Use of Pesticides in Bareroot Hardwood Seedbeds in the Southern United States

David B. South and William A. Carey

Professor and Research Fellow (deceased), School of Forestry and Wildlife Sciences, Auburn University, Auburn, AL

Abstract

Pesticides are used in bareroot hardwood nurseries to avoid losses and to reduce the cost of seedling production. In 2001, the Auburn University Southern Forest Nursery Management Cooperative sent a questionnaire to all its nursery members to assess the level of pesticide use. Fifteen questionnaires were returned from nurseries that were growing hardwoods. One objective of the survey was to determine the relative importance and use rates of pesticides in hardwood nurseries. Results indicate that, in growing a million hardwood seedlings, nursery managers use about 944 kg of fumigants, 13 kg of herbicides, 3 kg of insecticides, and 0.6 kg of fungicides (weights are expressed in terms of active ingredient). The overall cost of pesticide treatments account for about 3 percent of the crop value. Documenting actual pesticide usage is one way to assess how nursery practices have evolved over time.

Introduction

In 2001, a survey was mailed to 84 forest tree nurseries throughout the Southern United States. Managers from 39 nurseries returned the questionnaires. These managers produced 1.19 billion pine seedlings on 702 ha (about 81 percent of the actual production for the South). Fifteen of the 39 nurseries produced a total of 22.3 million hardwood seedlings, about 46 percent of the 47 million hardwood seedlings (table 1) reported for the South (McNabb and VanderSchaaf 2003). The 22 million hardwood seedlings were produced on 51 ha for an average stocking of 440,000 seedlings per ha.

All of the hardwood managers reported using fumigants, eight regularly used insecticides, seven reported regular use of fungicides, and all used herbicides. An earlier report described some of the chemicals used in pine nurseries (South and Zwolinski 1996). This report documents pesticides used during the production of bareroot hardwood seedlings in 2001.

Fumigation

Effective soil fumigation is a cornerstone of an Integrated Pest Management (IPM) plan for the production of hardwoods in bareroot tree nurseries. Several nurserymen indicated fumigation as more important in hardwood than in pine seedbeds because of less effective registered herbicides and the higher value of hardwood stock. Several managers reported growing hardwoods only on first-year fumigated fields (as opposed to growing two crops of hardwoods after 1 yr of fumigation). Fumigation was justified by reducing risks associated with injury from nematodes, white grubs, competition from weeds, and soilborne pathogenic fungi.

Table 1. A partial list of hardwoods produced in forest tree nurseries in 2002–2003 (adapted from McNabb and VanderSchaaf 2003).

Common name	Genus	Species	Seedlings produced
Oak	*Quercus*	various	27,325,800
Green ash	*Fraxinus*	*pennsylvanica*	2,621,500
Yellow poplar	*Liriodendron*	*tulipifera*	1,282,800
Dogwood	*Cornus*	*florida*	892,900
Pecan	*Carya*	*illinoensis*	892,000
Sycamore	*Platanus*	*occidentalis*	782,000
Sweetgum	*Liquidambar*	*styraciflua*	638,200
Black walnut	*Juglans*	*nigra*	508,000
Cottonwood	*Populus*	*deltoides*	320,000
Others	—	—	11,849,000
Total			47,112,200

Fumigation rates varied from 390 to 450 kg ai ha^{-1} of methyl bromide and chloropicrin, with chloropicrin making up 33 percent (8 nurseries), 10 percent (1 nursery) or 2 percent (6 nurseries) of the formulation.

Insecticides

Insect pests can be placed into a few categories based on where they live and how they feed. Root-feeding insects are typically killed by effective fumigation. Important airborne insects occurring in most bareroot hardwood nurseries can be divided into two groups: foliage feeders and sapsucking insects.

