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CHEMICAL VEGETATION MANAGEMENT IN REFORESTATION AREAS

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ABSTRACT - The past several decades have seen an increase in the number and importance of forest plantations. These plantations are a cost effective management strategy that produces more wood on less land in a shorter period of time. The use of herbicides to control weeds has developed into an integral part of plantation technology. Research has produced new chemistries for weed control in forest plantations as well as providing better understanding of their mode of action and how to use them. Herbicides are used in site preparation, herbaceous weed control, and in established stand management. Different chemicals, rates, or application technologies are warranted in each of these three distinct phases. New application methods have been developed to apply herbicides in the many different management situations where chemical vegetation control is indicated. In many cases, fire is an important partner in chemical vegetation management. Although a natural component of many ecosystems, particularly conifers, fire should be used by trained personnel under specific circumstances. The environmental impacts of fire and chemical weed control programs are an important issue for plantation managers. Even though forestry herbicides are generally very low in toxicity, caution should be exercised during their use, particularly as it might impact bodies of water. Streamside Management Zones are a buffer against herbicide movement into streams, lakes, and rivers. Even though there has been substantial gains in our knowledge of chemical weed control technologies, there are many areas were future research is warranted. First, as the development of new chemicals is unlikely, research should seek to improve the use efficiencies of existing chemicals. Second, more knowledge is needed about the interaction of herbicides and other cultural practices. Finally, the potential of herbicide resistant genotypes is only now beginning to be explored.

The Justification for Vegetation Management

Weed control has been an integral part of traditional agriculture for many decades and the benefits from weed control are well documented and generally accepted as standard practice to increase commodity production. Forestry, on the other hand, is just beginning to explore the potential improvements in productivity through weed control. It has only been in the last 15 years that research programs have been directed at improving the technologies for weed control in forestry situations. The task of developing cost effective yet environmentally responsible weed control strategies for woody crops is a challenging one. Forestry deals with a variety of crop species, a tremendous variety of both annual and perennial weeds, possible interactions with native fauna and flora, and crop rotations that are several years or decades. Certainly, weed control in forestry is much more complex than traditional agriculture.

Weed control in forestry is generally associated with the management of planted stands. The proportion of the world's wood supply coming from planted forests has increased dramatically in the last several years. Estimates put topical plantations as increasing by over 60 percent since 1960 (Evans 1992). The U.S. saw an increase in the number of hectares planted annually from 329,000 ha in 1955 to 980,000 ha in 1995, an increase of almost 200 % (Moulton et al. 1996). Brazil has also followed this trend with one estimate that between 1967 and 1987 there were 6.4 million hectares of plantations in the country (WRI Ltd. 1996). Whether all of these plantations were successes is difficult to determine, but undoubtedly, Brazil has become a recognized force in the area of pulp and paper primarily through its plantation productivity (Swann 1993). As a result of this increased capital input, weed control, particularly the use of chemicals, has become a more significant part of wood production.

The benefits of weed control are well documented and weed control is generally regarded as an integral part of successful plantation establishment (Mc Nabb et al. 1995, Duryea and Dougherty 1991). Numerous studies have shown positive growth responses to weed control in both conifers (Glover et al. 1989, Creighton et al. 1987, Glover and Dickens 1985, Carter et al. 1983) and hardwoods (Zutter et al. 1987, Miller 1987, Fitzgerald et al. 1975). One of the more interesting studies compared the effect of controlling herbaceous weeds, woody weeds, and total weed control for *Pinus taeda* over 8 growing seasons (Figure 1) on 13 sites throughout the southeastern U.S. After mechanical site preparation with a roller drum chopper, four treatments were imposed at each site (1) a check plot with no weed control, (2) a woody plant control where herbaceous weed were allowed to grow, but woody vegetation was completely removed, (3) a herbaceous plant control where woody plants were allowed to grow, but herbaceous weeds completely removed, and (4) complete removal of all herbaceous and woody competition. Total weed control increased eight year tree volumes 188% over the check plots and clearly indicate the negative effect of competition on tree growth. The results also indicate the relative importance of herbaceous weed control to the rapid development of planted forests. In the early years of plantation research only woody plants were considered competitive.

