Chapter 19
Vegetation Management after Plantation Establishment

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Abstract

Vegetation-management practices allocate available resources and provide favorable conditions to promote the growth of desirable species. Animals, chemicals, fire, hand tools, and machinery are used to control interfering vegetation in established pine stands, improving survival, growth, and stand value. Following site preparation, herbaceous plants, shrubs, and vines may interfere with pine stand establishment and early growth to a greater extent than hardwood tree species, whereas hardwoods can most significantly affect pine growth later in the rotation, particularly after the fifth or sixth growing season. Weed community development is a function of the species composition of the previous stand and adjacent areas, environmental conditions, and the timing and intensity of disturbances such as mechanical or chemical site preparation and fire. The magnitude of pine growth response to weed control depends on the nature of interfering vegetation, stand age at treatment, site productivity, and treatment effectiveness. Removing weeds accelerates stand development, yielding more volume in less time. Increases in diameter growth, generally more responsive than height growth to weed control, may shift product classes to favor the more valuable sawtimber and veneer materials. Although nonchemical vegetation management (cultivation, mowing, grazing, and prescribed fire) can be effective, silvicultural herbicide technology is emphasized. Herbicide characteristics, application equipment, worker safety, and prescription of appropriate treatments are discussed relative to current technology for herbaceous plant control, pine release, and timber stand improvement. Understanding the biology of interfering vegetation, stand development, and limitations of weed-control practices should help managers implement effective vegetation managers implement effective vegetation management.

19.1 Introduction

Forest vegetation management is the practice of channeling limited site resources into usable forest products rather than into noncommercial plant species [127]. Light, moisture, nutrients, carbon dioxide, and oxygen are basic resources supporting plant growth. The objective of forest vegetation management practices, indeed of most silvicultural practices, is to allocate available resources and provide favorable conditions for growth of desirable species. Vegetation management practices are most effective when both crop and noncrop species are manipulated in an integrated approach. For example, the benefit of accelerated growth in a young stand receiving weed control may be lost if the stand is not thinned at the appropriate time.

This chapter discusses vegetation management after southern pine regeneration. Once pines have been established, selective treatments which reduce interfering vegetation without significant adverse effects to the crop species must be used. A broad array of methods is available to manage interfering vegetation, including animals, chemicals, fire, hand tools, and machinery. Because of the recent, sizable increase in herbicide use in southern forests, this discussion focuses on herbicide technology. However, the practice of forest vegetation management is not limited to the use of herbicides.

19.2 Interference and Competition

Various woody and herbaceous plants interact with pines during part or all of a rotation. Burkholder [12] and Odum [99] characterized the nature of plant interactions, and Radosevich and Osteryoung [110] summarized these interactions as they relate to forest vegetation management. One plant growing in the same environment as another may result in neutral, positive, or negative interference. If the interference is neutral, one plant has no effect on the other; if positive, plant growth is stimulated. Infection of pine roots by mycorrhizae is an example of mutual positive interference, or symbiosis.

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However, negative interference, which may be due to competition for site resources, amensalism, or parasitism, is a major concern to forest managers. Competition is the mutually adverse effect of two plants utilizing the same resources. Amensalism refers to a relationship in which one plant is adversely affected and the other is not affected. Allelopathy is an example of amensalism, whereby one plant is inhibited by another through the action of a selective toxin. Parasitism describes a relationship in which one organism derives its resources from another. Parasitic relationships are very common in pine stands and include infection by microbial disease organisms such as fusiform rust *[Cronartium quercuum* (Berk.) Miyabe ex Shirai f. sp. *fusiforme],* parasitic seed plants such as black senna *[Seymeria cassioides* (J.F. Gmelin) Blake], and infestations by destructive insects such as Nantucket pine tip moth *(Rhyacionia frustrana Comst.).*

19.2.1 Resources for Growth

Site productivity is largely a function of the available supply of resources supporting plant growth. The supply of nutrients can be increased by fertilization, but in a commercial forestry setting the supply of other resources is determined by site reserves, natural inputs, and stand characteristics. Vegetation management practices are employed to limit the growth of undesirable vegetation, thus increasing resources available to crop trees.

19.2.1.1 Light

The southern pines are shade intolerant. Thus, they do not survive and grow well in limited light. Many hardwood tree species, on the other hand, are shade tolerant. Commonly found in the understory of pine stands, they replace pines as plant succession proceeds.

Because light is the energy source for photosynthesis, the availability and utilization of light are important factors affecting tree growth. Loblolly pine *(Pines taeda* L.) seedlings reach maximum photosynthetic rates at full illumination (100% sunlight), whereas photosynthesis peaks for many associated hardwoods at only about 30% sunlight [54, 57]. Pines have densely clustered, somewhat rounded needles which scatter light and shade one another [56]. Most associated hardwoods have broad leaves oriented perpendicular to the direction of incident light, often arranged such that mutual shading is minimized. These differences enable greater utilization of low light intensities by shade-tolerant hardwoods and high light intensities by shade-intolerant pines [115]. Weed control treatments reduce shading of pines by competing vegetation, enhancing the photosynthetic potential of pines and ultimately increasing pine crown volumes [136].

19.2.1.2 Water

Water availability during the growing season is a major limitation to the growth of southern pines. A mounting body of evidence indicates that many of the benefits from weed control are related to improved moisture availability.

Nelson et al. [95] found response of loblolly pine seedling height to weed control treatments during the first three growing seasons to be correlated with herbaceous weed cover and biomass. Measurements of the moisture status of pines and precipitation inputs indicated that weeds depleted soil moisture necessary for maximum pine height growth. Eliminating all competing vegetation within 1.5 m of 5-year-old loblolly pines resulted in significantly less moisture stress than when competing vegetation was retained, while nutrient content of pine foliage was unaffected [20]. In a 2-year-old loblolly pine plantation, soil moisture was found to be negatively correlated with the level of herbaceous vegetation. First-year pine height growth was most highly correlated with soil moisture level in late August, when soil moisture was lowest [135].

Moisture availability affects pine shoot growth [4, 16, 132], latewood production [9], bud and needle growth [50], root growth [6, 50, 105], and numerous physiological processes [36, 55]. Weed control treatments during the first growing season after planting significantly increase seedling root volumes [64, 95, 135], which enables greater utilization of soil moisture and nutrients.

19.2.1.3 Nutrients

The supply of mineral nutrients, especially nitrogen and phosphorus, often limits the growth of southern forests [109]. Phosphorus fertilization in young loblolly and slash *(Pines elliottii* Engelm.) pine stands is common on Lower Coastal Plain sites where this nutrient is limiting. Nitrogen fertilization of young stands is not a common practice, largely because much of the fertilizer may benefit competing vegetation [120].

Weeds should be controlled when fertilizer is applied to optimize utilization by crop trees. Such control fosters nutrient availability not only directly, through allocation of added elements [123], but also indirectly, through increased soil moisture, which improves nutrient supply and pine root development [92]. Many of the more mobile nutrients are moved to the site of absorption as roots take up water from the soil solution (mass flow). In addition, increased soil moisture may increase microbial breakdown of organic matter (mineralization) and asymbiotic nitrogen fixation by free-living bacteria.

19.2.2 Nature of Interfering Vegetation

For the purposes of discussing management alternatives and impacts on pine growth, interfering vegetation may be classified into four groups: (1) herbaceous plants, (2) shrubs, (3) trees, and (4) vines.

19.2.2.1 Herbaceous plants

Herbaceous plants are nonwoody annual or perennial species such as grasses, sedges, fortis, and lianas. Intensive mechanical site preparation (see also chapter 13, this volume), particularly in conjunction with broadcast burning, often results in conditions which foster the development of herbaceous plants [98]. In the southeastern United States, panicum grasses *(Panicum* spp.) and the asteraceae forbs [e.g., *Aster* spp., dogfennel *(Eupatorium* spp.), goldenrod *(Solidago* spp.), horseweed *(Conyza* spp.)] are most common after intensive site preparation [83]. Many herbaceous plants have morphological and physiological characteristics, such as fibrous root systems and C4 photosynthesis, which make them adept competitors. Some overtop pine seedlings, reducing the availability of light; this is a common problem on Lower Coastal Plain sites where a dense cover of panicum grasses and sedges develops following mechanical site preparation [117]. In addition, some herbaceous species, including broomsedge *(Andropogon virginicus* L.) and dogfennel, are thought to be allelopathic [44, 108].

19.2.2.2 Shrubs

Shrub species such as gallberry *(Rex glabra* L.), saw-palmetto *(Serena repens* Bartr.), sumacs *(Rh us* spp.), wax-myrtle *(Myrica cerifera* L.), and *Vaccinium* spp. are common in southern pine stands. Shrubs may overtop pines during early stand development and compete for site resources in the understory of older stands. At least one shrub species has been shown to have allelopathic effects on pine growth; foliar extracts from fetterbush *(Lyonia lucida* Lam.) strongly inhibited germination and radicle extension of loblolly and slash pines, and nutrient analyses of 4-month-old pine seedlings mulched with dried fetter-bush foliage indicated that growth retardation may be related to nitrogen uptake and metabolism [44].

19.2.2.3 Trees

Common hardwood tree species in southern pine stands, or mixed stands, include oaks *(Quercus* spp.), sweetgum *(Liquidambar styraciflua* L.), hickory *(Carya* spp.), red maple *(Ater rubrum* L.), and yellow-poplar *(Liriodendron tulipifera* L.). Many other species are locally important. Trees compete for site resources throughout a rotation and may interfere with pine growth through allelopathy. Many plants, including pines, are inhibited by toxic exudate from

Figure 19.1. Relative impact of woody and herbaceous vegetation on young pine stand development is demonstrated during February of the fourth growing season at the Tallassee, Alabama, location of the regionwide study by Miller et al. [83]: no weed control (A), woody plant control (B), herbaceous plant control (C), and control of both woody and herbaceous plants (D).

the roots of black walnut *(Iuglans nigra* L.) [7]. Understory vegetation is sparse below stands of cherrybark oak (Quercus falcata var. pagodaefolia Ell.), apparently because of an allelopathic toxicant, salicylic acid, that leaches from the oak crowns [26].

19.2.2.4 Vines

Vine problems can be severe, especially along drainages and on fertile sites. Vines can girdle individual stems and engulf groups of trees, pulling them to the ground. Kudzu (Pueraria lobata Willd.), honeysuckle (Lonicera japonica Thunb.), momingglories (Ipomoea spp.), trumpetcreeper (Campsis radican L.), and greenbriars (Smilax spp.) are common problem vines in southern pine stands.

