152

United States
Department of
Agriculture

Forest Service

**Southern Forest
Experiment Station**

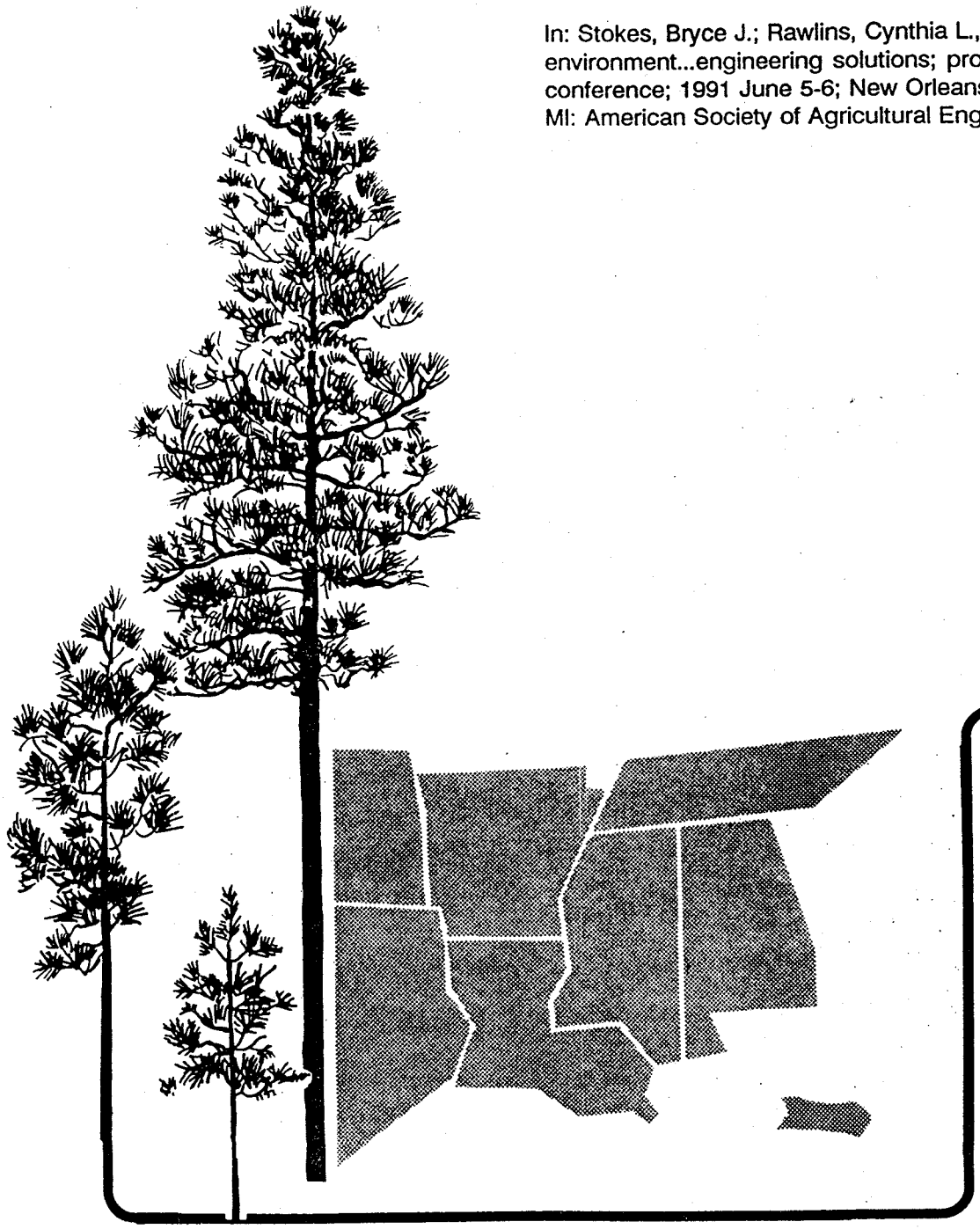
New Orleans,
Louisiana

Proceedings Reprint

FOREST HERBICIDE BENEFITS AND DEVELOPMENTS FOR INTENSIVE SOUTHERN PINE CULTURE

Miller, James H.

In: Stokes, Bryce J.; Rawlins, Cynthia L., eds. Forestry and environment...engineering solutions; proceedings of a conference; 1991 June 5-6; New Orleans, LA. St. Joseph, MI: American Society of Agricultural Engineers: 129-138.