Insecticides fall under three categories: systemic, stomach, and contact poisons. Systemic poisons (e.g., dimethoate) are applied to the seedling or soil and move into the plant cells. Sapsucking insects such as bugs, aphids, and scales consume large quantities of plant sap. Their feeding habits greatly increase the exposure of these insects to most systemic insecticides. Therefore, systemic insecticides can be effective at concentrations that are not generally toxic to foliage-feeding insects. In contrast, nonsystemic insecticides (stomach and contact poisons such as bifenthrin, chlorpyrifos, diazinon and esfenvalerate) have little effect on sapsucking insects because the insects don't consume foliage on which the insecticide has been placed.

Foliage-feeding insects are typically controlled by stomach poisons on the leaf surface, systemic insecticides, and, to a lesser extent, contact poisons sprayed directly on the pest. For example, stomach poisons such as esfenvalerate and chlorpyrifos have residual activity against grasshoppers (suborder Caelifera) and the larvae (caterpillars) of Lepidoptera. Therefore, when selecting an insecticide to control these foliage-feeding insects, either a stomach poison applied to the foliage or a systemic pesticide would be the preferred choice (assuming the cost and human hazards are similar).

Eight of the managers who produced hardwood seedlings either scheduled prophylactic applications of insecticides or expected to spot-treat part of the seedling crop after scouting for insect damage. Although the tarnished plant bug [*Lygus lineolaris* (Palisot de Beauvois)] is occasionally observed as a problem in hardwood seedbeds, the only sapsucking insects mentioned in the survey were pests from the family Phylloxeridae and aphids (both of which were reported on oak). These insects tend to be sessile (don't move around once they are established) and would be controlled by either systemic or contact insecticides.

Organophosphates. At six nurseries, a total of 59.5 kg of active ingredient (ai) of organophosphates was used to treat hardwood insect problems. One nursery applied 0.5 kg ai of malathion (a contact insecticide); the remaining 59 kg was evenly distributed among chlorpyrifos, diazinon, and dimethoate (table 2). Although the effective application rates are higher for organophosphates than for the fourth-generation pyrethroids such as esfenvalerate (see below), the organophosphates work better in the soil than most pyrethroids.

Chlorpyrifos was used by four hardwood managers, who treated at an average rate of 1 kg ai ha^{-1}. Much of the chlorpyrifos was reportedly used to control late-season foliage feeders such as grasshoppers. When insects are found in certain cover crops, the agricultural product (Lorsban®) might be appropriate.

Dimethoate was used at one hardwood nursery that, by virtue of four applications to all its hardwood seedbeds, made dimethoate the most used insecticide in terms of area treated. The target pests were foliage and sapfeeders; the use rate was 0.56 kg ai ha^{-1}. As a rule, systemic insecticides like dimethoate are most effective against sucking insects and mites and may not be effective against foliage feeders. The occasional use of dimethoate in an insect control program should reduce the chance that pyrethroid resistance will develop.

More diazinon was used in hardwood seedbeds in 2001 than any other insecticide (table 2). It was used for basically the same foliage-feeding insects as chlorpyrifos. Diazinon has been used since 1952, and there is considerable efficacy data for soil and foliage insects (especially for house and garden uses); however, there are few published data for nursery hardwood pests. Although diazinon is not a "restricted use pesticide," most managers prefer to apply other insecticides for managing destructive insects.

Synthetic Pyrethroids. The synthetic pyrethroids are chemically related to a natural insecticide (pyrethrum) that was originally obtained from chrysanthemums. Esfenvalerate is a fourth-generation pyrethroid that is the α-isomer of the third-generation fenvalerate, which it replaced. The original botanical extracts of pyrethrum were not stable in sunlight and rather expensive, but the synthetic pyethroids are more stable in light and are active for up to 10 d. Although earlier generation synthetic pyrethroids were effective at lower rates (112–224 g ai ha^{-1}) than the organophosphates, the fourth-generation products are effective at one-tenth those rates (11–22 g ai ha^{-1}).

Table 2. A partial list of pesticides used at 15 hardwood nurseries and the total amount used on 51 ha in 2001.

