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Marlin C. Galbraith

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*By Marlin C. Galbraith**

INTRODUCTION

Publicity about environmental problems has done for forestry what a half century of hard work in the woods couldn't do. It has made our forests a subject of popular concern. This is fortunate, as forests are a fundamental resource, essential to civilization.

Forests supply raw material for most of our buildings and for thousands of other products made from wood fiber, including pulp, paper and wood chemicals. The forest is a dynamic part of the ecosystem in which we live, supplying oxygen, watershed protection, wildlife habitat, recreation, and esthetic relief from the cities and suburbs. Forests are a major element in our esthetic life, a valued part of our experience. Forests are relatively efficient in supplying society's needs in that they directly capture solar energy and promptly convert it to useful products. In contrast, fossil fuels are the result of a process requiring millions of years. Above all, properly managed forests are renewable, providing not only great versatility but also endless bounty.

But this versatile and endless resource is not without problems. There are many conflicting demands on forest land. There are changing priorities related to natural resources. There are major decisions, with far-reaching consequences, to be made about the way we use our forests. Many believe forests cannot be used as a source for wood and wood fiber without reducing or destroying the other benefits forests provide.

Proposals have been made that our timber lands be preserved without roads or timber harvesting, but this may not always be the wisest and best use. Management for the production of successive crops of wood products is not necessarily incompatible with other uses and values; further, there is a real need for forest products. This demand will double by the year 2000, less than a generation away.

How can we provide the needed wood source and still maintain a proper forest environment for other uses and values? This question is especially acute in Rocky Mountain forests where the continuing harvesting of mature stands of lodgepole pine timber generally requires an even-aged silvicultural system of management to ensure regeneration and to cope properly with insect and disease problems.

Regeneration Systems of Forest Management

Over several centuries, foresters have developed two major groups of silvicultural systems, even-aged and uneven-aged. Though devised mainly for timber production, these systems are based on the ecology of forest tree species. Hence, they are also adaptable to other forest uses.

In the uneven-aged, or selection system of management, trees are harvested singly or in small groups throughout the forest on a regular schedule determined by a specific growth rate on a unit area of land. This system creates and maintains a forest that consists of all sizes of trees on small units of land, from seedlings in new openings following cutting to fully mature trees ready for harvest. The uneven-aged system simulates the process of death and replacement of trees in a forest free of the major natural disturbances that interrupt successional stages of forest ecosystems.

Even-aged silviculture simulates the process of death and replacement after major natural disturbances—fire, windthrow, or outbreaks of destructive insects or diseases. In the even-aged system, all trees over a larger area, rather than individual scattered trees, are harvested on a schedule that permits the process to go on indefinitely. Even-aged management is not as simple in practice as it sounds. Variations in soil productivity and species composition affect growth rates and harvest schedules.

In both systems of management, prompt regeneration is critical. Slowness or failure of regeneration adversely affects many values—production of timber, water yields, recreational opportunities, and scenic quality. In an uneven-aged system, a natural seed source is available from remaining trees, but regeneration must be left largely to chance because it is not feasible to prepare a favorable seedbed in the many small openings created by the cutting of many scattered trees. However, there is a recurring source of seed.

In even-aged management systems, three basic methods of harvest cutting provide seed in different ways. In the "seed-tree" method, a few selected, high quality trees are left in small groups or individually scattered over the harvest area. After the new stand is established from seed, these "leave" trees may be removed or they may be left until a future cut is made in the new stand. The "shelterwood" method leaves several times as many trees per acre, leaving a rather open canopy above the seedbed. These are usually removed as soon as regeneration is established. The "clearcut" method removes all trees from an area in patches or strips. Seed for regeneration is provided by surrounding standing trees or by conebearing slash in the cutover area. The cutting pattern for each of the three even-aged management methods permits seedbed preparation and other treatments to facilitate regeneration of the new stand, either naturally or artificially.

