applied to control fusiform rust (US Forest Service 1993).

TYPICAL NURSERY REGIME
Nursery crops are managed differently according to management objectives, pests and environmental conditions. At some nurseries, reducing operating costs is an overriding concern. At others, high seed efficiency is very important, because they use valuable genetically improved seed. Some nurseries have high populations of nutsedge while others may have problems with tarnished plant bugs.

Table 6 illustrates an example of the chemical use at a hypothetical southern pine nursery. This nursery is located on a Troup soil and is managed on a 1:1 rotation (one year pine to one year cover-crop). The soil is fumigated in the fall with 300 lbs/acre of chloropicrin. Ammonium nitrate (25 lbs N/acre) is applied to the pine crop on the following dates; June 7, 20, July 4, 18, August 1, and 15. Oxyfluorfen is applied preemergence on April 10 at a rate of 0.5 lbs a.i./acre. Postemergence applications of oxyfluorfen are applied (0.12 lbs a.i./acre) on the following dates; May 23, 30, June 6, 13, 19, 27, July 3, 10, 17, and 24. With this regime, it is very doubtful that measurable traces of chloropicrin, oxyfluorfen, sethoxydim, or triadimefon would leach into groundwater. Nitrate could leach into groundwater when soil water moves downward due to heavy rains that saturate the soil profile. However, this management regime will likely result in a reduced potential for nitrate loss via leaching when compared to an irrigated corn crop. This is because pine seedlings receive multiple, small applications of ammonium nitrate which increases nutrient use efficiency (U.S. Congress 1990).

MODELLING RUNOFF AND LEACHING AT THE ASHE NURSERY

Several risk assessments were conducted by Labat-Anderson Inc. for forest nurseries owned by the USDA Forest Service. The GLEAMS model was used to predict the runoff and leaching potential of various pesticides used at the Ashe Nursery in Mississippi. An outline of the methodology is provided by Weiss (1992). The GLEAMS model was used to analyze movement of pesticides away from seedbeds in the form of (1) runoff, (2) soil erosion (eroded sediment), and (3) leaching. Estimates of the relative leaching of various pesticides are given in Table 7. Even under a worst case scenario, this model predicts very little leaching of pesticides like oxyfluorfen, sethoxydim, chlorothalonil and thiram. However, the model predicted that 10 to 14% of the triadimefon would leach. In contrast, samples from lysimeters at the Ashe Nursery indicate less than 1 part per billion of triadimefon. Either the half-life of triadimefon is less than that used in the GLEAMS model, or the model has over-estimated the potential for this fungicide to leach. This suggests a need to verify predictive models with actual field tests.

MEASURES TO REDUCE AGRICHEMICAL CONTAMINATION OF GROUNDWATER

There are numerous political strategies which, if enacted, could reduce the usage of water soluble agrichemicals. Several propose that taxpayers pay farmers to reduce the use of agrichemicals on sensitive areas that are under croplands (U.S. Congress 1990). A few proposals would promote tree planting with its associated nutrient-scavenging and carbon storage benefits. "The potential benefits in reduced agrichemical use with respect to protection of national (e.g. groundwater) or global (e.g., atmosphere) resources may argue for increasing payments for those acres planted to trees" (US Congress 1990).

There are various options that the forest industry could choose to reduce the potential for groundwater contamination from use of agrichemicals in forest nurseries. One option would be to reduce the demand for seedlings by outplanting fewer trees per acre. Currently about 1.2 billion pine seedlings are grown each year in the South. Typically, many companies in the South plant 650 to 750 trees per acre. A few companies plant more than 1,000 trees per acre. In comparison, 350 trees per acre are frequently planted by forestry organizations in the Northwest. However, when no-thinning regimes are used, planting 300 to 500 trees per acre can be more profitable than planting 900+ trees per acre (Caulfield et al. 1992; Conrad et al. 1992; Dean and Jokela 1992). If companies that plant 1,000+ trees per acre in 1993 decided to plant only 500 trees per acre in 1994, then the use of agrichemicals at their nurseries could be cut in half without changing any nursery management practices. However, good planting supervision as well as good seedling performance would be needed to ensure stocking uniformity and high seedling survival. Some companies might not want to change their management approach and would rather spend money on overplanting to ensure adequate stocking.