Site preparation often creates open conditions in which vine species proliferate [98]. Honeysuckle may be troublesome following chemical site preparation because it is tolerant to commonly used herbicides [23]. Herbicide treatments after, as well as before, planting may also promote vines [47, 83]. Kudzu can become a severe competitor in established pine stands, particularly along stand edges and roads. Because it is difficult to control kudzu in young pine stands, planting should be delayed until the vine has been successfully eradicated.

19.2.2.5 Relative impact of woody and herbaceous weeds

The relative impact of woody and herbaceous plants on pine growth changes over the rotation. Miller et al. [83] reported results from 13 locations throughout the southeastern United States in which a common study design was employed to examine the impact of four competition levels on loblolly pine growth (Fig. 19.1). Selective herbicides were broadcast and nonselective herbicides directed to target vegetation during the first and second growing seasons to control (1) all interfering vegetation, (2) herbaceous plants (leaving the woody plants), and (3) woody plants (leaving the herbaceous plants). An untreated check was also included. After two growing seasons, pine growth was generally greatest where all interfering vegetation was controlled. In these juvenile stands, the herbaceous plants had a more negative effect on pine growth than did the woody plants; pine growth in the untreated check and where woody vegetation alone was treated did not differ at most locations.

Tiarks and Haywood [120] observed similar growth responses in a newly planted loblolly pine stand in Louisiana. After five growing seasons, the gain in pine volume was greatest with herbaceous plant control. Because of intensive site preparation, woody plant competition was retarded until the third growing season and did not affect pine growth until the fifth. Cain and Mann [14] found that woody plants began to affect pine growth after the fourth year on a site with higher initial hardwood density. Clason [21] reported a significant pine volume increase in a 7-year-old, thinned, natural loblolly pine stand when woody plants were controlled; herbaceous plant control had no effect on pine growth at that age.

Generally, herbaceous plants affect pine growth to a greater extent than do woody plants during establishment and early stand development (from planting to the fifth or sixth growing season), whereas interference of hardwoods is more significant in older stands, particularly where site preparation has been intensive.

19.2.3 Weed Community Development

The species composition of the previous stand, site preparation technique, effectiveness of prescribed fire, and a host of environmental factors determine weed community development. The timing of site disturbances has a marked effect as well. Knowledge of which weed community will develop on a particular site is an asset to prescribing the appropriate management alternative. Because the southern pine region comprises five physiographic regions and a tremendous diversity of sites [35], description of the many possible weed communities is beyond the scope of this chapter. However, foresters should strive to become familiar with weed community development on the sites they manage.

19.3 Benefits from Weed Control

Potential benefits from weed control treatments include increased survival, increased growth, fire protection, and increased economic value.

19.3.1 Increased Survival

Weed control treatments after planting may increase survival of pine seedling transplants, improving stand uniformity. Creighton et al. [25] summarized results from 16 studies in loblolly, longleaf *(Pinus palustris* Mill.), and slash pine plantations where herbicides were applied to control interfering vegetation during the first or second growing season after planting. Pine survival was significantly greater when weeds were controlled at five of the 14 locations where survival or density data were available. Application method (1.5-m band centered over planted rows, broadcast over the entire treatment area, or applied around individual seedlings in a tree-centered approach) did not affect survival, and a second year of weed control benefited survival at only one location. Metcalfe [75] reported increased pine survival (16% over that of untreated checks) at the end of the first growing season at 14 of 36 study locations following applications of herbicides commonly used to control herbaceous weeds. All locations examined in both of these studies were intensively site prepared, and herbaceous plants were the predominant weeds.

Following intensive site preparation, more pine seedlings survived when herbaceous rather than woody plants were controlled [120]. However, hardwoods can significantly affect pine survival when not adequately suppressed by site preparation, particularly if pines are overtopped. On highly productive land, herbaceous weed-control treatments have given mixed results with respect to pine survival. On a flood-prone bottomland site in the Coastal Plain of South Carolina, herbicide treatments did not increase pine survival, even though they nearly eradicated the weeds [77]. In another study located on a stream terrace in north Georgia, herbicide treatments increased first-year survival 15% [52]. Weed control after planting has significantly enhanced pine survival when the combined effects of low soil-moisture holding capacity, limited rainfall, and high levels of competing vegetation have inhibited stand establishment.

19.3.2 Increased Growth

Stewart el al. [116] summarize numerous studies regarding the impacts of interfering vegetation on forest growth and yield. The magnitude of pine growth response to weed control depends on the nature of interfering vegetation, stand age at treatment, site productivity, and treatment effectiveness.

19.3.2.1 Herbaceous plant and vine control

Grazing, mowing, herbicides, and fire have been employed to control herbaceous weeds in southern pine stands (section 19.4 and 19.5). Because of the recent development of selective herbicides, herbaceous weed control is more prevalent in young plantations. Herbicides have generally provided more complete and lasting weed control than other methods. Herbicide applications for herbaceous plant control are most common on intensively prepared sites, and are usually made at the onset of the first growing season. Such treatments have significantly improved pine growth in loblolly [25, 43, 45, 53, 95, 135], longleaf [25, 96, 106], and slash [3, 25, 119] pine plantations.

The magnitude of pine growth response to herbaceous plant control varies depending largely on inherent site productivity and treatment effectiveness. Diameter growth is usually more responsive than height growth [25, 135]. Cultivation in newly established pine stands has resulted in 5-year height growth 55 cm greater than that in uncultivated checks [114]. Hand hoeing after planting increased second-year total height and groundline diameter 21 and 44%, respectively, while total pine volume increased 63% after 5 years [120]. Even greater gains have been observed for herbicide treatments. Broadcast herbicide applications during the first 2 years after planting doubled both pine height and diameter at age 4 over those of untreated checks [53]. A single application of sulfometuron methyl gave 80% greater pine groundline diameter than that of untreated checks at age 2 [77]. Two growing seasons of complete weed control increased total pine biomass 877%, while a single herbicide application produced a 205% gain [136]. These and numerous other studies have led to an increased awareness of the effects of herbaceous plants on pine seedling performance, and the potential for dramatically increasing early stand growth.

Little data are available concerning the long-term impact of herbaceous plant control on pine growth and stand

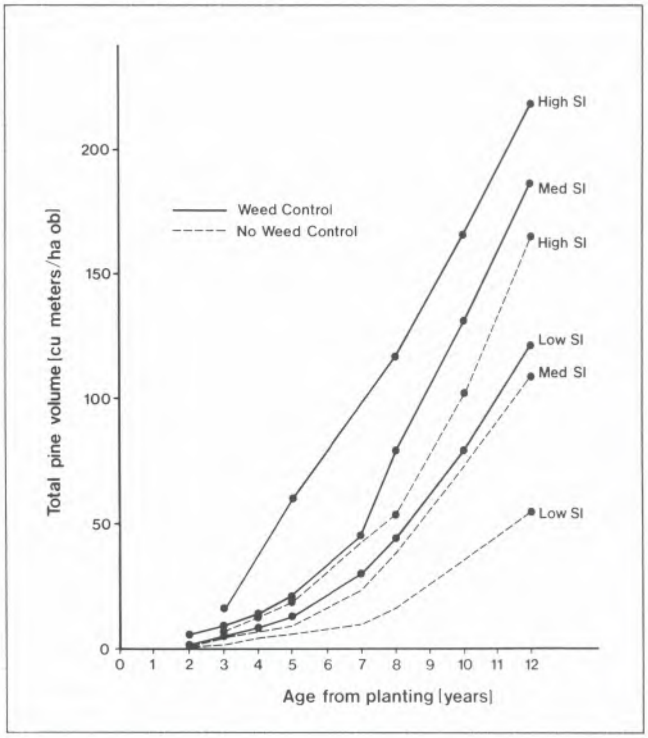

Figure 19.2. Total pine volumes (ob, outside bark) during 12 years of loblolly pine stand development at sites with low, medium, and high site indexes (SIs) for plots weeded during the first 3 years after planting and an unweeded check (adapted from [37]).

development. Glover et al. [37] summarize results from 12-year-old studies in which herbaceous weeds were controlled in loblolly pine stands with a combination of hand hoeing and herbicides during the first three growing seasons at locations with low, medium, and high site index (Fig. 19.2). At each location, pines in weeded plots had significantly greater diameter at breast height (dbh; 1.37 m above groundline) (1.5 to 6.1 cm) and total height (1.2 to 1.8 m) than untreated checks. At age 12, increases in total standing volume due to weeding ranged from 20 to 116%, with increases in standing merchantable volume from 33 to 131%. Absolute and percentage differences in height, diameter, and merchantable volume between weeded and unweeded plots were greater for the locations with low and medium site indexes than for the location with a high site index. Apparently, competition for site resources was less limiting to pine growth at the most productive location.

19.3.2.2 Tree and shrub control

As the amount of hardwood in a stand increases, pine volumes are reduced. Because pines bring higher stumpage prices and generally grow faster, removing interfering hardwoods improves stand value. Glover and Dickens [38] examined pine volume and hardwood basal area at 28 study locations where chemical hardwood control was compared to other control methods or to no control. Pine volume and the percentage of total stand basal area in hardwoods were

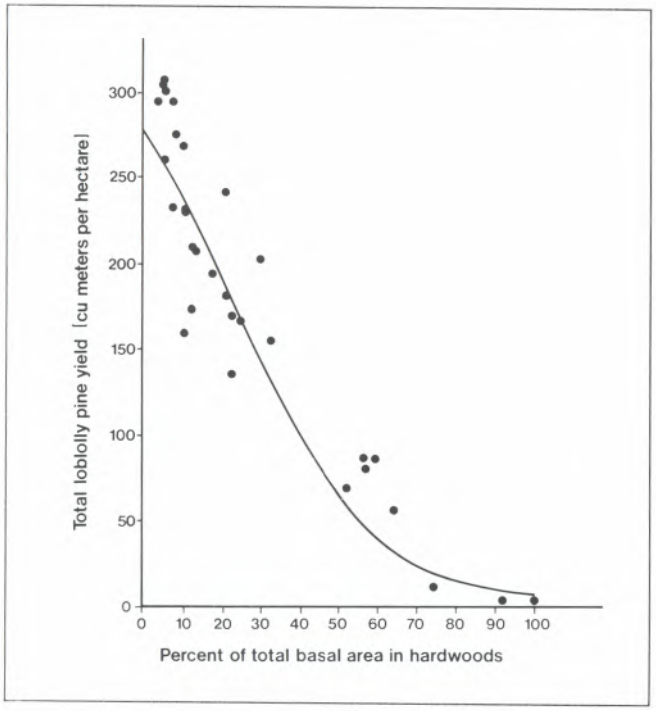

Figure 19.3. Relationship of pine volume to the percentage of total stand basal area in hardwoods in a 24-year-old loblolly pine stand where a variety of mechanical and chemical site-preparation treatments produced a wide range in hardwood stocking (adapted from [38]).

strongly and consistently related; Figure 19.3 shows this relationship for the Fayette study location, where hardwood basal area ranged from near 0 to 100%. Loblolly pine yield at 30% hardwood basal area was approximately half that at 4% hardwood basal area. At this and other study locations examined, pine yields were dramatically affected even by relatively low levels of hardwood basal area.