Not only has research demonstrated the significant impact of weed control on plantation productivity, but there has been tremendous improvements in the chemistries and methodologies of forestry herbicide use in the last two decades. Safer more selective chemicals have been discovered and tested. Crop tolerances, soil interactions, and application technologies were developed for these new chemicals. It is the objective of this paper to summarize the current use of herbicides in plantation management, provide information related to the various chemicals available for forestry, discuss some of the potential environmental interactions of herbicides, and finally to speculate as to the direction of future forestry herbicide research.

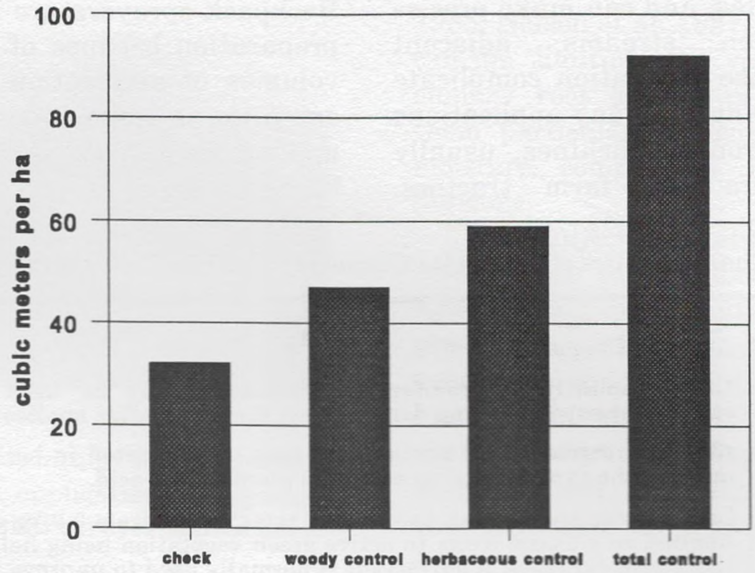

Figure 1 - Eight year volume index for loblolly pine by weed control treatment.

Methods

Site preparation

Site preparation has three major objectives; soil amelioration, improved planting access, and vegetation control. While undoubtedly there are many situations where soil improvement through subsoiling, bedding, or other techniques may be useful to improve site productivity, planting access and vegetation control are the major focus of most site preparation programs. A very effective site preparation technique is the combination of a chemical application followed by fire. This combination achieves the double objective of vegetation control and planting access. The use of herbicides and fire for site preparation during the establishment of pine plantations has been increasing in the southeastern United States in the last 10 years and approximately 50% of all site preparation is now done using chemicals (Du Bois et al. 1997). There are a number of chemicals used in forestry site preparation (Table 1) Most of them are both soil and foliar active, that is, they are absorbed into the plant through both the leaves and the roots.

Herbicides listed in Table 1 are often used together to provide more effective weed control. The most effect combinations are synergetic requiring lower rates of both chemicals. These combinations are mixed in the tank prior to application. The most effective of these "tank mixes" are: (1) glyphosate and imazapyr, and (2) picloram and triclopyr. In both cases the mode of action of each chemical complements the other. Glyphosate and imazapyr, for example, block the biosynthesis of different amino acids. In addition, glyphosate causes leaves to turn brown which facilitates burning. Imazapyr does not brown leaves, but has soil activity and longer residual effect.

Application methods used for site preparation are highly variable and include liquid and solid formulations, aerial, machine, and hand application. Liquid foliar sprays are the most common by far. Helicopters are one of the most effective methods of forestry site preparation. They are a highly efficient application tool particularly on uneven terrain with irregular boundaries, and can make precise applications when streams, adjacent property, and dense vegetation complicate the application. Even so, many applications are made with ground machines, usually converted skidders and farm tractors. Backpack sprayers are rarely used for site preparation because of the normally large volumes of application material. The one exception is Hexazinone which can be soil applied in a "spot grid" pattern using a backpack crew.