Southern Forest Experiment Station

1991

FOREST HERBICIDE BENEFITS AND DEVELOPMENTS FOR INTENSIVE SOUTHERN PINE CULTURE

James H. Miller

Silvicultural treatments that use forest herbicides can accelerate wood production, enhance wildlife and recreational habitats, aid in endangered species recovery, and encourage plants that improve the aesthetics of woodlands. This paper focuses on the benefits of increased wood production derived from competition control for establishing southern pine plantations. Research findings on the benefits of both woody and herbaceous competition control are reviewed and discussed. Since more is known about the economics of woody competition control, compared to herbaceous control, it is given more attention. The appropriate application methods and vegetation control strategies are reviewed along with possible innovations for improving efficiency.

BENEFITS OF COMPETITION CONTROL IN PLANTATIONS

Why do we control plant competition when growing a crop? Traditionally, weeds are controlled to increase seedling survival, to grow a larger and higher quality crop sooner, and to yield a crop that is easier to harvest. By controlling interfering vegetation, limited site resources of moisture and nutrients are channeled into producing more fruit, grain, fiber, and wood from less land area. This has always been deemed important, at least in the past, as populations have swelled and land resources shrank. As environmental risks and ecological consequences are included in the evaluation, the precept of "more from less" has a broader context and a new balance of cost-benefit must be assessed.

The traditional cost-benefit analyses of weed control operations for most annual crops have been determined, while those for southern pine culture, especially the long-term results, are poorly understood. What is known and the opportunities for the future will be discussed.

A South-wide research study performed cooperatively at 14 locations by the USDA Forest Service, universities, and industry shows that during the first 4 years, herbaceous competition limits growth of loblolly pine significantly more than woody competitors (Miller et al. 1987, Miller et al. in press). In this ongoing study, complete weed control for five growing seasons has yielded early volumes that are 4 to 7 times larger than those following only drum chopping and prescribed burning. These dramatic early growth gains with total competition control show the potential that herbicide technology may hold for intensive pine culture and increased wood production from southern forests.

Benefits of Hardwood Control

Speculative investment analyses for hardwood control treatments at the time of plantation establishment predict substantial real rates of return of 9 to 12.5

James H. Miller, Research Forester, U. S. Forest Service, G. W. Andrews Forestry Sciences Laboratory, Auburn University, AL.

percent on productive sites (Kline and Kidd 1986, Hickman et al. 1987, Clason 1988, Dangerfield and Merck 1990). These analyses suggest that early thinning of rapidly growing stands and shortened rotations are essential for capitalizing on financial returns (Langdon and Trousdell 1974, Clason 1989). As with any silvicultural treatment, the return rate is significantly improved on higher quality sites. Therefore, high site lands and lands near mills can be made even more productive, while yielding a more even wood supply from thinnings and shortened rotations.

A growth and yield model constructed by Burkhart and Sprinz (1984) provides estimates of the yield losses in loblolly pine stands with varying amounts of hardwood in the main canopy. This model, HDWD, and the accompanying economic analysis module, ECONHDWD, are based upon a critical relationship derived from long-term research initiated by Whipple and White (1965) in Alabama, and more recently reported by Glover and Dickens (1985). Periodic remeasurements on these and other long-term plots (Langdon and Trousdell 1974) show that the proportion of hardwood basal area in a stand remains constant from age 10 to 25 years. This indicates that if a stand has 30-percent hardwood basal area at age 10, it will still have 30-percent hardwood basal area at age 25. This research also found that hardwoods preempt a greater amount of softwood yield than their proportion of basal area would suggest. That is, a stand having 30-percent hardwood basal area will reduce pine yield by 50 percent. Thus, many hardwood species can maintain comparable height growth with pines, and will remain in a dominant or co-dominant crown position, eventually displacing more than an equal amount of softwood fiber. This means that the early elimination of even a small amount of hardwood competition (species that will remain in the upper canopy) can have pay-backs in enhanced pine yields.

What about the investment-return from controlling mid-story hardwoods? The growth benefits of mid-story control have been studied in only a few stands (McClay 1955, Russell 1961, Langdon and Trousdell 1974, Clason 1978, D'Anieri et al. 1986, Boyer 1987). Removal of sapling hardwoods and shrubs has often, but not consistently, increased rotational yields. These variable findings suggest that the effects of midstory and understory competition on pine growth are site specific. If deep-rooted species can survive as seedlings and saplings, they will eventually obtain moisture and nutrients from the lower soil profile in later years, despite competition. Where soils are poor, shallow, and rooting depth restricted, competition can be severe, which may warrant control measures.