Common name	Original trade name	Additional trade names	Total used in 2001 (kg ai)	Restricted use pesticide	Restricted entry interval (h)
Insecticides					
bifenthrin	Talstar	Bifenthrin	2.3	Yes	12
chlorpyrifos	Dursban	Chlorpyrifos, Lorsban	20.5	Yes	24
diazinon	Diazinon	various	24.5	Yes	12
dimethoate	Cygon	Dimethoate	14.1	Yes	48
esfenvalerate	Asana	—	1.8	Yes	12
malathion	Malathion	various	0.5	No	12
		Total	63.7		
Fungicides					
chlorothalonil	Bravo	Chlorothalonil	8.6	No	12
propiconazole	Banner	Propiconazole	0.027	No	24
thiram	Thiram	Gustafson 42-S	1.5	No	24
triadimefon	Bayleton	various	13.3	No	12
		Total	23.4		
Herbicides					
clopyralid	Lontrel	Stinger	2.3	No	12
fluazifop-butyl	Fusilade	—	9.5	No	12
glyphosate	Roundup	Various	51.3	No	4
oryzalin	Surflan		0.2	No	24
oxyfluorfen	Goal	Galigan	10.4	No	24
napropamide	Devrinol		148	No	12
prodiamine	Barricade	Endurance; Factor	33.6	No	12
sethoxydim	Poast	Sethoxydim	28	No	12
trifluralin	Treflan	Trifluralin	7.7	No	12
		Total	291		
Fumigants					
chloropicrin	Various	—	3,603	Yes	0.1 ppm*
methyl bromide	Various	—	17,452	Yes	5.0 ppm*

* May enter when concentration in the air is at or below this level.

Esfenvalerate was used at four hardwood nurseries to treat 54 ha, counting reapplications. The average rate per application was 34 g ai ha^{-1}. More hardwood seedbeds were treated with esfenvalerate than with chlorpyrifos in 2001. Bifenthrin was used at one hardwood nursery. Bifenthrin is rare among pyrethroids in having “significant” soil activity and is effective for control of the imported fire ant (*Solenopsis invicta*). It was used for soil insects and was normally applied at rates from 6 to 56 g ai ha^{-1}. It may be that bifenthrin will be used in the future as a soil treatment for many insect problems, including fire ants and termites (order Isoptera).

Dividing the total amount of insecticides applied (63.7 kg) by 22.3 million seedlings indicates that 2.9 kg of insecticides were applied to a million seedlings. In 1996, nursery managers in Finland applied about 1.2 kg of insecticides per million bareroot seedlings (Juntunen 2001).

Fungicides

Several fungicides are used to prevent or control diseases of hardwoods. Seven managers applied fungicides to their hardwood beds; the total amount applied was minimal (13.6 kg ai). Even doubling this amount to account for hardwood production reported in the production survey projects an “insignificant” market for fungicides.

Triadimefon was the most frequently used fungicide reported for hardwoods; it was used primarily to control powdery mildew on white oaks (*Quercus* spp.). It was used at four hardwood nurseries, which together used 3.2 kg ai. The average use rate in hardwoods was 302 g ai ha^{-1}.

Chlorothalonil was the most used fungicide by weight. It was used at four hardwood nurseries for various foliage diseases. The average reported use rate was 840 g ai ha^{-1}. Chlorothalonil is one of the most popular fungicides in general agricultural use. It is generally effective against most foliar pathogens that cause leaf spots, blights, necrosis, etc., in many crops.

Thiram was used by one hardwood nursery to treat acorns before sowing at a rate of 0.8 kg ai 100 kg^{-1} of acorns. In addition to being a fungicide, thiram may also be effective as a bird and mammal repellent (Abbott 1958; Holms and others 1988).

Propiconazole was used at one hardwood nursery for control of powdery mildew on white oaks. Its activity is similar to that of triadimefon, and its use for powdery mildew (numerous fungi fall under this general description) seems a matter of preference. Only 0.2 ha of oaks were treated in 2001.