Table 1 - Characteristics of herbicides Commonly Used for Forestry Site Preparation

imazapyr	
Trade names:	Arsenal, Chopper
Utilization:	Used primarily for conifer establishment. May be used prior to hardwood establishment if planting done at least 6 months after application.
Activity:	Absorbed through both roots and leaves, translocated in both phloem and xylem, inhibits the synthesis of an essential plant amino acid.
Application:	Labeled site preparation application rates[1] range from 0.9 kg ae/ha to 1.3 kg ae/ha. Applied as a liquid spray to active green vegetation using helicopters, machine, or hand held sprayers. A surfactant is normally used to improve leaf uptake.
glyphosate	
Trade names:	Roundup, Accord
Utilization:	Wide application in both hardwood and conifer site preparation.
Activity:	Absorbed through leaves only, no soil activity, translocated through both phloem and xylem, inhibits the synthesis of an essential plant amino acid.
Application:	Labeled site preparation rates range from 1.7 to 8.4 kg ae/ha. Applied as a liquid spray to active green vegetation using helicopters, machine, or hand held sprayers. A surfactant is used to improve leaf uptake
hexazinone	
Trade names:	Velpar, Pronone
Utilization:	Conifer site preparation
Activity:	Absorbed through the root system only, translocated through the xylem (unidirectional translocation), inhibits photosynthesis.
Application:	Labeled site preparation rates range from 2.25 kg ai/ha to 6.75 kg ai/ha. Applied as either liquid or granular formulations in the spring during leaf out of deciduous trees. Liquid forms may be spot or broadcast applied. Granular forms are broadcast applied using aerial, ground machine, or manual methods.
picloram	
Trade names:	Tordon
Utilization:	Used primarily for conifer establishment. May be used prior to hardwood establishment if planting done at least 6 months after application.
Activity:	Absorbed through both roots and leaves, translocated in both phloem and xylem, acts a growth stimulator resulting in disorganized tissue formation.
Application:	Labeled site preparation application rates range from 0.56 kg ae/ha to 2.24 kg ae/ha. Applied as a liquid spray to active green vegetation using helicopters, machine, or hand held sprayers.
triclopyr	
Trade names:	Garlon
Utilization:	Used primarily for conifer establishment, usually in combination with Picloram.
Activity:	Absorbed through leaves, very little soil activity, translocated in both phloem and xylem, acts as a growth stimulator resulting in disorganized tissue formation.
Application:	Labeled site preparation rates vary from 6.7 kg ae/ha to 10.1 kg ae/ha. Applied as a liquid spray to active green vegetation using helicopters, ground machines, or hand held sprayers.

(1) Labeled rates for the United States.

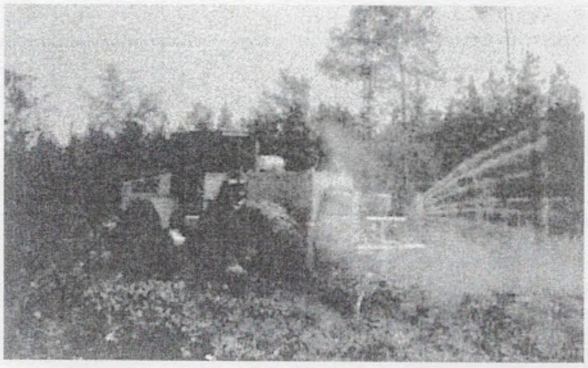

Figure 2 - Skidders can be modified with a variety of herbicide application arrangements such as the manifold sprayer shown here.

Herbaceous weed control

The term "herbaceous weed control" refers to the control of weeds during the first 12 months after planting. Usually these are grasses, forbs, and other non-woody vegetation that compete with tree seedlings during the establishment phase of regeneration. During this period competition for moisture and nutrients may be intense. The most important limiting factor appears to be moisture. Root volume growth during the first year after planting has been correlated to soil moisture levels as influenced by weed control (Lockaby et al. 1988, Nelson et al. 1981). Although nutrients can be limiting for young seedlings, the shallow root system of young pine make them particularly sensitive to weed driven moisture competition in the upper soil horizons.