When should herbicide treatments for hardwood control be applied? Early control is logical since smaller plants require less herbicide for control and early crop survival may be threatened without control. Therefore, delays in applying herbicides for pine release can result in reduced stocking and the labeled amount of herbicide will control less and less as woody competition increases in size with age. Since higher rates are labeled for site preparation, due to the absence of the crop on the site, maximum control is possible with such treatments. But as mentioned earlier, herbaceous competition subtracts more growth than woody competition in the first few years of a plantation. Thus, to optimize on a treatment, the site preparation herbicide should have residual herbaceous control effects that last into the first growing season. An innovation that is currently gaining widespread use is the post-plant application of a herbicide with pine tolerance and both woody and herbaceous control capabilities in the first growing season after a light mechanical site preparation. If pine damage is minimized, the young woody and herbaceous competitors may be controlled with a low rate that has maximum cost-effectiveness.

Benefits of Herbaceous Control

Growth boosts from herbaceous weed control in pine plantations have been repeatedly reported over the past 10 years (Nelson et al. 1981, Michael 1985, Glover et al. 1986, Knowe et al. 1985, Metcalfe 1986, Zutter et al. 1986, Creighton et al. 1987, Glover et al. 1989, Haywood and Tiarks 1990). Enhanced

diameter and height growth have been consistently found, as well as improved survival in drier areas and droughty years. Studies across the South have been under way for up to 12 years, investigating loblolly, slash, and longleaf pines. The 12-year results suggest that the same wood yield can be reached 1 to 3 years sooner after early herbaceous competition control and early thinning (Glover et al. 1989).

Other research results show that first-year weed control in a band along the planting row is as effective as broadcast treatments. This points to large savings in treatment costs by using banded or spot applications around seedlings in the first year, thus treating only 40 to 60 percent of a tract. On some sites, 1 year of weed control in a band yields comparable pine growth to 2 years of banded or broadcast weed control. On highly productive sites, additional years of control appear justified due to additional increments in growth and anticipated yields (Creighton et al. 1987).

The Economic Risks of the Herbicide Investment

The growth-response benefits from herbicide applications are not automatically assured. With today's herbicide technology there is a risk of ineffective control and possible crop-tree damage, in addition to the risks of liability claims from misapplication. Crop damage can be minimized by using only site preparation treatments prior to planting and/or release treatments with herbicides that have maximum crop tolerance. But even with these safeguards, the unpredictable nature of weather can never assure scheduling treatments for optimum effectiveness. It is rarely possible for managers to schedule all herbicide applications to coincide with ideal weather conditions. In general, pre-application moisture should be adequate for active plant growth and post-application rainfall should be timely, depending on the requirements of the specific herbicide. Furthermore, the ideal timing for the specific herbicide should be clearly understood and considered when scheduling application (Miller and Bishop 1989).

Several less understood factors often contribute to ineffective control and undue economic risks with herbicide investments. Inadequate information often leads managers to prescribe the wrong herbicide for controlling the specific species present. The prescription process requires a complex knowledge of the effectiveness of many herbicides on all possible species and sites in order to select the best one. Because of a lack of adequate research information this understanding is rare for forest managers, since it is gained by long-term experience. Computer-based expert systems hold the potential for managers to store this type of information and to impart it to others in an easily retrievable manner (Zedaker et al. 1988).

Other less understood factors that lead to poor herbicide control include the quality of water used in mixing, effects of surfactants added to the spray tank, and plant status for optimum receptivity. Also, when one set of competitors is successfully controlled, another set may take over a site due to release. But as broader spectrum forestry herbicides become labeled and more research and experience are brought into play, the risk of failure will be reduced but never eliminated.

HERBICIDE APPLICATION TECHNOLOGY AND ITS MANAGEMENT

The cost factors for herbicide treatments are dictated mainly by herbicide and application costs. Herbicides are priced by manufacturers relative to effectiveness, resulting in similar per-acre costs. This means that there is little latitude for cost savings from the selection process, other than selecting the most effective herbicide for the species present and applying it at the optimum time. Most savings are gained through efficiency in the application

process to minimize labor and equipment costs. Thus, the remainder of this paper focuses on application alternatives and their appropriate use.

For an application method to be most efficient, it should be tailored for a specific distribution of competition. Broadcast treatments are easily prescribed and routinely applied, but they are wasteful if the competition is not densely and uniformly spread across the entire area. When competition is scattered or in patches, other treatment patterns and methods may be more economical and environmentally safe.