Nursery managers do not have control over political issues or outplanting densities, but they do choose which chemicals to purchase. Fortunately, nursery managers in the South tend to choose pesticides that have a low potential to leach. Oxyfluorfen, lactofen, and fluazifop-p-butyl have chemical properties that cause them not to leach. In general, the soil sorption coefficient for these materials are very high (Table 4). In contrast, herbicides that could leach in sandy soils include atrazine, bentazon, DCPA (acid metabolites), dicamba and fomesafen. A list to aid managers in selecting pesticides to minimize water quality problems could be developed for all pesticides likely to be used in southern tree nurseries (Hornsby 1992). This list could be distributed to nursery managers so that they can make an informed decision on which pesticides have both low soil sorption coefficients and moderate persistance in soil.

One way to reduce the use of chemical pesticides would be to increase the use of biological pesticides. Currently, there are only a few biological pesticides on the market. Bacillus thuringiensis is currently registered and is specific to lepidoptera larvae. However, lepidoptera are not usually a problem in conifer nurseries. B. popillae or B. lenomorbus are avilable for use in controlling white grubs while a virus is labeled for use on redheaded pine sawfly larvae (Dixon et al. 1991). Biological control of weeds has been researched for several years. Currently, the US Forest Service in Pineville is hoping to control prostrate spurge with a fungus. However, to date, only two biological pesticides have been registered for use on weeds (Te Beest et al. 1992).

MITIGATING PRACTICES FOR NITROGEN

It is apparent that for southern pine nurseries, use of N fertilizers is more likely to result in groundwater contamination than use of pesticides. There are several ways to lower the potential for leaching of nitrates in bare-root nurseries.

An important factor in attempting to reduce movement of nitrates into groundwater is proper irrigation management. A problem that sometimes results is a lack of irrigation uniformity. When this occurs, nursery managers may over irrigate some areas in order to provide enough irrigation on the dry spots. This problem can often be remedied by recommendations from extension specialists. For windless tests, an irrigation system should have a coefficient of uniformity of 0.80 or greater.

The amount of irrigation water applied can vary greatly by nursery. For example, some managers that use mulches will use less irrigation water than those that use only soil to cover seed. However, the amount applied can vary with nursery manager. Some use tensiometers to assist in irrigation scheduling but many still use the "one inch a week" guideline (Wakeley 1954) in conjunction with the touch and feel method. New nursery managers are often not given enough instruction on how to monitor soil moisture and therefore tend to over-irrigate.

There are essentially four different irrigation regimes used during the growing season. The first is during the germination phase. Usually, this requires frequent irrigations to keep seed from drying out. Most nursery managers do not over-irrigate during this period because they need to shift irrigation frequently. The second regime is during the "growing" phase and begins when the taproot reaches about six inches and ends usually in September. Some nursery managers apply too much irrigation water during this phase. They often try to keep the soil surface moist instead of observing the soil moisture in the root zone. Use of tensiometers can aid nursery managers during this phase of growth (Retzlaff and South 1985a,b; Dierauf and Chandler 1991). At one nursery in Georgia, switching to use of tensiometers (in addition to switching to pine bark mulch) reduced annual water consumption. There is no doubt that some nursery mangers could benefit by scheduling irrigation during the growing phase, based on readings from tensiometers. The third irrigation regime is used during hot days to cool the seedlings. Each field is irrigated for about 15 minutes (about 0.06 inch) and irrigation is shifted as quickly as feasible (since most irrigation systems can not irrigate the entire nursery at once). Much of this water evaporates and little actually reaches below the soil surface.

The fourth irrigation regime is used during the "hardening" phase. Traditionally, irrigation is reduced or withheld during the fall to "harden-off" the seedlings. However, if the seedlings are put under too much stress, root growth potential could be reduced as well as root growth (Williams and South 1988; South et al. 1988). This stress is more likely to happen at sandy nurseries than at silt loam nurseries.

Although sandy soils often require more irrigation water than fine textured soils, this does not necessarily mean that the amount of water reaching the water table is greater. In some nurseries, a dry zone soil may develop in the lower soil profile and irrigation water may penetrate only the upper soil horizons. Applying an inch of irrigation water a week (0.25 inch on Monday, Wednesday, Friday, and Saturday) would not be enough to cause the entire profile to be saturated. Agrichemicals will move into groundwater only if there is no break in the soil water column. On sandy soils, it is usually not irrigation *per se*, but saturating rains that penetrate deep into the soil profile and cause agrichemicals to move to levels below three feet.