There are a variety of chemicals that have shown to be effective for herbaceous weed control in plantations (Table 2). Both pre- and postemergent technologies are used depending upon the crop species and competition situation. The most difficult obstacle when developing a herbaceous weed control program is the use of a chemical and application technique that achieves crop selectivity. Herbaceous weed control strategies must be based on the careful utilization of physiological, morphological, or physical selectivity. Many herbicides achieve selectivity through various means. Oxyfluorfen, for example, is a preemergent herbaceous weed control chemical commonly used for post-planting weed control in Brazil. It is essentially a contact chemical that does not translocate well and is not taken up by roots. In addition, the waxy cuticle of pine and Eucalyptus seedlings provide a partial barrier to chemical penetration. The waxy cuticle and narrow leaf form are the basis for much of the herbicide selectivity associated with conifers.

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Table 2 - Chemicals commonly used for herbaceous weed control

Atrazine	
Trade names:	Atrazine, Aatrex, others
Utilization:	Pre- and early postemergent applications in hardwood and conifer plantations
Activity:	Absorbed through the root systems, very limited foliar uptake, translocated through the xylem only, inhibits photosynthesis
Application:	Labeled herbaceous weed control rates are 2.25 kg ae/ha to 4.5 kg ae/ha. Applied as a liquid spray over the top of recently planted conifers or deciduous hardwood trees prior to leaf expansion in the spring.

Continue...

Table 2, cont.

Fluazafop-p-butyl	
Trade names:	Fusilade
Utilization:	Postemergent grass control in hardwood and conifer plantations.
Activity:	Absorbed through leaf surfaces, no soil uptake, translocated through the xylem and phloem, disrupts cellular membrane integrity.
Application:	Labeled rates are ..11 kg ai/ha to .43 kg ai/ ha. Applied as a liquid spray with a surfactant or crop oil concentrate to active green foliage using a tractor mounted or backpack sprayer. Very limited activity on broadleaved weeds.
glyphosate	
Trade names:	Roundup, Accord
Utilization:	Postemergent weed control as a directed spray in conifer and hardwood plantations. Limited utility for over-the-top applications in conifers.
Activity:	Absorbed through leaves only, no soil activity, translocated through both phloem and xylem, inhibits the synthesis of an essential plant amino acid.
Application:	Used as a 1 to 2% solution when directed. Applied with a surfactant to active green vegetation.
haloxyfop	
Trade Name:	Verdict, Gallant
Utilization:	Postemergent grass control in conifer and hardwood plantations in Brazil.
Activity:	Absorbed only through the leaves, translocated through the xylem and phloem, inhibits cell division in meristematic regions.
Application:	Recommended rates for grass control range from 0.06 to 0.56 kg ae/ha. Applied as a liquid spray for grass control. Broadleaves, sedges, and woody plants highly resistant.
hexazinone	
Trade names:	Velpar, Pronone
Utilization:	Pre- and early postemergent applications in conifer plantations.
Activity:	Absorbed through the root system only, translocated through the xylem (unidirectional translocation), inhibits photosynthesis.
Application:	Labeled rates range from 1.12 kg ai/ha to 2.25 kg ai/ha. Applied as either liquid or granular formulations over-the-top of pine seedlings. Lower rates mean that weed control is limited to pre- and early postemergent situations.
imazapyr	
Trade name:	Arsenal
Utilization:	Pre- and early postemergent applications in conifer plantations.
Activity:	Absorbed through both roots and leaves, translocated in both phloem and xylem, inhibits the synthesis of an essential plant amino acid.
Application:	Labeled rates range from 0.21 kg ae/ha ai to 0.35 kg ae/ha. Applied with a surfactant as a liquid spray over-the-top of pine seedlings in a pre- and early postemergent situation.
oxyfluorfen	
Trade name:	Goal
Utilization:	Pre- and early post emergent weed control in hardwood and conifer plantations.

Continue...