An appropriate silvicultural system for any forest must satisfy management objectives for the land unit, must meet the ecological and silvicultural requirements of the tree species, and must recognize the varying conditions within the forest stands and sites. Because the ecological and silvicultural requirements of tree species differ, and a variety of stand and site conditions and management objectives exist, a number of different silvicultural prescriptions may be required.

Silviculture of Lodgepole Pine

In the Rocky Mountains, lodgepole pine is a major commercial tree species. It grows in a wide range of environmental conditions. Lodgepole pine is a component in nine habitat types throughout eastern Washington and northern Idaho.[1] In the Intermountain Region, it is an important tree in at least five recognized ecological habitat types: (1) subalpine fir—Engelmann spruce/dwarf huckleberry; (2) subalpine fir/pachistima; (3) subalpine fir/pyrola; (4) Douglas fir/pinegrass; and (5) Douglas-fir/snowberry. In all five of these types, lodgepole pine is a seral or subclimax species: it is strongly intolerant of shade and dependent on such natural disturbances as wildfire, blowdown, or insect or disease attacks for the successful establishment of a new stand. If such disturbances do not occur for a long time—300 years or more—lodgepole pine is replaced by subalpine fir or spruce in the first three types, and by Douglas fir in the last two. Attacks by insects, especially the mountain pine beetle, can considerably hasten the succession and replacement of lodgepole pine, principally in the subalpine fir/pachistima and Douglas fir/pinegrass habitats. Lodgepole pine stands in the Rocky Mountains are also commonly infected by dwarf mistletoe, a small parasitic plant whose sticky seeds spread the infection, in young growth particularly, at the rate of about one foot per year from tree to tree. Dwarf mistletoe seldom completely kills all of the trees in a lodgepole pine stand, but it does cause severe reductions in their growth rate, and occasionally leads to death of individual trees.

To a degree, depending on the past history of a stand with respect to fire and insect effects, lodgepole pine shows the genetic trait of cone serotiny: cones may remain closed on the tree, thus "locking in" the seed for many years. Serotiny is generally assumed to be a hereditary trait that is passed from one generation of trees to the next. When a fire kills a stand of lodgepole pine having serotinous characteristics, the heat causes the normally closed cones to open and release the seed. Cones of the succeeding stand are predominantly serotinous. The trees in some stands of lodgepole pine do not possess the ability to store seed in closed cones.[2] Regeneration in the openings in such stands ordinarily comes from the open cone portions of each annual cone crop. Cone serotiny strongly influences the amount and availability of the seed source for regeneration and thus dictates the appropriate management prescription for harvest. In stands where there is enough seed stored in closed cones, relatively large openings can be regenerated naturally. In stands without such a seed source, only relatively small openings (less than 200 feet) can be regenerated naturally.[3]

Research and experience have conclusively demonstrated that where timber production is a principal objective of management for a lodgepole pine stand and where other values are not significantly affected by clearcutting, this method is one of the best ways to achieve optimum timber production. Four considerations are involved:

(1) Clearcutting is often the best way to regenerate the species. Lodgepole pine needs full sunlight and mineral soil to successfully establish its seedlings. Clearcutting provides both.

(2) Clearcutting in mature stands of lodgepole pine is a most

effective method of combating dwarf mistletoe. All sources of this parasitic infection must be destroyed if a healthy new timber crop is to be established and maintained to maturity.

(3) Clearcutting is effective in breaking up extensive contiguous stands of overmature timber—an important step in preventing or minimizing serious insect outbreaks. It is also an effective and efficient way to salvage timber killed as a result of such outbreaks.

(4) Clearcut areas are best suited to regeneration by planting. Planting stock of genetically improved seedlings can be used to produce a superior forest.

There may be additional benefits gained from clearcutting. It often provides improved wildlife habitat and increases beneficial vegetative cover edge effects. Likewise, it may increase water yield from forested watersheds.