Pine growth has significantly improved following woody plant control in stands of loblolly [21, 22, 58, 68], longleaf [8, 76], slash [107], shortleaf (*Pinus echinata* Mill.) [31, 40], and white (*Pinus strobus* L.) [48, 101] pine. The magnitude of pine growth response to hardwood control depends on several factors, including stand age at treatment, species composition and level of interfering vegetation, treatment effectiveness, and site index. Generally, hardwood control in young stands results in the greatest gain in pine volume, particularly when herbaceous weeds are also controlled [2]. The relative impact of different hardwood species is not well understood, but the density of interfering hardwoods before and after treatment has a marked effect on pine growth [137]. The greatest absolute response to hardwood control occurs on productive sites, but often the largest gains relative to untreated checks occur on land with low and medium site indexes.

19.3.3 Fire Protection

Wildfires are very destructive in young pine stands because thicker, insulating bark does not develop until the sixth or seventh growing season. Flick et al. [34] reported results from a study in which weeds were removed from around the base of 2- and 3-year-old pines by hoeing, and the study area was burned with a headfire. No pines died where weeds were removed from within a 1-m radius around individual trees, whereas 94% of pines died in unweeded checks. Economic analyses indicated that when the probability of fire is 10%, costs of annual herbaceous weed control ranging from $44 to 84/ha (depending on site index) for 3 years could be justified by the benefits of fire protection alone.

Disking effectively reduces ground cover and creates fire breaks. Herbicide treatments applied before weed cover has developed may provide fire protection, but those applied after may actually increase fuel levels and therefore the risk of fire until deadened vegetation decays. Persistent soil-active herbicides can be used to establish chemical fire breaks or to maintain mechanically prepared fire breaks, but this practice is not common.

19.3.4 Increased Economic Value

Vegetation management practices may enhance the economic value of a stand through shifts in stem sizes and product classes, and shorter rotation lengths.

19.3.4.1 Shifts in stem sizes

The economic value of a stand can be enhanced by increasing the average diameter. Larger trees are more valuable for several reasons: they contain more and higher quality wood, and they are also more efficient to harvest (lower harvesting cost per unit of wood). To illustrate the economic impact of hardwood control, an analysis was run with a predictive model prepared by Burkhart and Sprinz [11]; an initial stand density of 1,793 pines/ha, a site index$_{25}$ of 17 m (55 ft), and a 30-year rotation length were assumed. When hardwood basal area was 40% of the total basal area of the stand, average pine dbh was 16 cm. Reducing hardwood basal area to 10% of total yielded an average pine dbh of 20 cm — a gain of 4 cm. The number of pine stems/ha at age 30 increased from 612 at 40% hardwood basal area to 857 at 10% hardwood basal area. Merchantable volumes increased from 94 to 248 m^3/ha. Whereas the number of pine stems increased by 40%, merchantable volume increased by 165%.

19.3.4.2 Shifts in product classes

Increase in timber size, quality, and quantity increases economic value in another way, by shifting product classes. Gains are greatest in the number of stems in the sawlog and veneer classes. In the analysis discussed above, as the proportion of hardwood basal area decreased from 40 to 10%, total loblolly pine volume increased from approximately 161 to 430 m^3/ha (Fig. 19.4). Pulpwood volumes changed little, with almost all of the volume gain in the higher value sawlog and veneer classes. The dollar increase was even greater than the volume gain because of the differential prices for these products.

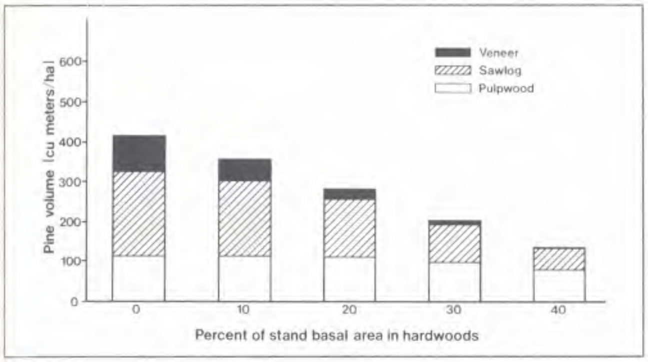

Figure 19.4. Veneer, sawlog, and pulpwood yields for various hardwood stocking levels in a 30-year-old loblolly pine stand from an analysis using a predictive model developed by Burkhart and Sprinz [11].

19.3.4.3 Shorter rotation lengths

Vegetation management accelerates pine stand development, producing more volume in less time. This gives the landowner the option of growing more wood over the original rotation length, or growing the same amount of wood over a shorter rotation. A shorter rotation allows landowners to recover their initial investments earlier, markedly increasing the rate on return, or, because trees reach merchantable size sooner, to retain inventory and defer selling until timber prices are high.

19.4 Nonchemical Vegetation Management

Cultivation, mowing, grazing, and prescribed fire have been used to improve seedling survival and growth in southern pine stands for many years. Although nonchemical approaches are generally not as long-lasting as chemical treatments, they may be cost effective.

19.4.1 Cultivation

Cultivation may be used to control interfering herbaceous and woody plants on areas previously used for agricultural crops or where rocky soils, large stems, or stumps do not impede tillage. This practice is not recommended where slopes are steep or soils erodible. Cultivation for 1 or more years after planting has improved pine survival, accelerated growth, and protected trees from wildfire [46, 131]

Young plantations are cultivated two or more times during the growing season, depending on weed growth. Disks and harrows are most commonly used. Plows are sometimes used, but tend to work the soil to an excessive depth. Seedlings should be planted in rows wide enough to accommodate tillage equipment. Soils are usually tilled between planted rows (one-way cultivation). but may also be tilled between pines in a row (two-way cultivation) where planting spacings are wide and regular. One-way cultivation cannot control weeds within the row. When a newly planted stand is first cultivated, the soil is worked 8 to 12 cm deep and to within 10 cm of seedlings. Subsequently, soil is tilled 5 to 8 cm deep and no closer to pines than their crowns extend. Stands usually are not cultivated after the second growing season because pine roots may be damaged.

19.4.2 Mowing

Tractor-mounted mowers, gas-operated brush cutters, or hand tools may be used to reduce interfering vegetation in young pine stands. Tractor-mounted mowers, or "bushhogs," are commonly employed where pines have been planted in open areas such as pasture or cropped land. Although stands must be mowed several times during a growing season, pine seedling survival and growth can be significantly increased [131]. Mowing often shifts weed species composition to favor grasses and sedges which tolerate repeated mowings better than broadleaf species, thus improving forage for livestock. Although weed control with mowing is only partial, the remaining ground cover reduces erosion hazard.

The recent development of gas-powered brush cutters has enabled herbaceous and woody plants to be mowed in stands inaccessible to tractor-mounted mowers. Most southern hardwood species resprout prolifically after mowing; however, herbicides may be applied to cut stumps to obtain cost-effective control [118]. Hand tools such as machetes and brush axes are sometimes used for weeding, although this approach is very labor intensive, and there is high risk of worker injury.

19.4.3 Grazing

Integrated timber and livestock management provides product diversification and may bring greater revenues [69, 103]. Stands of all ages are grazed by livestock. Silvicultural concerns with grazing include soil compaction and damage from browsing and trampling in young stands. However, Doescher et al. [27] suggest that livestock can be used to promote stand establishment as long as "numbers, distribution, and timing of use are carefully controlled."

Palatable forage must be available to minimize the allure of crop trees as browse. Intensive site preparation improves native forage development [62]. Pensacola bahiagrass *(Paspalum notatum)* and cool-season exotic grasses may be seeded following site preparation to improve forage quality and availability throughout the year [61, 102]. Because canopy density has a marked effect on forage yields, crop-tree spacings should be wide [103]. Fertilizer may be applied to improve tree growth and forage yields [60, 61], but fertilization may not be economical for meeting livestock nutritional needs [30].

The numbers and density of grazing livestock must be controlled to avoid excessive injury to crop trees. Grazing during the late winter and early spring after planting should be avoided since palatable forage may be in short supply [103]. The location of mineral blocks and supplemental feed stations can help control livestock distribution. Prescribed winter rotational burning may be used to better distribute livestock and regulate grazing intensity [104]. Heavy grazing (60% utilization of available forage) may increase mortality of pine seedlings, but damage to crop trees can be reduced or eliminated through proper management [103].

19.4.4 Prescribed Fire

Prescribed fire is used in southern pine plantation management to reduce wildfire hazards [71], improve visibility, access, and aesthetics [91], control diseases and. insects [63], improve forage and grazing [13], reduce levels of competing vegetation [65], improve or maintain habitat for selected wildlife species [42, 70], and on occasion precommercially thin young, overstocked pine stands [49, 97] (see also chapter 12, this volume).

The principle use of prescribed fire is to reduce wildfire hazard, and most of the lands thus burned are industrial, state, and federal [124]. Most states have burning assistance programs for nonindustrial private landowners, and many have voluntary or mandatory burning and/or smoke management guidelines [124]. The main advantage in using prescribed burning for the objectives listed is its low cost. Disadvantages include adverse public opinion, liability, and need for smoke management [90, 112, 125]. Concerns

Table 19.1. Herbicides registered for forestry use (1989).