Dividing the total amount of fungicides applied (13.3 kg) by 22.3 million results in 0.6 kg of fungicides per million seedlings. In Finland this value was 5.6 kg per million bareroot seedlings (Juntunen 2001).

Herbicides

Herbicides can be grouped into selective (not generally harmful to hardwood seedlings) or nonselective (should not contact bark and foliage). If an herbicide is applied to emerged hardwoods and kills both weeds and the hardwoods, it is nonselective. Glyphosate is typically a nonselective herbicide, but sethoxydim (which kills only grasses) is selective in hardwood seedbeds. These designations are useful when we know the specific crop/weed system involved.

The terms preemergence or postemergence are also used to describe when the herbicide is applied to the crop or weed. For example, herbicides such as napropamide kill germinating weeds before they emerge through the soil surface. This herbicide is applied after emergence of the hardwood crop but before emergence of the weed. Since the weeds have not yet emerged, napropamide is classified as a preemergence herbicide. This designation occasionally causes confusion, however, especially when the preemergence herbicide is applied after emergence of the crop.

Nonselective Herbicides. Glyphosate is a foliar-applied, nonselective herbicide with no soil activity. It inhibits an enzyme found only in plants and so may pose little risk for other organisms such as mammals, birds, fish, or insects. Glyphosate is bound tightly to soil particles and is unlikely to move offsite. The relatively slow absorption of glyphosate into foliage causes rain within a couple of hours of application to reduce effectiveness. There is no legal limit to the number of applications that may be applied in a year. Glyphosate may be applied between drills with shielded sprayers. Some genetically modified cover crops have a glyphosate-resistant gene that some managers use as part of an IPM program to reduce nutsedge (*Cyperus* spp.) in cover crops. Use of glyphosate may increase in both cover-crop and noncrop areas if the production of methyl bromide ceases. Five nurseries used glyphosate “as needed” to control troublesome weeds, and some used scheduled, shielded applicators; average use rate was 2.6 kg ai ha^{-1}.

Selective Herbicides. Sethoxydim was used at more hardwood nurseries than any other herbicide. Sethoxydim is a postemergence herbicide that is effective against annual and perennial grasses. It is quickly absorbed by foliage and is rain-fast after 1 h. Although there are limits to the amount that can be applied to certain agricultural crops, these rates are based on avoiding undue stress to the crop. The average reported application rate was 0.3 kg ai ha^{-1}, with rates ranging from 0.22 to 0.45 kg ai ha^{-1} per application, depending upon the size of the grasses. Most nurseries applied two treatments; a few applied three.

Napropamide was applied at six hardwood nurseries (average, 2.6 kg ai ha^{-1}), which made it the most used herbicide. Napropamide was applied to control both grasses and broadleaf annual weeds. Its selectivity is based mainly on the timing of herbicide application (i.e., after seedling establishment but before germination of weed seed). In some cases, napropamide can reduce germination of chestnut oak [*Quercus prinus* (L.)] (Reeder and others 1991). For this reason, it is commonly applied over established seedlings and after true leaves have emerged (South 1986). It does not have any contact activity, so it is best to apply napropamide to a weed-free soil.

Fluazifop-butyl was registered for nurseries in the 1980’s. The target weeds and application methods are very similar to sethoxydim**.** Both are selective, foliar-absorbed, systemic herbicides that are effective against grasses but have no effect on dicots or sedges. It is effective against crabgrass (*Digitaria* spp.) and bermudagrass [*Cynodon dactylon* (L.) Pers.]. It can be applied to most broadleaf crops with little risk of injury and is most effective applied to weeds in the two- to four-leaf stage. There is some soil activity at higher rates, and sensitive grasses may be affected for up to 4 mo after application. The active ingredient breaks down rapidly in the soil. The single application limit is 0.2 kg ai ha^{-1}, but the annual amount is not limited. This herbicide is toxic to fish and so should not be used too close to ponds, creeks, or rivers.