Plantations currently being harvested and needing reforestation have been established for the most part with some type of mechanical site preparation treatment--chopping, shearing, rootraking, and/or burning. The effectiveness of that treatment and the pre-treatment hardwood distribution have contributed to the distribution of woody competition presently confronting the manager. Windrowing will have concentrated hardwoods into strips, while chopping and shearing may have maintained the original distribution, depending on the uniformity and intensity of any burning or other supplemental treatment.

Terrain strongly influences the control and reestablishment of the woody component, especially the frequency and expanse of minor and major drainage bottoms. Hardwood regrowth is more dominant on bottoms, making control treatments less effective. Yet these are highly productive pine sites as well, which may warrant careful treatments with herbicides to assure their continued productivity. In the process, streamside management zones must be protected because, in addition to their many other benefits, these zones minimize herbicide entry into streams and ponds (Michael 1986).

The two basic patterns that result from the interplay of past treatment and regrowth are; a uniform distribution across the area, either dense or scattered, or a grouped pattern due to terrain, windrowing, or other past treatments. The forester who prescribes herbicide treatments wisely will identify tracts having these different distributions and select application methods accordingly.

Evenly-distributed woody competition

When woody competitors are greater then 2,000 stems per hectare (800 stems per acre) and are evenly distributed across a tract of over 20 hectares (50 acres), then the first alternative to consider is aerial broadcast application (Kidd 1987, Lowery 1987). For this application to be successful, adequate preparation of the tract and operational supervision is required. On industrial tracts appropriate heliports should be permanently established in compartments and maintained for this purpose. With ideal weather, proper layout, and good supervision, one helicopter can treat hundreds of hectares in a single day, which is attractive to the busy industrial manager.

Tractor-mounted sprayers and spreaders can also provide broadcast applications on certain tracts (Sage et al. 1984, Miller et al. 1985, Miller 1985). Treatment costs for tractor-applied site preparation average less than those for aerially applied, but can be considerably more for tractor-applied vs aerial release treatments (Dubois et al. 1991).

Skidder- or crawler-mounted equipment can be efficient if the terrain, stand conditions, and utilization permit consistent operating speeds of 1.6 to 4.8 kph (1 to 3 mph). Ground sprayers can presently apply foliar-active herbicides to woody competition up to about 5 m (16 ft) tall with a 9 to 12 m (30 to 40 ft) swath. Spreaders and sprayers can apply soil-active herbicides and treat under hardwoods greater than 5 m (16 ft) tall if uniform soil coverage is possible. The 26 m (85 ft) swath of the Omni Spreader (Miller 1985) is the widest for any spreader now in use with most high-mounted sling spreaders only capable of a 12 m (40 ft) swath. With these speeds and swath widths, the average productivity for tractor-mounted applicators range from 1.6 to 7.2 hectares per hour (4 to 18 acres per hour).

As densities of hardwoods drop to below 2,000 stems per hectare (800 stems per acre), broadcast treatments become inefficient, and individual stem treatments become comparable or less in cost per hectare (Dubois et al. 1991). Application and herbicide efficiency also improve for certain crew-applied methods when stem sizes decrease. Individual stem treatments include directed foliar sprays, streamline basal sprays, tree injection, and soil spots (Williamson and Miller 1988). Directed foliar sprays are used to treat woody plants up to 1.8 m (6 ft) tall. Basal streamline applications and soil spot applications can control many species of hardwoods up to 15 cm (6 inches) in d.b.h. Injection treatments are capable of controlling trees 5 to 75 cm (2 to 30 inches) d.b.h. Crews using several methods can be formed that are appropriate for stand conditions.

Data on file suggest that backpack crews are cost-effective at densities of 1,250 to 10,000 stems per hectare (500 to 4,000 stems per acre) and injector crews at densities of less than 2,000 stems per hectare (800 stems per acre). Productivity ranges from 0.08 to 0.2 hectares per hour (0.2 to 0.5 acre per hour) for injection, 0.4 to 0.6 hectares per hour (1.0 to 1.5 acre per hour) for directed sprays and streamline basal sprays, and 0.6 to 0.8 hectares per hour (1.5 to 2.0 acres per hour) for soil spots in grids. Applicators on all-terrain vehicles (ATV's) can also apply foliar and basal sprays, with rapid movement among scattered stems. ATV and backpack methods have terrain limitations for safe operations, but the future use of ATV sprayers for flat to rolling terrain appears promising.

Patch distribution of hardwoods

Skidder-mounted sprayers are most effective for traveling from patch to patch and along old windrows to apply sprays, pellets, or granules. Application can be directed to one side of a tractor to treat along old windrows, and handgun attachments can be used to spray tall scattered hardwoods. ATV's or small skidders may be more efficient for higher speed travel between patches, although backpack crews may be effectively trucked between large patches where access is possible.