Table 2, cont.

Activity:	a contact herbicide absorbed through young roots and leaves, does not readily translocate in the plant, causes disruption of cell membranes.
Application:	Rates range from 0.45 kg ai/ha to 2.24 kg ai/ha. Applied as a liquid spray after planting and over-the-top of Eucalyptus and other hardwoods, as well as conifers.
pendimethalin	
Trade name:	Pendulum
Utilization:	Pre- and early postemergent weed control in hardwood plantations.
Activity:	Limited uptake and translocation by both shoots and roots, inhibits cell division and elongation.
Application:	Rates vary from 0.2 kg ai/ha to 2.25 kg ai/ha. Applied as a liquid spray after planting and over-the-top of hardwoods and conifers.
sethoxydim	
Trade names:	Poast, Vantage
Utilization:	Postemergent control of grasses in hardwood and conifer plantations
Activity:	Foliar uptake and readily translocated in both the xylem and phloem, inhibits cell membrane function and growth.
Application:	Applied at 0.52 kg ai/ha as a liquid spray with a surfactant or crop oil concentrate to active green foliage using a tractor mounted or backpack sprayer. Very limited activity on broadleaved weeds.
simazine	
Trade name:	Princep, Herbadox
Utilization:	Pre- and early postemergent weed control in conifer and hardwood plantations. Limited availability in North America
Activity:	Absorbed by the root system and translocated in the xylem, inhibits photosynthesis.
Application:	Rates vary from 2.2 to 4.4 kg/ha ai. Applied as a liquid spray to bare ground or germinating weeds using a tractor mounted or backpack sprayer.
sulfometuron	
Trade name:	Oust
Utilization:	Pre- and early postemergent weed control in conifer and hardwood plantations. Some species, particularly Eucalyptus are sensitive to sulfometuron.
Activity:	Absorbed by both roots and shoots, translocated in the phloem and xylem, stops or inhibits cell growth in shoot and root tips.
Application:	Used as a liquid spray over-the-top in conifer plantations at rates of 0.11 to 0.31 kg ai/ha. Applied to dormant deciduous hardwoods in early spring at rates of 0.05 to 0.11 kg ai/ha.
terbacil	
Trade name:	Sinbar
Utilization:	Pre- and early postemergent weed control in hardwood plantations.
Activity:	Taken up mostly by roots with limited foliar absorption, translocated primarily in the xylem, inhibits photosynthesis.
Application:	Applied as a liquid spray to dormant deciduous hardwoods or recently planted cuttings at 0.9 to 1.8 kg ai/ha.

A number of "tank-mixes" are used for herbaceous weed control. As in the case of site preparation applications, the best mixes are those that complement each other on the spectrum of weeds controlled and their respective herbicidal properties. The following are the more commonly used mixes in conifer plantations:

sulfometuron and atrazine
sulfometuron and hexazinone
sulfometuron and glyphosate
sulfometuron and imazapyr

Applications in bands of 1.0 to 1.5 meters in width along the planting row is generally considered the most cost effective method of herbaceous weed control (Miller and Mitchell 1988). Liquid applications can be made with machine mounted or backpack sprayers. Application accuracy and calibration are important components of a herbaceous weed control program. Because crop species selectivity is frequently based on a balance of species characteristics and herbicidal properties, poor application methodologies can cause significant harm to the crop or result in ineffective weed control. Ground speed is particularly important to insure accuracy in both machine and manual application methods. Small shifts in ground speed can mean major changes in application rates. The height of the spray nozzle is important as it determines the band width and therefore application rates per hectare. The nozzle configuration is important for maintaining crop safety. Nozzles that overlap the planting row can cause the application rate to double directly above the crop tree. Certainly, factors such as blocked nozzles, improperly spaced nozzles, and leaking hoses can affect application accuracy. The margin for error in herbaceous weed control is less than other forestry weed control situations.