Fluazifop-butyl is effective at rates as low as 112 g ai ha^{-1}; the average use rate was 336 g ai ha^{-1} (5 of 8 nurseries used less than 224 g ai ha^{-1} per application). Most nurseries made about two applications per year. Although only 9.5 kg ai were used in 2001, about as many ha were treated with fluazifop-butyl as with any other herbicide.

Oxyflurofen is labeled for use on field-grown deciduous trees. It was used primarily as a preemergence herbicide (applied just after sowing) on large-seeded hardwoods at five nurseries. Newly emerged seedlings can be injured (South 1984). A granular formulation (containing 2 percent oxyflurofen and 1 percent oryzalin) can be applied to emerged hardwoods without significant injury (Reeder and others 1991; 1994). Five nurseries used oxyflurofen at an average rate of 448 g ai ha^{-1}, and one manager used 0.4 kg ai of the granular formulation. This herbicide is active against a broad range of annual broadleafed weeds and grasses. Granular formulations that contain oxyfluorfen will cause less injury to foliage than an emulsifiable concentrate formulation. At some nurseries, the liquid formulation is also applied as a directed spray to established field-grown hardwoods (South 2004). Oxyflurofen binds to soil particles, forming a chemical barrier to weed emergence that can be broken by mechanically disturbing the soil surface. Large-seeded hardwoods can usually penetrate this soil barrier without much damage. The label restricts application to not more than 2.2 kg ai ha^{-1} yr^{-1}.

Clopyralid was used at one hardwood nursery. This herbicide is active against troublesome legumes such as javabean [*Senna obtusifolia* (L.) Irwin and Barneby], which has tolerance to methyl bromide fumigation. Clopyralid is a selective postemergence herbicide that is absorbed by both foliage and roots (South 2000).

Prodiamine is a selective preemergence herbicide that control annual grasses and some broadleaf weeds (South 1992). Weeds are not controlled after they have emerged, and weed control is best when application is followed by at least 1.25 cm of irrigation. There is no limit on the annual application of this herbicide except as made necessary by crop sensitivity (Altland 2005). Prodiamine was used at three hardwood nurseries, but one nursery accounted for 72 percent of the total amount applied. The typical application rate was 448 g ai ha^{-1}.

Trifluralin is typically incorporated into the soil before sowing agronomic crops, but in hardwood nurseries it is often applied and watered in just after sowing. This reduces the likelihood of reducing root growth. Irrigation is applied immediately after treatment to reduce volatilization. Small-seeded species are sensitive to trifluralin; therefore, managers should not apply this herbicide to small-seeded hardwoods, such as sycamore. Two nurseries applied trifluralin as a preemergence herbicide at 1.1 kg ai ha^{-1}, and one applied this rate after germination was complete.

After dividing the total amount of herbicides applied (291 kg) by 22.3 million seedlings, the amount used is approximately 13 kg per million seedlings. For the southern pines, this value is about 2.5 kg per million seedlings (South and Zwolinski 1996). In contrast, in Finland the ratio was 5.6 kg per million bareroot seedlings (Juntunen 2001). In bareroot nurseries in the Southern United States, managers applied, on average, about 2.0, 2.9, and 1.7 kg a.i. ha^{-1} $crop^{-1}$ of herbicides, fungicides and insecticides, respectively (South and Zwolinski 1996).

Economics

Some nursery managers base their pest management decisions on securing economic profits and on maintaining good reputations for producing disease-free stock. The main economic justifications for using pesticides include keeping seed efficiency high (South 1987) and production costs low. Examination of a hardwood nursery budget might reveal that pesticide treatments amount to less than 4 percent of the retail value of the crop (table 3). Currently, fumigation with methyl bromide and chloropicrin before sowing accounts for a large portion of these costs.

It is interesting to note that pest control costs in hardwood seedbeds represent a lower overall percentage of retail seedling sales than such costs in pine seedbeds. This percentage might be 3 percent for hardwoods (table 3) but 6–7 percent in pine seedbeds (South and Enebak 2006).