Herbaceous Weed Control Applications

The same application options are available for herbaceous weed control as presented for woody control: helicopter, tractor, ATV, and backpack sprayers and spreaders. Banded and spot (small patch) treatments along planting rows and over individual seedlings are recommended in the first year to minimize costs and soil erosion. A 1.2- to 1.5-m (4- to 5-ft) wide band or a 1.8-m (6-ft) diameter spot result in about the same pine growth as broadcast treatments (Knowe et al. 1985, Creighton et al. 1987, Dougherty 1990). Presently, backpack crews apply most spot treatments, with productivity being about 0.6 hectares (1.5 acres) per hour.

Aerial broadcast is the best option for second and third year treatments for intensively managed plantations. In the spring-flooded flatwoods, broadcast by helicopter is presently the only usable equipment for all applications.

Planting machines have also been equipped with sprayers to apply banded treatments simultaneously with planting, which lowers application costs even further (White 1962, Gilbert 1972, Garner and Olinger 1982, Miller 1985). However, herbicide rates must be increased, often doubled, and/or herbicides with more residual activity must be used for preemergent applications in the early planting season to ensure residual control.

Even with some banded treatments, accelerated erosion can still occur because all acreage cannot be treated with bands parallel to the contour. Minor drains and gullies can run across bands, channeling water and soil. Inspection of the terrain and soil during the prescription process should result in wise applications to minimize erosion. Spot treatments centered over individual seedlings is an option that is less prone to erosion and still can produce

comparable growth gains and better investment returns than banded treatments (Busby 1989, Dougherty 1990).

HERBICIDE TECHNOLOGY - FUTURE POSSIBILITIES

If the use of forest herbicides continue at the present or expanded levels, not diminished by public "pesticide phobia" and regulatory restraints, herbicide manufacturers will continue to develop broader spectrum products for this viable market. These newer herbicides, or mixtures of herbicides, will permit more precise control of woody and herbaceous species while further minimizing environmental risks. Such treatments will permit the speedy and assured reforestation and reclamation of southern forests--pines, hardwoods, and mixtures. However, costs will escalate as manufacturers pass on soaring developmental investments associated with new product registration. The ten-fold increase in product development and registration costs seen during the past ten years will continue to rise as additional health and environmental testing is imposed.

Early plantation growth will be dramatic, accelerated by herbicide treatments, fertilizers, and insecticides applied to genetically improved planting stock. However, accelerated early growth will mean higher proportions of juvenile wood, especially as rotations are shortened. As fast-grown plantation wood becomes more available, utilization and pulping practices will be modified to accommodate the cheaper resource. An alternative may see the careful management of wood growth by adjusting planting densities and thinnings in concert with growth acceleration treatments to yield specific wood quality for selected products.

Larger future investments by users will demand more critical decisions on where, what, and how herbicide treatments will be applied. The prescription process will become even more complex, with the usual inputs of crop and target species, soil-site, and terrain factors mixed with new inputs involving multi-resource considerations, multiple liability hazards with diverse ownership patterns, and new regulatory constraints. Computer-based decision support systems for prescribing forest herbicides, like the recently released ChESS system by Virginia Tech University, will be required (Zedaker et al. 1988). ChESS is a usable prototype system that integrates most site-stand information and liability considerations to provide the user with a list of registered herbicides, along with the best application rates, and ratings of potential outcomes. Such systems will be increasingly needed so that new and casual users can continue to receive the benefits from this highly technical and evolving field.

In the realm of herbicide application technology, many future scenarios are possible. Much hinges on the continued use of helicopters for applications as forest lands and homesites become even more interspersed. New guidance systems using electronic telemetry will be required to ensure effective coverage and to prevent chemical trespass of adjoining lands.

Probably less total land area will be treatable by helicopters, as land use becomes diverse and more sites are placed into sensitive zones, buffer areas, and special management zones. This will require more selective and efficient ground applications with tractors, ATV's, tree injectors, and backpack crews. With the increased utilization of hardwoods and better forest access, the possibilities for ground application by tractors and handcrews will increase and thus become profitable on more sites. As industry realizes the need for these alternative application systems, a concerted effort will be required to develop low-drift, high performance, and electronically guided sprayers and spreaders, mounted on suitably balanced ground equipment. Some of this development is already underway by certain companies, but the efforts tend to be piecemeal and not integrated.

Well-trained and reliable ground applicators will be in demand. To build this labor force will require more training on proper handling procedures, application techniques, and safety equipment. Ergonomically designed protective clothing,

head gear, and eye wear will be increasingly needed that eliminates herbicide exposure while preventing excessive heat stress. The use of modern fabrics and materials should permit their development.