Registered trade name[1]	Manufacturer	Common name of active ingredient	Herbicide family
AAtrex 80W	Ciba Giegy	Atrazine	Triazine
AAtrex 4L	Ciba Giegy	Atrazine	Triazine
AAtrex Nine-0	Ciba Giegy	Atrazine	Triazine
Accord	Monsanto	Glyphosate	Unclassified
Acme Super Brush Killer	PBI Gordon	2,4-DP	Phenoxy
		+ 2,4-D	Phenoxy
		+ dicamba	Benzoic acid
Amizine	Rhone Poulenc	Amitrole	Triazole
		+ simazine	Triazine
Arsenal	Amer. Cyanamid	Imazapyr	Imidazolinone
Banvel 720	Sandoz	2,4-D	Phenoxy
		+ dicamba	Benzoic acid
Banvel CST	Sandoz	Dicamba	Benzoic acid
Banvel Herbicide	Sandoz	Dicamba	Benzoic acid
Chopper RTU	Amer. Cyanamid	Imazapyr	Imidazolinone
DuPont Atrazine	DuPont	Atrazine	Triazine
Garlon 4	Dow	Triclopyr	Pyridine
Garlon 3A	Dow	Triclopyr	Pyridine
Goal	Rohm & Haas	Oxyfluorfen	Diphenyl ether
Fusilade 2000	ICI	Fluazifop-butyl	(grass herbicide)
Norosac 4G	PBI Gordon	Dichlobenil	Benzonitrile
Oust	DuPont	Sulfometuron methyl	Sulfonyl urea
Poast	BASF	Sethoxydim	(grass herbicide)
Pronone 5G	Pro-Serve	Hexazinone	Triazine
Pronone 10G	Pro-Serve	Hexazinone	Triazine
Riverside 912	Riverside Chem.	MSMA	Organ. arsenical
Rodeo	Monsanto	Glyphosate	Unclassified
Roundup	Monsanto	Glyphosate	Unclassified
Tordon K	Dow	Picloram	Pyridine
Tordon 101M	Dow	2,4-D	Phenoxy
		+ picloram	Pyridine
Tordon 101R	Dow	2,4-D	Phenoxy
		+ picloram	Pyridine
Tordon RTU	Dow	2,4-D	Phenoxy
		+ picloram	Pyridine
Trans-Vert	Rhone Poulenc	MSMA	Organ. arsenical
Velpar L	DuPont	Hexazinone	Triazine
Velpar ULW	DuPont	Hexazinone	Triazine
Vertac Weed Rhap A-4D	Vertac	2,4-D	Phenoxy
Weedar 64	Rhone Poulenc	2,4-D	Phenoxy
Weedone CB	Rhone Poulenc	2,4-D	Phenoxy
Weedone 170	Rhone Poulenc	2,4-D	Phenoxy
		+2,4-DP	Phenoxy
Weedone 2,4-DP	Rhone Poulenc	2,4-DP	Phenoxy

[1] These products are being neither recommended nor endorsed.

about site degradation, soil erosion, and impacts on water quality have largely been alleviated by numerous long-term studies [72, 73, 126].

The frequency and timing of prescribed fires dictate the degree of control of understory vegetation and the remaining species composition. Annual summer burns are most effective for eradicating hardwood brush, but favor the growth of forbs and grasses and may be most appropriate when the objective is to reduce competition or improve visibility, aesthetics, or recreation potential. Likewise, periodic summer or winter burns may encourage hardwood sprouting, thereby producing more succulent browse for deer [125, 126].

19.5 Chemical Vegetation Management

The number of herbicides available for forestry use has increased in recent years (Table 19.1). The Environmental Protection Agency (EPA) is responsible for registering all pesticides (herbicides, insecticides, fungicides, rodenticides) used within the United States. The registration process involves a lengthy, ongoing examination of risks and benefits associated with the use of individual products. The EPA is also charged with enforcing the primary laws concerning herbicide sale, distribution, and use as set forth by the Federal Insecticide, Fungicide, and Rodenticide Act of 1947 (FIFRA), the Federal Environmental Pesticide Control Act of 1972, and the Federal Pesticide Act of 1978 (amending FIFRA).

Herbicides are classified by EPA (and state agencies) as general or restricted-use pesticides. Restricted-use pesticides, such as Tordon M®, are for purchase and use only by certified, licensed applicators. Application of pesticides from aircraft is regulated by the Federal Aviation Administration. State agencies and county governments may also impose additional restrictions concerning pesticide sale, distribution, and use. Before using any herbicide, individuals should check with local authorities concerning these restrictions. A list of appropriate agencies is given in Cantrell [18].

19.5.1 Herbicide Characteristics

Knowing the physical, chemical, and biological properties of herbicides enables the choice of appropriate products and application methods to ensure safe, effective results. Of greatest concern are volatility, solubility, persistence, mechanism of plant absorption, translocation, mode of action, species susceptibility, and toxicity. In addition to product labeling, several references describing herbicide characteristics and uses are available [5, 18, 41].

19.5.1.1 Formulations

Herbicides are prepared in solid and liquid formulations and may contain one or more active ingredients, adjuvants (additives), and inert ingredients. Commonly used solid formulations include wettable powders, soluble powders, dry flowables, granules, and pellets. Wettable powders are suspended in water, through constant agitation, and applied as a spray. Soluble powders are highly soluble in water and form a homogeneous solution. Most dry flowables are readily dissolved in water, but may require agitation to keep them from precipitating in the spray tank. Herbicides may by incorporated with inert ingredients, such as clay, to form granules or pellets which are applied to the soil and which dissolve slowly when exposed to dew or rain, gradually releasing herbicide to the soil. Clay granules, commonly used in forestry, dissolve very slowly, but the herbicide leaches out of the carrier readily.

Liquid formulations may be used undiluted or may be mixed with water or oil carriers to prepare a spray solution or emulsion. Many common forestry herbicides are available in amine or ester liquid formulations. Amines are water soluble and translocate within plants more readily than esters. Esters are oil soluble and are more readily absorbed through the leaf cuticle than amines. Esters are generally more volatile than amines.

The amount of herbicide in a product is expressed as the weight of active ingredient or acid equivalent per volume or mass of product. The amount of active ingredient or acid equivalent may also be given as a percentage of the volume or mass of the product. The active ingredient (ai) is the chemical in a herbicide formulation primarily responsible for phytotoxicity. Acid equivalent (ae) refers to the theoretical yield of parent acid from the active ingredient content of a formulation.

19.5.1.2 Adjuvants

Adjuvants are substances included in product formulations or added to spray preparations to improve herbicidal activity or application characteristics. Most herbicides contain surfactants, emulsifiers, buffers, and other adjuvants in the product formulation. Herbicide performance may be improved with adjuvants, but crop tolerance may also be affected. Some surfactants increase herbicide absorption by pines, decreasing selectivity. Drift-control agents included in glyphosate spray solutions, for example, may excessively damage pines. Before adding adjuvants to a spray preparation, check the product label of the herbicide and adjuvant to ensure compatibility.

19.5.1.3 Absorption by plants

Herbicides may enter a plant through the foliage, stems, or roots. "Foliar activity" describes absorption through the foliage, whereas "soil activity" describes root absorption from the soil. Some herbicides are applied to the stem and are absorbed through the bark and epidermal tissues (see 19.5.6.2). Herbicides may also be injected directly into the stem with specialized equipment, or applied to frills, which are wounds made to expose the cambium and vascular tissues (see 19.5.6.1).

19.5.1.4 Dosage rates and calibration

Herbicide dosages are described in three general ways

Table 19.2. Toxicities of silvicultural herbicides.

Material	Approximate LD_{50}[1], mg/kg	Oral toxicity rating[2]	Signal word
Herbicide, by trade name			
AAtrex 80W	5,100	IV	Caution
AAtrex 4L	1,886	III	Caution
AAtrex Nine-0	1,600	III	Caution
Accord	> 5,000[3]	IV	Caution
Acme Brush Killer	2,010	III	Caution
Amizine	> 4,000	III	Caution
Arsenal	> 5,000	IV	Caution
Banvel CST	> 5,000	IV	Caution
Banvel 720	1,707	III	Caution
Banvel Herbicide	2,629	III	Caution
Fusilade 2000	3,328[3]	III	Danger[5, 6]
Garlon 4	2,460	III	Caution
Garlon 3A	2,830	III	Danger[5]
Goal	3,500	III	Warning[5]
Norosac 4G	> 3,160	III	Caution
Oust	> 5,000	IV	Caution
Poast	4,900	III	Warning[5]
Pronone 5G	> 5,000	IV	Caution
Pronone 10G	> 5,000	IV	Caution
Riverside 912	1,400[4]	III	Caution
Rodeo	> 5,000	IV	Caution
Roundup	5,400	IV	Warning[5]
Tordon K	5,000-6,000	IV	Caution
Tordon 101M	3,000	III	Caution
Tordon 101R	8,000	IV	Warning[5]
Tordon RTU	8,000	IV	Warning[5]
Trans-Vert	1,400	III	Caution
Velpar L	7,080	IV	Danger[5]
Velpar ULW	1,690[3]	III	Danger[5]
Vertac Weed Rh A-4D	> 1,000	III	Caution
Weedar 64	1,615	III	Caution
Weedone CB	2,140	III	Warning[7]
Weedone 170	2,000	III	Caution
Weedone 2,4-DP	2,200	III	Caution
Other, for comparison			
Table salt	3,000	III	
Baking soda	3,500	III	
Aspirin	1,240	III	
Caffeine	200	II	
Gasoline	150	II	

1 LD_{50} value: lethal dose to 50% of test population in mg/kg body weight. Unless otherwise indicated, values are for the formulated product.
2 See Table 19.3 for an explanation of this rating system.
3 Value is for the active ingredient.
4 Estimated.
5 Severe eye irritant.
6 Corrosive to skin (burns).
7 Assigned signal word because of low dermal LD_{50}.

The most common method is to specify the amount of ai or ae to be applied per treated area; for example, "apply 4 kg ai/ha hexazinone as a broadcast spray." A second method is to describe the dilution of herbicide in the spray solution; for example, "apply a 2% solution of glyphosate in water to wet the crowns of hardwood sprouts." The third method is to specify the weight or volume of herbicide product to be applied per unit of land area.

Regardless of how dosage is specified, application equipment must be calibrated [18, 128], and calibration should be checked periodically during application to ensure uniform, efficient herbicide use. The basic principles of calibration are the same regardless of equipment. In the case of herbicide sprays, the nozzle output, effective swath width (width of area receiving full rate), and travel speed are used to calculate the liters per hectare of total spray solution. The herbicide is then diluted with sufficient carrier to give the desired rate. In the case of solid formulations, the concentration of herbicide in the carrier depends on the product formulation. The desired rate is obtained by manipulating herbicide output, swath width, and travel speed. Calibration of solid formulations is more difficult and less precise than that of sprays.

19.5.1.5 Worker safety

The hazard associated with herbicide use depends on the toxicity of materials and exposure (Table 19.2). A highly toxic pesticide may be used without hazard if there is no exposure. Conversely, a slightly toxic pesticide may impose significant hazard if there is a high level of exposure.

Toxicity may be described as acute or chronic. Acute toxicity refers to potential injury or illness shortly after exposure to a relatively large dose. A common measure of acute toxicity is the lethal dose to 50% of a test population (LD_{50}), usually male rats. The LD_{50} values, determined for oral and dermal exposure, are expressed in milligrams of toxicant per kilogram of body weight. The higher the LD_{50} value, the lower the acute toxicity. Acute toxicities are also described by "toxicity category" and a "signal word" found on the pesticide label (Table 19.3). Chronic toxicity, determined by long-term feeding studies with animals, refers to potential injury or illness after repeated exposure to relatively small doses. In addition to determining acute and chronic toxicity, pesticides are tested for carcinogenic, mutagenic, and teratogenic effects before labeling.