Post-regeneration weed control

Herbicides are often used for control of unwanted vegetation in plantations well after the initial regeneration phase. In this case the crop species is competing against other woody vegetation. The intensity of this competition depends upon the type and amount of competition existing on the site prior to planting, the type of site preparation, weed species pressure from outside the plantations and length of the rotation. In the southeastern U.S., "release" treatments are common during year 3 to year 6 of a conifer plantation. Chemicals with reasonable selectivity for conifers, such as imazapyr and hexazinone, are broadcast applied over a plantation usually from the air. Table 3, outlines those chemicals commonly used for release work and their method of application.

Table 3 - Chemicals, selectivity, and application methods of herbicides used for weed control in established stands

Chemical	Conifer Selectivity	Application Methods
Imazapyr	High	Aerial broadcast, backpack directed foliar spray, backpack directed stem application (streamlining), and injection
Hexazinone	Medium	Aerial broadcast, backpack soil spot applications
Triclopyr	Low	Backpack stem applications, injections
Glyphosate	Low	Directed foliar sprays, injection

Figure 3 - Streamline applications can be used to control small diameter trees.

There are a variety of application methods possible in release work. Broadcast applications are useful only if the crop species is tolerant to the chemical. There are a number of techniques, however, where the chemical may be directed to a specific individual woody weed. Streamlining, for example, is a technique whereby single streams of chemical are applied to the individual stems of woody weeds at about 20 to 80 cm above the ground. This method is effective only on smaller stems of 1 to 8 cm in diameter. Triclopyr and imazapyr are the chemicals most commonly used for streamlining and are mixed with a penetrant oil that carries the herbicide to the site of activity and translocation in cambium and phloem. Injection refers to the actual scarring of the tree stem with a machete or hand axe and a specified amount of chemical applied directly to the would, again with the intent to place in the phloem and xylem. Chemicals translocated only in the xylem are not suitable for stem applications. While effective, individual stem applications can be costly if the number of stems treated per unit of area is high.

Release work in hardwood plantations is complicated by the fact there are few truly selective chemicals that can be broadcast applied without harming the crop species. For the most part, chemical release work in hardwood plantations must depend upon directed stem and foliar applications to protect the crop. Usually, chemicals with no soil activity, such as glyphosate and triclopyr are the most appropriate. Another key concept in reducing woody plant competition in hardwood plantations is to remove all potential competitors at the time of site preparation. Intensive site preparation, whether mechanical or chemical usually results in a greatly reduced population of woody plants that become weeds or produce offspring. In this case, a good offense is an effective defense.

The use of fire as a vegetation management tool

Prescribed burning is commonly used as an integral part of a chemical weed control program. Whether used for site preparation or release, fire used in conjunction with herbicides is a valuable tool for weed control. Fire is a natural part of many ecosystems throughout the world. Most conifer forests, whether, boreal, temperate, or tropical, normally owe their existence to the regular and often catastrophic occurrence of fire. In addition, most savannas and semi-arid forest lands, including those in Brazil, are routinely subjected to fire. In the southeastern U.S., for example, the longleaf, slash, and loblolly pine (*Pinus palustris, elliottii*, and *taeda*, respectively) ecosystems that dominate the landscape, are all fire dependent. Natural wildfires, whether lightning or human originated have contributed to the establishment and maintenance of these conifer ecosystems for eons. Fire is today considered an integral part of forest management, both in natural and planted stands.

Figure 4 - Prescribed burning is a cost effective technique for controlling small diameter trees and to reduce fire hazard.

Prescribed burning is used in pine silviculture for site preparation and release. Fire is perhaps the most cost effective tool to improve planting access after harvesting. Under the correct conditions and when properly conducted, fire can quickly reduce planting slash to ashes which effectively cleans the planting site and releases many important plant nutrients. Site preparation burns are frequently done by helicopter, dropping pre-ignited fuels in a grid or strip pattern across the area to be burned. This method is particularly useful in large areas or where access and terrain makes manual burning too difficult. The weed control benefits of site preparation burns are marginal. Although some smaller woody competitors and even seeds are killed, these fires only temporarily suppress the weed pressure.