Another innovation worthy of development is a herbicide applicator combined with a tree shear or saw felling head (Vidrine 1984, 1988). Hardwood stumps could be treated simultaneously with felling and resprouting easily prevented. Application costs would be minimized and regeneration time shortened with the right system. Figure 1 shows a possible design using multiple directional valves along a shear head for dispensing the appropriate amount of herbicide relative to the stump size.

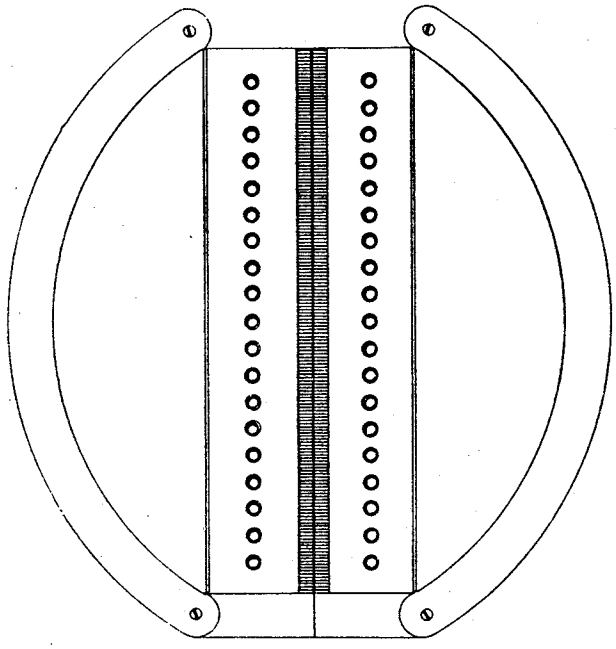


Fig. 1. A Shear Head With Rows of Directional Valves for Herbicide Application to Stumps of Varying Size.

A growing data base is also accruing on preharvest hardwood treatments--those that are made 1 to 5 years prior to harvest. Soil-active herbicides with pine tolerance and the use of several growing-season prescribed burns are showing promise as treatments to lower site preparation costs of the next stand. Some preharvest treatments can be expensed as a harvesting aid and thus have a tax benefit. The tax savings reinforce the other benefits of reduced competition in the next stand, easier harvesting, reduced haulage costs for deadened hardwoods (due to lower wood moisture content), and a shortened regeneration time. Thus, preharvest hardwood utilization combined with control treatments will be a strategy of the future for many sites.

The one-pass minimum-tillage trend in agriculture can be brought into silviculture. Figure 2 shows an integrated regeneration train of equipment that can shear, subsoil, and cultivate while applying herbicides, insecticides, and fertilizers. Savings in application costs can be realized with the right one-pass approach, while minimizing soil compaction that deters seedling growth.

Integrated research and development is required that extends across proprietary bounds and individual piecemeal efforts. The main effort will have to be shouldered by industry, owing to the government's current leaning toward privatization. Some Northern European countries and Canada, New Zealand, and Australia are leading the way in regeneration mechanization. We should learn from these countries and initiate our own integrated development programs. This is a worthy area of research and development that requires a cooperative responsibility and jointly shared expense.

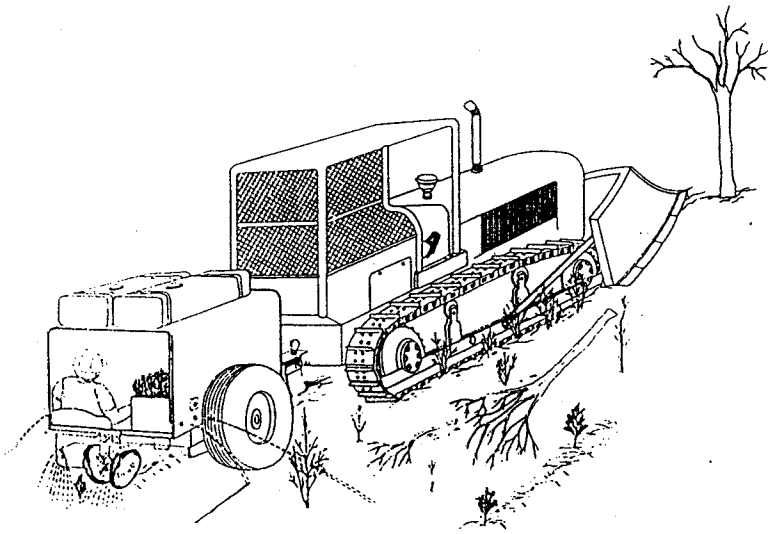


Fig. 2. A Conceptual Integrated Regeneration Train of Equipment Having a Shearing Blade, Ripping Blade, Cultivator, and Tree Planting Machine. Fertilizers, Insecticidies, and Herbicides for Woody and Herbaceous Weed Control can be Simultaneously Applied.