Silvicultural herbicides have low toxicities; nevertheless care should be taken to minimize exposure. Applicators should be particularly careful when working with undiluted herbicides, which are much more toxic than diluted spray solutions. Appropriate precautions such as protective clothing and equipment, which greatly reduce exposure, are determined by product toxicities and application methods. Several references describe safety precautions in detail [93, 113, 129].

A few general precautions are mentioned here. When mixing herbicides, workers should wear rubber gloves, eye protection, and protective clothing. Clothing should be washed daily, but never mixed with other laundry. Workers should breathe through respirators when loading dusty solid herbicide formulations. Soap and water should be available for washing at the mixing site. Some of the commonly used forestry herbicides can cause eye damage. Therefore, in

Table 19.3. Toxicity categories for pesticides.

Oral toxicity category	Signal word	LD50, mg/kg			Effects		Estimated oral dose (ml) to kill the average person[1]
		Oral	Dermal	Inhalation	Eyes	Skin	
I	Danger	< 50	< 200	< 0.2	Corrosive; corneal opacity not reversible within 7 days	Corrosive	< 5
II	Warning	50-500	200-2,000	0.2-2.0	Corneal opacity reversible within 7 days; irritation persisting for 7 days	Severe irritation at 72 hours	5-30
III	Caution	500-5,000	2,000-20,000	2.0-20	No corneal opacity; irritation reversible within 7 days	Moderate irritation at 72 hours	30-475
IV	Caution	> 5,000	> 20,000	> 20	No irritation	Mild or slight irritation at 72 hours	> 475

[1] For the labeled product.

addition to protective eyewear, workers should carry water to rinse herbicide from their eyes should an accident occur. Applicators should avoid walking through treated areas although, in most cases, it is impossible to avoid some exposure; check labels for re-entry restrictions. Application equipment should be maintained in good condition and built to withstand woods use. Careful planning, cautious application, and proper equipment are elements of safe, effective herbicide use.

19.5.1.6 Environmental precautions

Herbicides are registered for very specific uses, and then only after extensive research has indicated that these uses will not cause unreasonable adverse environmental impact. Problems generally arise when workers do not follow label directions, or apply herbicides under adverse environmental conditions.

Herbicide movement off site through air or water is of greatest concern. The potential for drift increases when herbicides are applied as fine sprays or when solid materials contain fine particles or dust. Risk is greatest with aerial applications. Herbicides should be aerially applied only during calm conditions, which are most likely during early morning and evening hours. Untreated buffers between the treated site and adjoining landholdings or sensitive areas reduce the potential for chemical trespass. When appropriate, drift-control agents may be added to thicken the spray solution or specialized application equipment used to reduce drift hazard.

Atmospheric conditions must be considered. Nighttime inversions, common during the spray season, may be present during morning and evening hours. Herbicide aerially applied above inversion layers may drift several kilometers from the target area. Inversion layers can be easily detected by observing the rise of smoke from a burning fire. If a layer is present, the smoke will rise up to it, then spread horizontally. Herbicides may also drift as vapors during treatment or for several days after application. This can be a problem with volatile chemicals, such as ester formulations of phenoxy herbicides, and is most severe when temperatures are high (> 30°C).

If proper precautions are not taken, herbicides also may move off site in water, in surface flow, particularly during storms, or by leaching through the soil profile to contaminate ground water. The water solubility of the herbicide, soil absorption, precipitation pattern, and herbicide degradation are important factors affecting the potential for adverse environmental impacts. An untreated buffer, or streamside management zone along active and intermittent streams, will greatly reduce the risk of stream contamination. With the exception of herbicides registered for aquatic use (Banvel 720®, Accord®, Rodeo®), herbicides should never be applied directly to water. Aquatic herbicides may be applied to water only to control aquatic weeds.

19.5.2 Application Equipment

A variety of application equipment is used to apply silvicultural herbicides. Treatment objectives, site conditions, herbicide characteristics, and numerous management constraints are considered when selecting the appropriate equipment. Aircraft, ground machinery, backpack sprayers, and tree injectors are the most commonly used types of application equipment.

19.5.2.1 Aircraft

Aerial application is generally most effective when undesirable vegetation is too tall for good coverage with ground equipment, when the density and size of vegetation impede the movement of ground crews or equipment, where steep slopes or plastic soils make it difficult to operate ground equipment, or where large areas are to be treated. Both helicopters and fixed-wing aircraft may be used for aerial applications of either solid or liquid herbicide formulations. Helicopters are more commonly employed and are recommended for aerial forestry applications for several reasons. Many forestry sites are relatively remote. Helicopters can land on the treatment site to refuel and load herbicide, whereas fixed-wing aircraft

Figure 19.5. Modified fertilizer spreaders are commonly used to apply solid formulations of forestry herbicides.

may have to travel several kilometers from the site to land. Fixed-wing aircraft generally have the advantage of greater payload capacity, but must fly much faster than helicopters. Greater airspeed increases shearing of spray drops, which increases drift hazard. Helicopters are more suitable for treating small or irregularly shaped areas, and can follow the contour of the land to maintain a constant spray height and herbicide rate.

Aerial application of solid formulations. — Solid herbicide formulations have been applied by air in forestry only recently, and efforts are under way to improve application equipment. Currently, aerial spreaders are modifications of equipment used in forest fertilization or direct seeding (Fig. 19.5). Fertilization equipment is designed to apply hundreds of kilograms of fertilizer per hectare, yet herbicide applications involve much smaller amounts. With equipment currently in use, it is difficult to obtain uniform distribution. This is a major concern, particularly for herbaceous weed control or pine release treatments, where selectivity is largely rate dependent.

Aerial spray equipment. — Spray solutions are applied with a variety of aerial delivery systems, most commonly the "conventional boom," the Microfoil® boom, and the recently developed Through-Valve® boom. The conventional boom typically is fitted with disc-core cone nozzles or Raindrop® nozzles. These systems give good coverage, but may be subject to drift problems. Applicators should consider adding a drift-control agent when working with a conventional boom. Indeed, with some herbicides, such as Garlon 4®, the use of drift-control adjuvant is required to comply with label directions when using a conventional boom. The effective swath width depends on spray height and boom length, but generally ranges from 15 to 30 m. The outer edges, or tails, of the swath tend to have reduced volume. Flight lines are spaced on the basis of the effective swath, and the tails overlap.

The Microfoil® boom (Fig. 19.6) was developed for rights-of-way applications, such as vegetation control along power lines, where a precise spray pattern is essential. Very low spray pressures are used and nozzles are oriented to minimize wind shear, reducing drift hazard by avoiding fine spray drops. Drift-control agents are generally not used with Microfoil® booms, and may clog the fine nozzles if too much is added or if the adjuvant is not thoroughly

Figure 19.6. The Microfoil® boom, commonly used for aerial herbicide applications, is designed to minimize fine spray droplets, which are prone to drift.

Figure 19.7. The Omni® spreader, used to apply solid herbicide formulations, provides uniform herbicide distribution across a 28-m effective swath.

mixed with the spray solution. The effective swath width of Microfoil® booms is generally between 12 and 20 m, depending on spray height and boom length. The volume distribution is uniform across the swath, and the edge of the swath is distinct. Accurate flight-line flagging is essential for uniform applications with the Microfoil® boom to avoid skips (areas unintentionally not treated) and double rates (areas treated twice).

The Through-Valve® boom, like the Microfoil® boom, works at very low spray pressures to limit fine spray drops. The unique design minimizes wind shear and produces uniform droplet size to control drift; the boom is not as likely to clog with particulate matter as is the Microfoil® system, and the applicator can fly faster.

Preparation for aerial application. — A suitable heliport and flight-line stations should be established. If foliar sprays are to be used, roads to the heliport must be adequate to provide access for batch trucks carrying heavy loads. Hilltops or ridges are good sites for heliports. Trees should be removed from within a 60-m radius around the heliport, and one or more clear approaches at least 300 m long should be available.

Flight-line stations are positioned at each end of the treatment area so that workers can direct the path of the aircraft on each swath. Stations should be installed using a staff compass and chain, correcting for slope and offset angles, to ensure parallel flight lines spaced at the desired distance. This distance between flight lines is usually the same as the effective swath width, although sometimes stations are located at half the distance of the effective swath to provide 100% overlap with herbicide applied at half the application rate in each swath. Flight lines normally should be < 1 km long to ensure good visibility for the pilot. Flaggers use brightly colored helium balloons or flagged poles to indicate the middle of each swath, and move to the next station when a swath is completed. The pilot should be instructed to stop spraying 30 m before reaching flaggers to avoid exposure. After all flight lines have been sprayed, the perimeter area may be treated.

Many aerial applications are made without flight-line control, particularly where treatment areas are small or irregularly shaped or where the edge of the treatment area is clearly distinguishable. Although flight-line stations add to the cost of treatment, they help ensure application of the proper rate, reduce overlapping and skips, and prevent accidental application outside the treatment area.

19.5.2.2 Ground machinery

Herbicide applications with ground machinery were once common in southern forests, when mistblowers were used to apply 2,4,5-T. Although aerial applications have been prevalent in recent years, several new ground-based systems have been developed to apply silvicultural herbicides [82, 111, 122]. Ground machinery is preferred near sensitive sites and may be used to treat small areas where aerial application is not economical. Equipment designed to apply solid formulations or sprays may be mounted on a variety of prime movers: farm tractors, crawler tractors. skidders, and three- or four-wheeled off-road vehicles.

Spreaders. — Solid herbicide formulations can be applied with inexpensive fertilizer spreaders or seeders, which have an effective swath up to 15 m wide. These devices utilize a spinning disk to broadcast granules or small pellets, and rate is controlled by adjusting the flow of herbicide through a gate located between the hopper and spinning disk. Spreaders are usually driven by electric motors and can easily be mounted on a variety of prime movers. However, they tend to apply more herbicide to one side of the swath, and dense vegetation can greatly impede herbicide distribution. The capacity of most hoppers is limited, and abrasive materials may cause the disk to wear out quickly.

A much more sophisticated spreader, developed by Omni Spray, utilizes hydraulically driven blowers to broadcast granules or pellets (Fig. 19.7). Materials are blown upward through a spreader manifold with great force to produce a 28-m effective swath. Herbicide distribution is more uniform than with other spreaders, particularly when working in dense brush. The blowers and spreader manifold are mounted on a dampened pendulum that remains vertical on slopes up to 20%, thus ensuring even coverage on sloping land. The Omni® spreader utilizes radar to measure ground speed, and adjusts the flow of herbicide from the hopper to the blowers to automatically obtain the desired herbicide rate. One version of the Omni ® spreader with a 0.5-m^3 hopper, is designed for mounting on skidders or crawler tractors. A smaller model may be mounted on four-wheeled off-road vehicles or other small tractors.