Although the clearcutting system is an ecologically sound method for harvest and regeneration of mature and overmature stands of lodgepole pine in the central and northern Rocky Mountains, it is criticized by many people as a timber harvest practice. Some environmentalists relate clearcutting to "devastation;" others have indicated that the practice has some undesirable environmental effects. Still others question the need for and the soundness of the practice.

Some of the identified problems can be solved, or at least markedly reduced, by better quality work in timber sales layout and administration, and by improved cultural practices following timber harvest operations. Such work and practices include properly locating, designing, and constructing roads to avoid readily visible and long-lasting scars; making clearcut patches or strips relatively small; shaping and spacing the patches irregularly to fit and blend in with the natural terrain and landscape; providing prompt and thorough slash disposal and roadside cleanup; and taking action to assure prompt and complete regeneration of the cutover area. One major problem which does need further study is the condition and appearance of clearcut units following cutting and removal of the merchantable material. Figure 1 shows a typical cutover area immediately following cutting and removal of the merchantable timber but prior to post-harvesting operations. As a comparison, Figure 2 shows a cutover area after "near-complete" harvesting has occurred.

FIGURE 1
Typical cutover area following cutting and removal of the merchantable timber and prior to post-harvesting operations.

LOGGING RESIDUE PROBLEMS

Current general practice is to use large bulldozers to place the mass of logging debris remaining on the ground following logging of clearcut units into individual piles of long, continuous windrows to be burned when burning conditions are satisfactory. Depending on the degree to which the piling or windrowing of the material was done and the completeness of the burning operation, the subsequent appearance and condition of the area varies considerably. In some instances, it may be a tangle of unsightly, half-burned, charred logs, limbs, and tops. In other situations, it may be fairly clean, except for the conspicuous charred stumps in blackened spots or windrows.

The physical appearance of the area is only one consideration, however. Current practices of timber harvest and treatment of the logging residue cause: (1) wood that is technologically suitable for

FIGURE 2
Cutover area after "near-complete" harvesting.

use being burned or left to decay; (2) possible environmental and ecological problems relating to nutrient cycling, regeneration, and erosion hazards; (3) increased fire hazards while debris remains on the ground; and (4) air pollution from the burning of residue.

A Study to Alleviate the Problem

Concern for these environmental and ecological problems of residue accumulation and for the utilization of more of the wood fiber was confined neither to the land managing agency nor to those criticizing timber harvesting practices. The timber industry itself was extremely interested in the possibility of solving some of the problems by making economic use of the residue. Leading in this direction was U.S. Plywood-Champion Papers, Inc., a major producer of lodgepole pine wood products in the Rocky Mountain area. Their concern culminated in their requesting a meeting with officials of the United States Forest Service to propose a joint study of potential economic use of lodgepole pine logging residues.

Testing of harvesting methods and utilization practices that would accomplish a higher degree of utilization and would be compatible with ecological, environmental, and economic objectives of management of timber resources on public lands was a basic part of the proposal. It was further proposed that the study involve use of the following combination of specialized timber harvesting machines, which appeared to offer the best possibilities for compatibility and minimum impacts on the forest environment:

1. Feller Buncher. This machine fells trees up to 24 inches in diameter and bunches them for easy pickup. It is particularly adaptable to close utilization practices, since it cuts trees off very close to the ground.
2. Grapple Skidder. The skidder moves the commercial tree-length logs to a loading area and all other material, except stumps, to the chipper site.
3. Chip Harvester. This machine is portable and can be set up in the woods. It is fed all live, dead, and down wood material not utilized for lumber products, chipping it up to make it available for total utilization of the wood fiber.

Both the administrative and research arms of the Forest Service expressed enthusiastic interest. Verbal agreement was reached to undertake a joint cooperative effort in studying post logging cleanup, residue utilization and positive regeneration following timber harvest. Scientists, technicians, and managers within the Forest Products Laboratory, the Intermountain Forest and Range Experiment Station, and the Intermountain Region of the Forest Service joined with professional personnel of U.S. Plywood-Champion Papers, Inc. for a study of complete tree and residue utilization of an overmature lodgepole pine forest within the Teton National Forest in Wyoming near the Continental Divide.