When nursery pests are controlled using effective chemicals, the cost of producing a thousand hardwood seedlings can be less than $300 per thousand, while the cost of

Table 3. Approximate costs of pest management in hardwood nurseries based on average use rates reported in 2001. Value calculations assume 440,000 seedlings ha^{-1} and a price of 30 cents per seedling.

Pest group	Active ingredient (kg/ha^{-1})	Cost ($) per		Percentage of total crop value
		ha	thousand seedlings	
Foliage and stem fungi	0.3	44	0.10	0.03
Birds and mice	0	0	0	0
Annual weeds	2	190	0.43	0.14
Insects	1.25	100	0.23	0.08
Nematodes, soil fungi, and sedges	400	3,800	8.64	2.9
Total		4,134	9.40	3.1

pesticide treatments might be $10 per thousand (table 3). The retail price for bareroot oak seedlings in the Southern United States may vary from $200 to $400 per thousand.

Address correspondence to: David South, School of Forestry and Wildlife Sciences, Auburn University, AL 36849-5418; e-mail: southdb@auburn.edu; phone: 334-844-1022.

Disclaimer

The mention of commercial products is solely for the information of the reader. Endorsement is not intended.

Acknowledgments

This report was supported by the Auburn University Southern Forest Nursery Management Cooperative. We thank the nursery managers who took the time to fill out and return the questionnaires.

References

Abbott, H.G. 1958. Application of avian repellents to eastern white pine seed. Journal of Wildlife Management. 22: 304–306.

Altland, J. 2005. Weed control in nursery field production. EM 8899-E. Corvallis, OR: Oregon State University Extension Service. 15 p.

Holm, B.A.; Johnson, R.J.; Jensen, D.D.; and Stroup, W.W. 1988. Response of deer mice to methiocarb and thiram seed treatments. The Journal of Wildlife Management. 52: 497–502.

Juntunen, M.L. 2001. Use of pesticides in Finnish forest nurseries in 1996. Silva Fennica. 35: 147–157.

McNabb, K.; VanderSchaff, C. 2003. A survey of forest tree seedling production in the South for the 2002–2003 planting season. Technical Note 03-02. Auburn, AL: Auburn University Southern Forest Nursery Management Cooperative. 10 p.

Reeder, J.A.; Gilliam, C.H.; Wehtje, G.R.; and South, D.B. 1991. The effects of selected herbicides on propagation of chestnut oaks in containers. Combined Proceedings of the International Plant Propagators' Society. 41: 325–329.

Reeder, J.A.; Gilliam, C.H.; Wehtje, G.R.; South, D.B.; and Keever, G.J. 1994. Evaluation of selected herbicides on field-grown woody ornamentals. Journal of Environmental Horticulture. 12(4): 236–240.

South, D.B. 1984. Response of loblolly pine and sweetgum seedlings to oxyfluorfen. Canadian Journal of Forest Research. 14: 610–604.

South, D.B. 1986. Herbicides for southern pine seedbeds. Southern Journal of Applied Forestry. 10: 152–157.

South, D.B. 1987. Economic aspects of nursery seed efficiency. Southern Journal of Applied Forestry. 11: 106–109.

South, D.B. 1992. Prodiamine: A herbicide for pine and hardwood nurseries. Southern Journal of Applied Forestry. 16: 142–146.

South, D.B. 2000. Tolerance of southern pine seedlings to clopyralid. Southern Journal of Applied Forestry. 24: 51–56.

South, D.B. 2004. Weed control in hardwood nurseries. In: Dumroese R.K.; Riley, L.E.; and Landis T.D., technical coordinators. Forest and Conservation Nursery Associations; 2004 July 26–29; Medford, OR. Proceedings RMRS-P-35. Fort Collins, CO: Forest Service, Rocky Mountain Research Station: 34–38.

South, D.B.; Enebak, S.A. 2006. Integrated pest management in southern pine nurseries. New Forests 31: 253–271.

South, D.B.; Zwolinski, J.B. 1996. Chemicals used in southern forest nurseries. Southern Journal of Applied Forestry. 20: 127–135.