Ground sprayers. — Various systems are used to apply spray suspensions or solutions in forestry. The basic

Figure 19.8. Tractor-mounted ground sprayer equipped with a cluster nozzle, which is raised or lowered to obtain adequate coverage of treated vegetation.

Figure 19.9. Ground sprayer equipped with a manifold nozzle system utilizing straight-stream nozzles to apply solutions of soil-active forestry herbicides.

elements of a spraying system are the tank, pump, regulator, strainer, and nozzle [82]. There are two general categories of forestry ground sprayers: (1) boom sprayers, which have nozzles arranged some distance apart on a horizontal boom, and (2) boomless sprayers, which utilize a single nozzle, cluster nozzle, nozzle manifold, or controlled droplet applicator to broadcast spray from a single point.

Boom sprayers are commonly used for herbaceous weed control where intensive site preparation has removed standing stems which would otherwise impede movement of the boom. Most booms have a "break away" feature which activates a spring-loaded hinge to prevent damage when obstructions are hit. The nozzles are arranged on the boom to provide uniform coverage. Appropriate nozzle spacing is determined by boom height and type of nozzle. Boom sprayers may be used for broadcast or banded applications.

Boomless sprayers are most commonly used for site preparation and pine release where obstructions may prevent the use of a boom sprayer. A single flooding fan nozzle mounted at a 4-m spray height may produce an effective swath more than 9 m wide, but spray volume distribution is not uniform. Flooding fan nozzles tend to give coarse droplets on the outer edges of the swath and fine droplets in the center. Cluster nozzles, often used for boomless sprayers, consist of two large off-center nozzles and up to four flat fan nozzles mounted in a housing. The cluster nozzle assembly is usually placed behind the primary mover, and can be raised or lowered to adjust for differences in the height of target vegetation (Fig. 19.8). The overlapping spray pattern produced by the nozzles in the cluster yields an effective swath up to 17 m wide. Cluster nozzles are used to broadcast foliar- or soil-active herbicides, although coverage with foliar-active herbicides is adequate only when target vegetation is < 6 m tall [82].

The spray volume distribution across the swath is reasonably uniform, although the flat fan nozzles produce fine spray droplets prone to drift.

Manifold sprayers are constructed by mounting numerous straight-stream or flat fan nozzles in a manifold (Fig. 19.9). Straight-stream nozzles are oriented to cover 1- to 2-m sections of the spray swath, which can be up to 20 m wide; these nozzles produce a stream, rather than a spray, and are primarily used for applying soil-active herbicides. The most recent development in boomless sprayer technology is the controlled droplet applicator, such as the Directa-Spray®, Orbitor®, and Radi-Arc®, which produce large droplets with low drift potential. Effective swaths up to 12 m wide may be obtained with excellent uniformity.

Mist!,lowers. — Mistblowers are constructed by positioning spray nozzles directly in front of high-speed fans which deliver a forced-air column containing very fine droplets. In the late 1960s and early 1970s, mistblowers were used extensively to apply 2,4,5-T to control undesirable hardwoods. Although coverage was effective even on very tall hardwoods, clouds of fine herbicide vapor presented a serious drift hazard. Mistblowers are now rarely used to apply forestry herbicides.

19.5.2.3 Backpack sprayers

Backpack or hand-carried sprayers are used to apply broadcast, banded, directed, and basal sprays. Most have tank capacities of 8 to 15 L and are pressurized with a lever-operated pump. Diaphragm pumps, generally more durable than piston pumps, are recommended when applying wettable powders. Comfort and durability are the most important considerations when choosing from the variety of sprayers available. Fisher and Deutsch [32] evaluated the features, components, and operation of 37 backpack sprayers.

Figure 19.10. The tubular injector makes an incision through the bark of undesirable hardwoods and applies a measured amount of herbicide into the wound.

19.5.2.4 Tree injectors

Three types of injection methods are currently in use: (1) "hack and squirt," (2) tubular injection, and (3) the Hypo-hatchet®. The hack-and-squirt approach involves making cup-shaped incisions through the bark with an ordinary hatchet or machete and applying herbicide to the exposed cambium meristematic tissue (just inside the bark, often green) and vascular tissues with a spray bottle. The equipment involved is inexpensive, but workers must take care to apply the appropriate amount of herbicide to each incision. Tubular injectors have a sharp bit on one end, a lever-operated piston pump to inject a measured amount of herbicide through the bit, and a self-contained reservoir (Fig. 19.10). Tubular injectors facilitate injection near the root collar, which may provide better control than when herbicide is injected higher on the stem [15, 24]. Although tubular injectors are durable and easily maintained, most models are heavy and difficult to carry through dense vegetation. The Hypo-hatchet® is used to make an incision in the stem and inject herbicide with one continuous motion. The force of striking a stem with this hatchet-shaped tool activates a piston pump that injects a measured amount of herbicide into the incision. Herbicide is carried in a separate reservoir attached to the worker's belt and supplied to the hatchet through plastic tubing. Hypo-hatchets® need daily maintenance, but are lightweight.

19.5.3 Herbicide Prescriptions

To maximize cost effectiveness and ensure environmental and personnel safety, herbicide users must carefully evaluate site conditions, environmental factors, and herbicide characteristics before prescribing treatments. The six major steps of the prescription process are: (1) identifying sites needing herbicide treatment, (2) setting priorities and selecting sites to receive treatment, (3) analyzing individual sites and identifying problems, (4) selecting the specific herbicide treatment, (5) evaluating treatment results, and (6) maintaining up-to-date vegetation control data [17].

Important factors to consider in identifying sites and setting priorities (steps 1 and 2) include competition severity, treatment costs, potential site productivity, tract size, and availability of labor and equipment. However, the single most critical step is individual site analysis (step 3). For this, as with many silvicultural prescriptions, there are no substitutes for experienced personnel. The analysis must always be made on site by qualified individuals [19].

Numerous constraints are identified during site analysis. Species composition, size, and density of interfering vegetation are always important considerations. For pine release or herbaceous weed control, the pine species, stocking, size, and vigor must be evaluated to ensure herbicide selectivity. Soil factors, especially texture, organic matter content, acidity, and internal drainage, have a marked effect on herbicide performance as well as weed community development. Slope and soil erodibility should also be considered. The proximity to sensitive areas such as dwellings, crops, streams, ponds, and wells should be noted. Hazards to the applicator such as power lines, gullies, open wells, and cliffs should be identified. Maps, preferably topographic maps, indicating tract location, property boundaries, access roads, sensitive areas, and all features should accompany the site analysis [79, 81].

Selecting the appropriate herbicide treatment involves many of the constraints identified for the site analysis, as well as the characteristics of alternative herbicides, available equipment, costs, environmental impact, and worker safety. Individuals with this responsibility should rely on current literature and records concerning herbicide performance on the sites they manage. Sites should be visited to assess treatment effectiveness at the end of the first growing season after treatment for herbaceous plant control, and 2 years after treatment for woody plant control, and data concerning treatment effectiveness overall and for individual species collected. Site analysis and spray-session records should be reviewed to aid in evaluating treatment effectiveness (step 5). Maintenance of up-to-date vegetation control data (step 6) is vital to the prescription process and any successful vegetation-management program.

Table 19.4. Herbicides registered for herbaceous plant control (1989).

Trade name[1]	Application timing[2]	Weeds controlled		
		Grasses	Broad-leaves	Woody plants
AAtrex 80W	Pre- and post-	X	X	
AAtrex 4L	Pre- and post-	X	X	
AAtrex Nine-0	Pre- and post-	X	X	
DuPont Atrazine	Pre- and post-	X	X	
Arsenal	Pre- and post-	X	X	X
Roundup	post-	X	X	X
Accord	post-	X	X	X
Goal[3]	Pre- and post-	X	X	
Fusilade 2000	post-	X		
Poast	post-	X		
Oust	Pre- and post-	X	X	
Pronone 5G	Pre- and post-	X	X	X
Velpar L	Pre- and post-	X	X	X

[1] Grouped by active ingredient or herbicide family.
[2] Controls weeds when applied Pre- or post-emergence of weeds.
[3] Goal is registered for this use only as a tank mix with Poast.

19.5.4 Herbaceous Plant Control

The use of herbicides to control herbaceous weeds in young pine plantations has become more common because of the development of selective herbicides and greater awareness of the potential benefits. The herbicides registered for this use (Table 19.4) may be sprayed over pine seedlings and will control herbaceous weeds without significant injury to pines when the appropriate rate is applied.

Herbicides may be broadcast, banded, or applied in a tree-centered spot. Creighton et al. [25] examined pine seedling growth and survival at 16 study locations throughout the southeastern United States to ascertain the effects of application method and treatment duration. Application method did not significantly affect pine growth or survival. Additional herbicide applied during the second growing season increased pine seedling growth where competition was most intense, but did not significantly increase survival. Because herbicide costs are considerably lower for band or spot than for broadcast application, the latter is seldom employed. However, broadcasting may be necessary if aerial equipment is used, if seedlings are not in rows or are obscured by weeds, or if weeds are expected to spread from untreated areas. Banded or spot treatments are also preferred because they cause less erosion hazard and are more favorable to wildlife habitat. The most commonly used herbicides and mixtures for herbaceous weed control are discussed in the next six sections [19.5.4.1 through 19.5.4.6).

19.5.4.1 Sulfometuron methyl

Sulfometuron methyl (Oust®) is currently the most widely used herbicide for herbaceous weed control. It is absorbed through both roots and foliage. Best results are obtained with applications during March and April [94]. Effective control of numerous grasses and broadleaf weeds is obtained at rates tolerated by pines. However, broomsedge, bermudagrass *[Cynodon dactylon* (L.) Pers.], and trumpetcreeper tolerate this herbicide and may proliferate following treatment. Application rates range from 100 to 420 g ai/ha (1.5 to 6 oz ai/ac), with most applications at 210 g ai/ha. On very sandy sites, 175 g ai/ha is usually adequate; for clayey or organic soils, higher rates are needed. Where soils are very clayey or organic, combinations of sulfometuron methyl and hexazinone or glyphosate are usually most cost effective.

19.5.4.2 Hexazinone

Hexazinone rates must be carefully prescribed on the basis of soil texture and organic matter content; otherwise, severe seedling damage and mortality will result [33]. On sandy sites, 280 g ai/ha (0.25 lb ai/ac) is effective; on organic soils, as much as 2,250 g ai/ha (2.0 lb ai/ac) or more may be needed. Hexazinone is available in solid (Pronone 5 G®) and liquid (Velpar LO) formulations; when using the solid, workers should be careful to apply herbicide uniformly. Both solid and liquid formulations are most effective when applied in March and April. The solid formulation is activated by rainfall, which is usually abundant during this period. The liquid formulation should be sprayed over seedlings in early spring because pine tolerance decreases as temperatures increase.