REFERENCES

Boyer, W.D. 1987. Volume growth loss: a hidden cost of periodic prescribed burning in longleaf pine? South. J. Appl. For. 11(3):154-157.

Burkhart, H.E. and P.T. Sprinz. 1984. A model for assessing hardwood competition effects on yields of loblolly pine plantations. School of Forestry and Wildlife Resources. Va. Polytech. Inst. & State Univ., FWS-3-84, 55 p.

Busby, R.L. 1989. Economic returns using sulfometuron methyl (Oust) for herbaceous weed control in southern pine plantations. In: Proceedings Fifth Biennial South. Silv. Res. Conf., Memphis, TN. p. 359-364.

Clason, T.R. 1978. Removal of hardwood vegetation increases growth and yield of a young loblolly pine stand. South. J. Appl. For. 2:96-97.

Clason, T.W. 1989. Early growth enhancement increases loblolly pine growth. South. J. Appl. For. 13:94-98.

Clason, T.W. 1988. The economics of competition control for loblolly pine plantations. p. 11-1 to 11-7 in J.H. Miller and R.J. Mitchell (eds.), A Manual on Ground Applications of Forestry Herbicides. USDA For. Serv. Manage. Bull. R8-MB-21. 316 p.

Creighton, J.L., B.R. Zutter, G.R. Glover, and D.H. Gjerstad. 1987. Planted pine growth and survival responses to herbaceous vegetation control, treatment duration, and herbicide application technique. South. J. Appl. For. 11:223-227.

Dangerfield, C..W., and H.L. Merck. 1990. Helping pines earn more with weed control. USDA For. Serv. Tech. Publ. R8-TP-14. 23 p.

D'Anieri, P., S.M. Zedaker, and A.B. Hairston. 1986. Understory hardwood control in Virginia coastal plain loblolly pine stands. In: Proc. South. Weed Sci. Soc. 39:253.

Dougherty, P.M. 1990. Survival and growth responses of loblolly pine to a range of competition control. Georgia For. Res. Paper No. 81, Georgia Forestry Commission, 5 p.

Dubois, M., W.F. Watson, T.J. Straka, and K.L. Belli. 1991. Costs and cost trends for forestry practices in the South. Forest Farmer, manual edition. 28:26-33.

Garner, J.W. and H.L. Olinger. 1982. Modification of a tree planter to include herbicide application. Tree Planters' Notes 33(3):13-14.

Gilbert, R.C.A. 1972. Sprayer-equipped planter applies herbicides at planting time. Tree Planters' Notes 23(2):8-10.

Glover, G.R. and D.F. Dickens. 1985. Impacts of competing vegetation on yield of the southern pines. Georgia For. Comm. Res. Paper No. 59. 14 p.

Glover, G.R., J.L. Creighton, and D.H. Gjerstad. 1986. Vegetation control significantly increases loblolly pine growth for 10 years. Auburn Univ. Silv. Herbicide Coop. Res. Note No. 86-6, 10 p.

Glover, G.R., J. Creighton, and D.H. Gjerstad. 1989. Herbaceous weed control increases loblolly pine growth. J. Forestry 87:47-50.

Haywood, J.D., and A.E. Tiarks. 1990. Eleventh-year results of fertilization, herbaceous, and woody control in a loblolly pine plantation. South. J. Appl. For. 14:173-177.

Hickman, C.A., W.C. Anderson, and R.W. Guldin. 1987. Economic assessment of chemical versus mechanical site preparation. In: Proceedings Fourth Biennial South. Silv. Res. Conf., Atlanta, GA. p. 274-282.

Kidd, F.A. 1987. Application and use of herbicides in forest and industrial right-of-way sites. p. 297-312 in C.G. McWhorter and M.R. Gebhardt (eds.) Methods of applying herbicides, monograph series, Weed Sci. Soc. Am. No. 4. 358 pp.

Kline, W.N. and F.A. Kidd. 1986. Economics of brush control in loblolly pine plantations. Proc. South. Weed Sci. Soc. 39:324-329.

Knowe, S.A., L.A. Nelson, D.H. Gjerstad, B.R. Zutter, G.R. Glover, P.J. Minogue, and J.H. Dukes, Jr. 1985. Four-year growth and development of planted loblolly pine on sites with competition control. South. J. Appl. For. 9(1):11-15.