Most N is applied in conventional granular form (as ammonium nitrate, diammonium phosphate, ammonium sulfate, or calcium nitrate). Slow release formulations are sometimes used in container nurseries but are generally not used in bare-root nurseries even though they have been evaluated for three decades (Anonymous 1964; Benzian et al. 1967). Slow release formulations have an advantage when compared with just a single application of a conventional fertilizer. However, since an optimum nutrient management can be obtained with split applications of conventional fertilizers (Oertli 1980), there is not much growth advantage in using slow release formulations. In fact, once applied, the nursery manager looses some control over nitrogen release. However, the main reason slow release formulations are not used in bare-root nurseries is due to their relatively high cost.

Nitrogen fertilizers are applied by one of four methods. Granular fertilizers are usually applied with 5- or 4-foot-wide hoppers (centered over the bed) or with an oscillating spreader. The oscillating spreader covers the entire ground and is favored by some managers because they can treat more beds/mile (4-foot hoppers when mounted three in line, only treat three beds/mile). However, the oscillating spreader applies fertilizers to the tractor paths as well as the seedbed. A 17 to 25% reduction in the use of N could be accomplished if nurseries with oscillating spreaders switched to using 5- or 4-foot hoppers.

The third method involves applying fertilizers through the irrigation system. Several nursery managers have applied fertilizers through the common riserline irrigation system. Most found the results less than satisfactory and have gone back to using tractors to apply fertilizer. One reason for using fertilizer spreaders is due to the lack of uniformity in irrigation. However, relatively uniform irrigation can be achieved with a center pivot system. Currently there are three southern pine nurseries that use a center pivot system.

The fourth method involves applying liquid fertilizers as a tank-mix with herbicides (typically oxyfluorfen). Nurseries in Alabama, Florida, Texas, and Virginia are currently using this technique. This method holds some promise for increasing nutrient use efficiency because multiple, small applications of fertilizer generally promote better plant uptake (U.S. Congress 1990). However, if the number of applications were doubled by applying liquid fertilizer on a weekly basis, as opposed to every two weeks as is typical with granular N, then nutrient use efficiency might increase slightly. A particular advantage to this system is that the nursery manager can eliminate five or six tractor trips each year. Since the herbicide oxyfluorfen is often applied on a weekly basis, combining fertilizer in the mix would, in effect, eliminate the need for additional fertilization trips. This system has been in use in Virginia for several years.

Tile drainage systems are currently used at some nurseries to remove excess water and to improve soil aeration. This system could also be used to reduce the potential for groundwater contamination of nitrates (Landis et al. 1992). To install this system costs approximately $1,000 to $2,000 per acre (depending on the spacing between pipes). The system can be installed in both new nurseries and existing nurseries. Experience indicates the system can work well in sandy nurseries. A large reservoir, with an impermeable bottom, would be needed to retain runoff. The runoff could be recycled for irrigation, thus reducing the drain on groundwater reserves.

One final way to reduce the movement of agrichemicals is to abandon the bare-root system and switch to producing seedlings at a container nursery with a water-recovery system. A prototype water-recovery system has been developed at an ornamental nursery at Eustis, Florida (Rackley 1992). This system involves covering the soil with a ground cloth and a 6-mil polyethylene and constructing a catchment pond to hold the runoff. This system retains 50 to 75% of the irrigation water. The rest is retained by the crop and lost to the atmosphere. Installation of this system costs an additional $8,000 to $10,000 per acre. The runoff from the pond is re-used as irrigation water. Currently, the price of container-grown loblolly pine seedlings can be four times that for bare-root seedlings. If one assumes that a container nursery could produce 9 million seedlings per acre before the tarp would need replacing, then the cost would add about $1/thousand (assuming it cost $8,000 to replace the tarp). Therefore, the cost of installing this system for a container nursery would not greatly increase the overall cost of production. The major deterrent to switching from a bare-root nursery would be the higher cost of producing container-grown stock. Some container nurseries sell pine seedlings for $120/thousand, as compared to $30/thousand for bare-root stock.

RECOMMENDATIONS

Nursery managers in the South currently use relatively small amounts of the following herbicides: atrazine, simazine, DCPA, bentazon, dinoseb, prometon and alachlor. Ceasing the use of these herbicides would not significantly affect the economics of producing southern pine seedlings. Therefore, it is recommended that nursery managers cease using these seven herbicides as well as any use of lindane, chlordane, EDB, dibromochloropropane, hexachlorobenzene and mancozeb. When appropriate, nursery managers should continue to use the EPA approved pesticides that have a low probability of leaching (e.g. oxyfluorfen, lactofen, fluzifop-p-butyl).