19.5.4.3 Glyphosate

Glyphosate (Accord® or Roundup®) may be applied at rates up to 670 g ai/ha (0.6 lb ai/ac). However, a minimum of 190 L/ha (20 gal./ac) total spray solution should be used to ensure pine tolerance, as the concentration of glyphosate in the spray solution has a significant effect on damage to pines. Because glyphosate is absorbed only through the foliage, it is typically used in late spring when most weeds have germinated.

Directed or shielded sprays of high rates of glyphosate can be used to control weeds tolerant to selective herbicide rates. A section of stove pipe can be placed over individual seedlings to shield them while a backpack sprayer is used to treat a circular area around each tree. More sophisticated shielded sprayers can be mounted on ground machinery to apply banded treatments. Directed sprays using a 1.5 to 2.0% solution of Roundup() in water give very good control of species such as bermudagrass, which are tolerant to most selective herbicides. However, extreme care must be taken to avoid getting any spray solution on pine seedlings or they may die.

19.5.4.4 Imazapyr

Imazapyr (Arsenal®) was recently labeled for herbaceous weed control in loblolly and slash pine plantings, and registration for other pine species is pending. Typical use rates are 210 to 350 g ae/ha (0.2 to 0.3 lb ae/ac), depending on weed species and soil type. Imazapyr controls a very broad spectrum of herbaceous weeds, including many of the vines and perennial grasses not controlled with other herbicides. If excess rates are applied, severe stunting may result, although in loblolly pine this response is only temporary. A nonionic surfactant may be added at 0.1% by volume. Optimum application timing is as an early post-emergent treatment.

19.5.4.5 Grass herbicides

Fluazifop-butyl (Fusilade 2000®) and sethoxydim (Poast C)) were recently registered for grass control in conifer plantings and may also be used in combination with other herbicides such as oxyfluorfen (Goal()) to control broadleaf weeds. Control is optimum when grasses are treated in early spring, before seed heads develop. Normal use rates range from 220 to 450 g ai/ha (0.2 to 0.4 lb ai/ac), depending on species composition; multiple or "split" applications are employed to control resistant species such as bermudagrass.

19.5.4.6 Common herbicide combinations

Sulfometuron methyl plus hexazinone. — The most common herbicide mixture for herbaceous weed control is 160 g ai/ha (2.25 oz ai/ac) sulfometuron methyl plus 280 to 560 g ai/ha (0.25 to 0.5 lb ai/ac) hexazinone. This combination, most effective when applied in March or April, gives broad-spectrum weed control with good persistence [1, 78]. For clayey soils or soils with > 10% organic matter, 560 g ai/ha hexazinone or more is used in the mixture; for loamy soils, 280 g ai/ha hexazinone is adequate. Hexazinone mixtures may injure pines on sandy sites.

Sulfometuron methyl plus glyphosate. — This combination is effective over a wide range of site conditions [29, 124] and is safer for pines than sulfometuron methyl plus hexazinone on sandy sites. Sulfometuron methyl plus glyphosate treatments are broadspectrum, but not as persistent as sulfometuron methyl plus hexazinone. Sulfometuron methyl plus glyphosate is most effective when applied in April and May. Because glyphosate is strictly foliar active, weeds should germinate before treatment. The most common mixture is 160 g ai/ha (2.25 oz ai/ac) sulfometuron methyl plus 560 g ai/ha (0.5 lb ai/ac) glyphosate. Total spray volume has a marked effect on pine tolerance, and a minimum of 190 L/ha should be used.

Sulfometuron methyl plus atrazine. — Sulfometuron methyl in combination with atrazine gives broad-spectrum weed control, but residual activity (persistence) is usually not as great as for sulfometuron methyl plus hexazinone. This treatment is most often recommended for old-field plantings, in particular where sicklepod *(Cassia obtusifolia* L.), morningglory, or Texas panicum *(Panicum texanum* Buckley) form most of the weed community. The mixture is usually applied during May or June to obtain adequate control of weeds such as morningglory, which germinate in late spring and summer. The most common combination is 160 g ai/ha (2.25 oz ai/ac) sulfometuron methyl plus 2,250 to 4,480 g ai/ha (2 to 4 lb ai/ac) atrazine. Atrazine rates are prescribed on the basis of soil texture, organic matter content, and pH. Rates should be low on sandy sites or where soil pH is > 6.0, but higher on clayey or organic soil.

Table 19.5. Herbicides registered for pine release (1989).

Trade name[1]	Application timing	Application method			
		Broad-cast	Directed spray	Basal stem	Soil
Accord	Late summer-	X	X		
Roundup	early fall	X	X		
Arsenal	Late summer-early fall	X	X		
Garlon 3A	Spring-early		X		
Garlon 4	summer[2]		X	X	
Pronone 5G	Early spring	X			X
Pronone 10G		X			X
Velpar L	Spring	X			X
Velpar ULW	Early spring	X			X
Weedone 2,4-DP[3]	Late spring-early summer	X	X		

[1] Grouped by active ingredient.
[2] Basal stem applications of Garlon 4 are effective year-round, but stems are usually treated in the dormant season.
[3] Weedone 2,4-DP is registered for release of loblolly pine under FIFRA Section 24-C in Alabama, Arkansas, Louisiana, Mississippi, North Carolina, Oklahoma, and Tennessee.

19.5.5 Pine Release

Various herbicides are registered for selective control of woody plants (hardwoods) to release pines, usually when 2 to 5 years old, in natural and planted stands (Table 19.5). For treatment to be most effective, hardwood sprouts should first be allowed to emerge; this enables greater absorption of foliar-active herbicides through larger crown volumes and of soil-active herbicides through transpiration from hardwood foliage. Pines are more tolerant to herbicide treatment as they grow older, but significant growth can be lost if release is delayed too long. Concurrent control of herbaceous plants with pine release treatments benefits pine growth substantially.

19.5.5.1 Broadcast applications

The selective herbicides 2,4-DP, glyphosate, hexazinone, and imazapyr may be broadcast by aerial or ground equipment to control undesirable hardwoods (and herbaceous plants) in pine stands.

2,4-DP. — Weedone 2,4-DP® is registered for pine release under FIFRA Section 24-C ("state special local need") in several southeastern states (Table 19.5). This herbicide is broadcast in late spring, usually at a rate of 2,250 g ae/ha

(2 lb ae/ac), applied in 90 to 140 L/ha (10 to 15 gal./ac) total spray solution. Some needle burn and dieback of terminal leaders may be observed, but pine seedlings usually do not die, except where spray swaths overlap or rates are excessive. 2,4-DP is most effective against upland hardwoods, in particular sumacs, locust *(Robinia* spp.), and white oak *(Quercus alba* L.). Bottomland hardwood species, especially red maple, ash *(Fraxinus* spp.), elm *(Ulmus* spp.), and willow *(Salix* spp.), are tolerant to normal use rates [18, 66]. Because 2,4-DP is somewhat volatile, it is not applied near sensitive areas or when air temperatures exceed 32°C (90°F).

Glyphosate. — Glyphosate (Accord® or Roundup®) is broadcast late in the season when pines are not actively growing and before hardwood leaf fall [59, 100]. Normal use rates range from 1,680 to 2,240 g ai/ha (1.5 to 2.0 lb ai/ac), depending on hardwood species composition [28]. Low carrier volumes (45 to 90 L/ha) generally result in more effective hardwood control than high volumes, except for dense or multistoried canopies. White oak and sumacs are susceptible species, whereas hickories and red maple are tolerant to normal use rates [137].

Hexazinone. — The liquid formulation (Velpar LC)) may be applied as a broadcast spray, and is both foliar and soil active. The solid formulations (Pronone 5 G®, Pronone 10 G®, and Velpar ULW®) are primarily soil active. Solid formulations, which gradually release hexazinone to the soil, are more effective than foliar sprays on sandy sites, whereas sprays are most effective on sites with clayey soils [87, 89]. Solid hexazinone formulations are applied during the period from spring leafout through May, when rainfall is adequate to foster herbicide absorption. Liquid formulations may be broadcast beginning a little later, once leaves are two-thirds developed through May.

Hexazinone rates are prescribed on the basis of soil texture, organic matter content, and pH, plantation age, and hardwood species composition [89]. Low rates are used on sites with porous soils, for which the range of rates is very narrow. High rates are needed on clayey or organic soils because these soils absorb more herbicide and herbicide degradation may be more rapid. Oaks are very susceptible to hexazinone, whereas yellow-poplar, blackgum *(Nyssa sylvatica* Marsh.), and vaccinium species are tolerant to normal use rates.

Imazapyr. — Imazapyr (Arsenal®) is a new herbicide which provides excellent broad-spectrum control of woody species at rates safe to loblolly pine. This herbicide is both foliar and soil active, and solid formulations show potential for use on sandy sites [84]. Normal use rates range from 450 to 1,120 g ae/ha (0.4 to 1.0 lb ae/ac), depending on soil texture and hardwood species composition [67, 85]. Excessive rates may temporarily stunt apical and branch leaders, but pine mortality is not a concern in young loblolly stands. In addition to loblolly, shortleaf and Virginia *(Pinus virginiana* Mill.) pine are quite tolerant to this herbicide, whereas slash pine is less tolerant and longleaf pine somewhat susceptible. Elms, buckeye *(Aesculus* spp.), blackberry *(Rebus* spp.), and waxmyrtle *(Myrica cerifera* L.) are tolerant to normal use rates, whereas oaks and blackgum are somewhat tolerant. Hickories, red maple, privet *(Liqustrum* spp.), and flowering dogwood *(Cornus florida* L.) are difficult to control with most herbicides, but are susceptible to imazapyr. Both pine tolerance and hardwood control are best when imazapyr is applied at the end of the growing season (September-October) [88].

Herbicide combinations. — Although operational experience with broadcast applications of herbicide combinations for pine release is limited, mixtures may improve the spectrum of species controlled and cost effectiveness. Recent research has demonstrated the effectiveness of spring applications of imazapyr plus hexazinone and fall applications of imazapyr plus glyphosate [39, 86].

19.5.5.2 Directed foliar sprays

Directed sprays of nonselective herbicide solutions may be applied with backpack sprayers or ground machinery to control interfering hardwoods in young pine stands. Although herbicide costs are generally low, this approach is very labor intensive. Herbicides are usually sprayed during the second or third growing season, once most hardwood sprouts have emerged and before sprouts become too tall to obtain good coverage. When this approach is used in older stands, considerably more herbicide is needed because crowns are larger. Where brush is dense, directed foliar sprays may be applied from horseback (Fig. 19.11).