The primary objectives of prescribed fire in established plantations are (1) fuel reduction, (2) competition control and (3) improved access. While fuel reduction is probably the most important benefit of regular prescribed burns, hardwood suppression and control is also important. Woody plants of less than 10 cm can be killed by a prescribed burn while larger trees are girdled. Backfires and strip headfires are the most common methods for release work in plantations because they travel slow and are generally considered safer fires. In addition, slower fires achieve better weed control as lethal temperatures are held for longer periods of time resulting in more cambium and root damage to susceptible hardwoods. Young conifers are also sensitive to fire and must develop the bark thickness and height necessary for protection. In the southeastern U.S. this is usually at about 8 to 10 years after planting. Thereafter, release fires are done on intervals of 3 to 5 years.

Prescribed burning should be considered a job requiring both skill and planning. In many places the proximity of human habitations makes smoke and smoke management an issue. Moreover, fire always carries an inherent risk of danger to the user in those rare circumstances where a prescribed burn turns into a wildfire. Not only is there an element of human risk, a fire improperly executed can be environmentally destructive. Extremely hot fires are to be avoided whenever possible. This is for both site preparation and release burns. Such fires destroy the important organic matter layers of the soil, possibly impacting site productivity. Volatilization of nitrogen is also an issue and frequent burning intervals may decrease site productivity for nitrogen deficient sites. Both organic matter and nitrogen loss are serious considerations when evaluating the potential use of fire as a silvicultural too.

Environmental Impact of Chemical Vegetation Management

Potential impact on fauna

Forestry herbicides are generally very low in mammalian and fish toxicity and do not pose a direct threat to wildlife. Table 4 presents the LD50, LC50, environmental half-life, and leaching potential of key herbicides. Even though the toxicity of these chemicals is generally low, there are exceptions, however, like oxyfluorfen, which is highly toxic to fish and aquatic organisms. Obviously, the applicator must be aware of these characteristics if the material is to used in a safe manner. These materials are also biodegradable in that the longest half-life is 63 days. Not only do herbicides represent a very low toxicity hazard, but they also decompose and do not accumulate in the environment. In terms of direct toxicity to wildlife, forestry herbicides pose a minimal risk.

The biggest effect of chemical weed control on wildlife populations is not through direct toxicity but rather habitat modification. Intensively managed plantations are frequently devoid of the diversity and presence of species that can be used for forage and shelter for animals. Weeding programs, whether chemical or mechanical, have the elimination of unwanted vegetation as their objective. The removal of this vegetation undoubtedly impacts a wide variety of fauna that might otherwise use plantations as their habitat.

Water quality protection

One of the most critical areas where forestry herbicides have the potential for a negative environmental impact are applications made close to streams, rivers, and lakes. There are some herbicides, glyphosate and imazapyr, for example, that are actually labeled for wetlands and bodies of water. These chemicals are safe to use near bodies of water as long as the recommended application rates are not exceeded. Label contents can vary between location, however, and what is allowed in one state or country may not be in another.

Table 4 - Toxicity and half-life and leaching potential of common forestry herbicides

Name	LD 50 (mg/kg)	LC50 (mg/l)	Half-life (days)	Leaching Potential
atrazine	3,080	4.5	49	High
fluazafop	4,096	5.4	21	Low
glyphosate	5,600	86	61	Very Low
haloxyfop	599	0.2	55	Medium
hexazinone	1,690	274	30	High
imazapyr	5,000	100	27	Medium - High
oxyfluorfen	5,000	0.2	35	Very Low
picloram	8,200	19.3	63	High
pendimethalin	1,200	138	90	Low
sethoxydim	2,676	170	11	Low
simazine	5,000	2.8	44	High
sulfometuron	5,000	12.5	10	Medium

Figure 5 - An SMZ is a protected strip of forest along water courses where harvesting and site preparation are not allowed.