Nitrogen is used in nurseries to increase seed efficiency and to increase height growth after outplanting. Although several practices can be used to reduce nitrate leaching, growing legumes as cover-crops or reducing the total amount of N applied to pine seedlings are not recommended. Instead, managers of bare-root nurseries should first consider the following to reduce the potential for leaching nitrates:

(1) Check irrigation uniformity and make adjustments if the coefficient of uniformity is less than 0.80.

(2) Schedule irrigation during the "growing" phase to avoid saturating the soil. At some nurseries, managers may not need to water until the soil tension reaches 30 kPa.

(3) Avoid applying N to tractor paths.

(4) Increase nutrient use efficiency by applying N on a frequent basis.

(5) Apply ammonium sulfate when soil acidification is needed. Use gypsum where calcium is needed if lime application is not feasible.

(6) When feasible, reduce the amounts of N applied to cover-crops.
(7) Where tile drainage exists, consider building a reservoir to store effluent to use as an irrigation source.

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Table 6. Two-year pesticide and nitrogen use at a hypothetical nursery in the southern United States (rates in lbs a.i./acre).

	crop	**Irrigation**	**Rain**	**Chloropicrin**	**Goal**	**Poast**	**Bayleton**	**Asana**	**Ammonium nitrate**
Fall	fallow	0	-	300	0	0	0	0	0
Jan	oats	0	4.9"	0	0	0	0	0	0
Feb	oats	0	4.4"	0	0	0	0	0	0
Mar	fallow	0	5.9"	0	0	0	0	0	0
Apr	sow	2"	4.4"	0	0.5	0	0.01	0.2	0
May	pine	3"	4.0"	0	0.24	0	0.3	0.2	0
Jun	pine	3"	3.4"	0	0.48	0.15	0.3	0.2	50
Jul	pine	2"	4.7"	0	0.48	0	0	0.1	50
Aug	pine	2"	3.4"	0	0	0.15	0	0	50
Sep	pine	1"	3.2"	0	0	0	0	0	0
Oct	pine	1"	2.5"	0	0	0	0	0	0
Nov	pine	0	3.4"	0	0	0	0	0	0
Dec	pine	0	4.2"	0	0	0	0	0	0
Total		**14"**	**48"**	**300**	**1.7**	**0.3**	**0.6**	**0.7**	**150**
Jan	pine	0"	4.5"	0	0	0	0	0	0
Feb	fallow	0"	4.0"	0	0	0	0	0	0
Mar	fallow	0"	6.0"	0	0	0	0	0	0
Apr	sorghum	0"	4.5"	0	0	0	0	0	50
May	sorghum	0"	4.0"	0	0	0	0	0	0
Jun	sorghum	0"	3.0"	0	0	0	0	0	25
Jul	sorghum	0"	5.0"	0	0	0	0	.1	0
Aug	sorghum	0"	3.5"	0	0	0	0	0	0
Sep	sorghum	0"	3.0"	0	0	0	0	0	0
Oct	fallow	0"	2.0"	0	0	0	0	0	0
Nov	oats	0"	3.5"	0	0	0	0	0	0
Dec	oats	0"	4.0"	0	0	0	0	0	0
Total		**0"**	**47"**	**0**	**0**	**0**	**0**	**0.1**	**75**

Table 7. Estimated percent of applied pesticide leaving the field with runoff, sediment, and leachate (From Weiss 1992). (0.10 = one-tenth of one percent).

	Runoff	Sediment	Leachate
longleaf crop followed by loblolly			
benomyl	0.41	0.10	0.09
captan	0.00	0.00	0.00
chlorothalonil	0.64	0.37	0.00
diazinon	1.34	0.05	1.85
glyphosate	0.46	0.04	0.43
oxyfluorfen	0.31	0.76	0.00
sethoxydim	0.39	0.03	0.01
thiram	0.00	0.00	0.01
triadimefon	0.85	0.03	14.39
loblolly crop followed by loblolly			
benomyl	0.07	0.02	0.05
captan	0.00	0.00	0.54
chlorothalonil	0.12	0.17	0.00
diazinon	0.28	0.02	1.48
glyphosate	0.05	0.01	0.33
oxyfluorfen	0.06	0.33	0.00
sethoxydim	0.00	0.00	0.02
thiram	0.00	0.00	0.00
triadimefon	0.04	0.00	9.94