2,4-DP. — The herbicide 2,4-DP (Weedone 2,4-DP®) is mixed with sufficient water to prepare a 4% solution, which

Table 19.6. Herbicides registered for timber stand improvement (1989).

Trade name	Tree injection	Cut stump	Frill girdle	Basal stem	Basal soil
Acme Super Brush Killer	X	X	X	X	
Banvel CST	X	X	X		
Banvel Herbicide	X	X	X		
Chopper RTU		X		X	
Garlon 4				X	
Garlon 3A	X	X	X		
Pronone 5G					X
Pronone 10G					X
Roundup	X		X		
Tordon 101M	X	X	X		
Tordon 101R	X	X	X		
Tordon RTU	X	X	X		
Velpar L	X				X
Vertac Weed Rhap A-4D	X				
Weedar 64	X				
Weedone CB		X		X	
Weedone 170		X	X	X	

Figure 19.11. Where taller, dense brush is present, directed sprays are sometimes applied from horseback.

is thoroughly sprayed over individual hardwood crowns [66], normally during the period from full hardwood leaf expansion in spring to early summer. It is important to avoid spraying pines to prevent needle burn, dieback of terminals, and mortality. When air temperatures exceed 30 °C, some pines may be damaged because of the volatility of this herbicide. Although 2,4-DP is relatively inexpensive, care must be taken to obtain complete coverage for effective results, particularly for red maple, ash, elm, and willow.

Glyphosate. — Directed foliar sprays of glyphosate [Accord ®, Roundup®) may be used to control hardwoods at any time during the growing season, but are most effective from mid-August through mid-October. These herbicides are mixed with water to prepare a 1 to 2% solution, depending on the species to be controlled. Accord® lacks a surfactant in the product formulation, and a nonionic surfactant should be added at the rate of 1% of the spray solution. When applied in and around drainages (a registered use), Accord® must be mixed with an appropriate nonionic surfactant also labeled for aquatic use. Because glyphosate translocates readily, it is not necessary to spray the entire crown, except for tolerant species such as red maple and hickory. The spray should be directed away from pines to avoid needle burn, dieback of terminals, and mortality.

Imazapyr. — Directed foliar sprays of 0.5% Arsenal® are very effective in controlling a broad spectrum of hardwood species in young loblolly pine plantations. Imazapyr can be applied any time during the growing season, but pine release sprays are most effective from mid-August to mid-October. Because the product formulation does not contain surfactant, a nonionic surfactant should be added at the rate of 0.25 to 1% of the spray solution. Best results are obtained with complete coverage of hardwood crowns, but control may be acceptable with partial coverage because this herbicide readily translocates within plants. Sprays should be directed away from pines. If accidentally sprayed, terminals of loblolly pines may be stunted, although seedling mortality is not a concern.

Triclopyr. — Triclopyr (Garlon 3A®, Garlon 40O) is a broad-spectrum herbicide which can selectively control hardwoods in young loblolly, slash, longleaf, and white pine stands when applied as a directed spray. A 1 to 5% solution of herbicide in water is used, depending on hardwood species composition. Hardwoods may be sprayed throughout the growing season, but are most susceptible in the spring following full leafout [51]. Crowns of individual hardwoods should be sprayed to the point of wetness, but not runoff. Best results are obtained with thorough coverage. Because Garlon 40 is an ester formulation, it is more readily absorbed through the leaf cuticle than Garlon 3A®, the amine formulation, and may injure pines when used during warm weather because of its volatility. Either product can cause needle burn, injury to terminals, and pine mortality.

19.5.5.3 Basal stem treatment

Garlon 4® solutions may be applied to the bases of individual hardwood stems with equipment delivering the spray solution in a straight stream [130]. Diesel fuel, kerosene, and oil-water mixtures are used as carriers to improve herbicide absorption through the bark. Solutions containing 20 to 30% Garlon 4® are sprayed for "streamline" applications, in which the herbicide is directed to treat a narrow band (5 to 10 cm wide) on the stem. Less concentrated solutions are used when more of the stem is treated (see 19.5.6.2). Although this approach effectively controls hardwoods < 8 cm in diameter either during the growing season or when trees are dormant [10], pines may be injured during warm weather because of herbicide volatility.

19.5.5.4 Soil treatment

Hexazinone (Velpar L®) can be used to control hardwoods in newly planted loblolly, slash, shortleaf, and longleaf pine stands. Applications may be made directly to the soil at the base of undesirable hardwoods (see 19.5.6.3) or in a grid over the treatment area [80], optimally from spring budbreak through May. The herbicide is applied with a metered-delivery handgun (Spotgun®) or unmetered handgun (Gunjet®), using 1 to 6 ml of herbicide solution in spots 1 to 2 m apart, at normal use rates ranging from 1,120 to 2,800 g ai/ha (1 to 2.5 lb ai/ac) depending on soil characteristics, pine vigor, and hardwood species composition. It is best to dilute the herbicide product to half-strength with water to avoid gumming in the handgun. The product label should be consulted to ascertain the appropriate rate and grid spacing for soils to be treated.

Hexazinone should be applied during the first, or after the third, growing season. In newly planted stands, soil within a 1-m radius of each pine seedling should not be treated. Newly planted pines have limited root systems but may absorb a damaging or lethal dose.

However, pines 2 and 3 years old are more susceptible; their root systems are more expansive, yet these trees lack the size and vigor needed to tolerate a dosage which will effectively control hardwoods. Pines are much more tolerant after the third growing season. Soil treatment is very cost effective on sandy sites, particularly where oaks are the predominant hardwood species.

19.5.6 Timber Stand Improvement

Timber stand improvement (TSI) treatments are made after stand establishment to alter species composition, favoring the growth of crop trees. As in pine release, interfering hardwoods are of greatest concern. With most chemical TSI practices, such as tree injection, basal stem treatment, and basal soil treatment, individual stems are treated. A relatively new practice involves broadcasting selective herbicides in stands near harvest age (late-rotation or preharvest treatment). Herbicides registered for TSI applications are given in Table 19.6.

19.5.6.1 Tree injection

Tree injection is most commonly used on sites where interfering hardwoods are large and not numerous (< 250 stems/ha). A variety of equipment is used to make incisions through the bark and inject herbicides into the wounds (see 19.5.2.4). Most labels recommend 1 ml of herbicide product (or a diluted solution) per incision, and one incision per 2 to 3 cm of diameter at the height that incisions are made. Species vary in herbicide susceptibility [74]. Resistant species such as red maple, hickory, and dogwood are treated with overlapping incisions, providing control through chemical and mechanical girdling.

The herbicides most widely used for tree injection are 2,4-D amine and a combination of 2,4-D amine and picloram, the latter favored for dormant-season applications. Injection is effective during any season for most species, but results are best in spring when hardwoods are actively growing [18]. Injection of red maple in early spring may be ineffective because of strong sapflow, which inhibits herbicide movement into the stem.

19.5.6.2 Basal stem treatment

Basal stem applications are used in stands where numerous small hardwoods are present (Fig. 19.12). Herbicide solutions are applied to the bark at the base of individual stems. Carriers such as diesel oil, kerosene, or aqueous solutions containing penetrant adjuvants foster herbicide absorption through the bark. Herbicide solutions are either sprayed to wet 20 to 30 cm of the stem above groundline [134] or applied in a stream to a narrow band on the stem about 20 cm above groundline [130]. The latter "streamline" application requires concentrated solutions (20 to 30% herbicide), whereas more dilute solutions (4 to 12% herbicide) are used when a greater portion of the stem is treated.

Basal stem treatments are most effective for stems < 8 cm in diameter and for thin-barked species. Although many

Figure 19.12. Basal stem treatments control small-diameter hardwoods for pine release and timber stand improvement.

hardwood species are effectively controlled by basal sprays, a greater portion of the stem should be treated to control blackgum, oaks, sassafras (*Sassafras albidum* Nutt.), and yellow-poplar. Basal sprays are most effective just before spring budbreak but may be applied year-round. Dormant-season applications are most common because stems are obscured by foliage during the growing season, resulting in greater herbicide use.

19.5.6.3 Soil treatment for individual stems

Hexazinone (Velpar L®, Pronone 5G0, and Pronone 10G0) may be used to control hardwoods in pine stands when applied to the soil within 1 m of the base of individual stems. The liquid formulation (Velpar L®) is applied with a metered-delivery handgun at the rate of 0.8 to 1.6 ml of undiluted product for each centimeter of stem dbh. The solid formulations (Pronone 5G® and 10G0) are used at the rate of 5 to 15 g product per centimeter of stem dbh. Higher rates are needed on clayey or organic soils and when resistant species (hickory, red maple, yellow-poplar, vacciniums) are treated. Results are best in early spring following budbreak.

19.5.6.4 Cut-stump treatment

Herbicides, usually undiluted, may be applied to the cambium of cut stumps during thinning [121] or at harvest [122, 133] to prevent sprouting. To be cost effective, herbicides should be applied with straight-stream equipment and directed only to the cambium. Results are best when the herbicide is applied immediately after cutting.

19.5.6.5 Late-rotation treatments

Control of interfering hardwoods in pine stands near rotation age improves logging access, enhances pine growth, and may eliminate the need for intensive site preparation before replanting. Hexazinone products (Pronone 5G®, Pronone 10G0, Velpar L0, and Velpar

ULW®) selectively control hardwoods with little pine injury because older pines are very tolerant to these herbicides. Herbicide is applied in early spring with metered-delivery handguns, ground machinery, or aircraft. Pine growth is enhanced if harvest is delayed for 2 or more years. If earlier harvests are desired, logging should be delayed for at least 10 weeks after application to ensure adequate herbicide absorption and translocation to hardwood root systems. Sites are normally burned following harvest to complete site preparation.

19.6 Conclusions

Interfering vegetation can be controlled at any age after planting, but is most often treated during the establishment period or in older stands (10 years to rotation age). The timing of treatments and methods employed depend on the nature of interfering vegetation, objectives, site conditions, and numerous operational constraints. Weed control should be integrated with other silvicultural practices in a management system, rather than used only remedially.

Forest managers should strive to understand the biology and ecology of herbaceous and woody weeds, and their impact on stand development. Vegetation management practices do not eradicate noncrop vegetation, but instead shift the species composition of stands to favor crop trees. As the impacts of interfering vegetation on pine yields are better understood, weed control is becoming more common. Understanding the limitations associated with the many chemical and nonchemical alternatives for vegetation management will ensure the best choice - one that provides cost effective control with minimum adverse environmental impact.

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