One of the favored methods to ensure water quality is the use of streamside management zones or SMZs. These are strips of natural vegetation left untreated around perennial streams and lakes. Usually these strips are defined at the time of harvest and site preparation. Although selective harvesting of high value individuals may occur in an SMZ, site preparation is not allowed. The width of the strip depends upon the size of the stream, keeping in mind the basic objective of maintaining water quality. SMZs keep applicators away from streams and act as a filter to overland flow and aerial drift. Usually a minimum width of 10 meters is recommended. The characteristics of the soil and herbicide used also affect the width of the SMZ. A readily soluble chemical such as hexazinone applied to a sandy soil may require wider strips than what would otherwise be used. Application methods also affect SMZ width as aerial applications must have wider buffers than do machine or hand applications. It is possible, also, that some herbicides may be used inside the SMZ if applied by hand to individual stems.

The determination of the correct width for an SMZ is a complex task. The stream width, soil type, chemical characteristics, and method of application may influence the manager's definition of an SMZ. Most states in the U.S. have left the establishment of SMZs to the professional in the field. It is up to the trained forester to assess the situation and match the various interacting factors affecting herbicide movement. Current regulatory philosophy holds this flexibility as the best option for maintaining stream integrity, which is the ultimate goal.

Future Research Directions

It does not appear probable at this time that the development of new chemistries for weed control in forest plantations will be a high priority for herbicide manufacturers. The relative market share of forestry plantations is very small when compared to agriculture while at the same the cost of developing a new product is extremely high. It is estimated that to discover, test, label, promote, and sell a new herbicide in the U.S. will cost about $50 million. Much of these expenses are associated with the voluminous environmental fate studies that need to be done to label a forestry herbicide. Therefore, if new chemistries are few and far between, then weed science research should concentrate on learning how to better use existing chemicals.

There are a number of methods that herbicide effectiveness can be improved. Surfactant chemistry, slow release formulations, and tank mixes are several areas of potentially productive research. Application technologies may also be explored such as electrostatic spraying, improved nozzle configuration, and the use of injection systems that mix herbicides as they are sprayed. And although herbicides specific to forestry may not be a high priority with chemical companies, manufacturers are routinely searching for better agricultural chemicals. We in forestry must keep aware of these chemistries as they develop and ensure they are tested for our conditions. Oxyfluorfen is a good example of a product developed for the agricultural market that was found to be very effective in a forestry context. Research has shown that individual herbicide selectivity is very species dependent, varying even between species within a given genus. Slash pine, for example, is more sensitive to imazapyr than is loblolly and the timing and rate of applications must be adjusted accordingly. The possible combinations of species and herbicides that can be tested is formidable. Selectivity data is particularly lacking for hardwood species.

A second area of research that needs to be pursued is the interaction between herbicides and silvicultural practices. Plantation establishment should be viewed as an integrated process whereby no single event is separate and unique with each influencing and interacting with the other. Recent research has shown that seedling size has a large impact on initial survival and growth (South et al. 1995). Larger diameter slash pine seedlings with no weed control can actually outperform smaller seedlings with weed control (Shrock 1994). This concept may be extended to other silvicultural practices as well. For example, can depth of planting affect seedling sensitivity to a specific chemical? How much does the shift to "minium cultivation" affect herbicide efficiencies? These and other areas of herbicide/silviculture interaction need to be explored if the full potential of our current chemistries are to be realized.

A final area of future research relates to the use of herbicide resistant genotypes for plantation establishment. It would appear this has a great deal of potential in Brazil. Glyphosate resistant agricultural crops are already on the market in many countries, a product of the new science of biotechnology and gene manipulation. Surely, glyphosate resistant trees are not far behind. Given its lead in clonal Eucalyptus forestry and ability to propagate a single genotype over large areas, Brazil could implement a large scale glyphosate resistant planting program relatively easily. However, there are serious obstacles to this program, other than the biotechnology component. Ensuring environmental safety is a key issue that must be overcome. Any herbicide resistant genotypes planted to the field will probably be required to be sterile. Another strategy is to have a biochemical switch (a promoter gene) so that resistance is initiated only after exposure to some specific chemical key, a key that would have to be applied by forest managers. However the science develops, biotechnology appears to loom on the horizon as a major influence on the practice of weed control in intensively managed plantations.

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