Langdon, O.G. and K. Trousdell. 1974. Increasing growth and yield of natural loblolly pine by young stand management. In: Proceedings Symposium on Management of Young Pines, Alexandria, LA, and Charleston, SC. p. 288-296.

Lowery, R.F. 1987. Granular formulations and application. p.165-176 in C.G. McWhorter and M.R. Gebhardt (eds.), Methods of Applying Herbicides, monograph series, Weed Sci. Soc. Am., No. 4. 358 pp.

McClay, T.A. 1955. Loblolly pine growth as affected by removal of understory hardwoods and shrubs. USDA For. Serv. Southeast. For. Exp. Stn. Res. Notes 73. 2 p.

Metcalfe, C.S. 1986. Effect of herbaceous weed control on young pines. Proc. South. Weed Sci. Soc. 39:192.

Michael, J.L. 1985. Growth of loblolly pine treated with hexazinone, sulfometuron methyl and metsulfuron methyl for herbaceous weed control. South. J. Appl. For. 9(1):20-26.

Michael, J.L. 1986. Fate of Arsenal in forest watersheds after aerial application for forest weed control. USDA Forest Service, Southern Forest Experiment Station Final Report No. FS-SO-4104-1.20.

Miller, J.H. 1985. Ground applications. In Herbicides and Forestry. Univ. of Georgia, Center of Continuing Education. December 12-13, 1985, Athens, GA, p. 36-55.

Miller, J.H., Z. Qiu, and D.L. Sirois. 1985. Ground sprayer designs for forestry applications. Proc. South. Weed Sci. Soc. 38:271-282.

Miller, J.H., B.R. Zutter, S.M. Zedaker, M. Cain, M.B. Edwards, G.K. Xydias, A.R. Applegate, R.L. Atkins, S. Campbell, E. Daly, C. Hollis, S. A. Knowe, and J. Paschke. 1987. A region-wide study of loblolly pine seedling growth relative to four competition levels after three growing seasons. In: Proceedings Fourth Biennial South. Silv. Res. Conf., Atlanta, GA. p. 581-591.

Miller, J.H., and L.M. Bishop. 1989. Optimum timing for ground-applied forestry herbicides in the South. USDA Forest Service, Management Bulletin R8-MB 28. 2 pp.

Miller, J.H., B.R. Zutter, S.M. Zedaker, M.B. Edwards, J.D. Haywood, and R.A. Newbold. A regional study on the influence of woody and herbaceous competition on early loblolly pine growth. South. J. Appl. For. (in press)

Nelson, L.R., R.C. Peterson, L.L. Autry, S. Dudley, and J.D. Walstad. 1981. Impacts of herbaceous weeds in young loblolly pine plantations. South. J. Appl. For. 5:153-158.

Russell, T.E. 1961. Control of understory hardwoods fails to speed growth of pole-size loblolly. USDA For. Serv. South. For. Exp. Stn. Note 131. 4 p.

Sage, R.D., D.L. Dowdell, and J. Stephenson. 1984. Large scale-ground applied Velpar[R] L Weed Killer herbicide for forestry site preparation. Proc. South. Weed Sci. Soc. 37:156-160.

Vidrine, C.G. 1984. Machine application of herbicides for hardwood control--a concept. In: Proceedings Third Biennial South. Silv. Res. Conf., Atlanta, GA, p. 118-121.

Vidrine, C.G. 1988. Machine application of cut stump treatment herbicides. Proc. South. Weed Sci. Soc. 41:211-215.

Whipple, S.S. and E.H. White. 1965. Response of planted loblolly pine following various conversion methods. Auburn Univ. Agric. Exp. Stn. Bull. 362. 26 p.

White, G. 1962. Chemical weed control as a planting operation. J. For. 60:256-257.

Williamson, M. and J.H. Miller. 1988. Handcrew application methods for woody plant control. p. 2-1 to 2-11 in J.H. Miller and R.J. Mitchell (eds.), A Manual on Ground Applications of Forestry Herbicides. USDA For. Serv. Manage. Bull. R8-MB-21. 316 p.

Zedaker, S.M., G.J. Buhyoff, and J.W. Roach. 1988. A chemical silviculture expert system. Proc. South. Weed Sci. Soc. 41:217.

Zutter, B.R., G.R. Glover, and D.H. Gjerstad. 1986. Effects of herbaceous weed control using herbicides on a young loblolly pine plantation. For. Sci. 32(4):882-899.