Study Objectives

The primary purpose of the study is to test the possibilities of utilization of logging residues. This will involve quantifying the nature and amounts of residues left on the site following conventional logging, how these residues can most efficiently be moved from the logging site, and if the conversion of residues into products is economically feasible. Studies of how this effects the cutting area will be closely related. Removal of logging residues, including the process used in such removal, will change the conditions for regeneration. It will radically reduce the need for slash disposal by burning. It will also have some effect on the protection or enhancement of esthetics, air quality, water quality, wildlife habitat, and other forest values and uses.

Studies have been initiated to provide answers to six basic questions:

1. What is the nature and amount of residues now left on a site following logging, including live and dead wood, standing and down trunk wood, and branches and needles? This will vary widely from site to site, depending on stand composition, age, and condition, so it is important to develop techniques for accurately estimating the amount and nature of this material before the initial cut is made.

2. What products can be manufactured from this material, by categories of mixes and residues? It is essential to know what can be deliberately produced from various mixes, instead of just taking mixes as they might come from the particular forest stand and seeing what can be made from them.

3. How can these residues be moved most efficiently from the forest to the wood-using plant? Since the residues to be moved may include dead and down material, tops, branches, and twigs, the materials handling problem is much different from the problem of handling logs. It may involve tree-length logging and chipping in the woods.

4. To what extent will regeneration problems be changed by removal of residue? How can we assure adequate, rapid regeneration? Even though in some situations there is an adequate seed source for natural regeneration provided by serotinous cones in lodgepole pine, there are other situations either where this is not the case or where the process of logging and debris disposal destroys the seed supply. This could be aggravated by tree-length logging that removes branches and twigs. Removal of the bulk of residues during logging may permit more prompt regeneration—perhaps even the same year as cutting takes place.

5. To what extent will the removal and utilization of residues, and the process used in such removal, protect or enhance forest values, including esthetics, air quality, water quality, and wildlife habitat? To what extent will residue removal alleviate the need for slash disposal by burning? Impacts of present utilization on these features of the environment are largely responsible for the opposition to timber harvesting. It is obvious that, in the evaluation of

feasibility of residue utilization, we must know to what extent we have overcome the impacts.

6. Is the conversion of residues into products economically feasible? Does this conversion as part of the total system have suitable cost-benefit ratio? It is apparent that certain portions of the present logging residual have commercial value as saw logs, posts, corral poles, or other solid wood products. Essentially, all of the sound material 4 inches and larger should be suited for such uses. Similarly, material of this size from dead trees and material unsuited for solid wood products because of length or form should be suitable for pulpwood chips or particle board. The value of this material depends, in part, on how its processing costs are related to the cost of the total manufacturing mix. Likewise, material less than 4 inches in diameter, including even limbs, could undoubtedly be utilized for chips or particles, provided the costs of processing in the woods were offset by other recoveries. Product values vary from time to time. Because of this, the point of marginality will vary. Similarly, the value yields will vary from one timber operation to the next, depending upon the offsetting effects of high-value and low-value products in the mixes. Along with the establishment of the break-even point for the various industrial products, the social values that affect the final "profit line" also must be considered. An input-output model is needed with which product costs and values along with social costs and values can be used to determine cost-benefit ratios. The ultimate tradeoffs can then be calculated using this model.

Study Design

Figure 3 illustrates the general layout of the study. As shown, commercial logs from all four units were hauled to the sawmill. The residual logging debris from units 1 and 4 was then skidded to the landings and chipped. The logging residues on units 2 and 3 will be piled by tractors for later burning, or will be broadcast burned in place.

Details of the studies set up to answer the six previously enumerated basic questions follow.

Characterization and Volume of Logging Residues

Part of this study has already been completed. Two different harvesting treatments, as previously described, were made on the four units. The two treatments compared were "conventional"

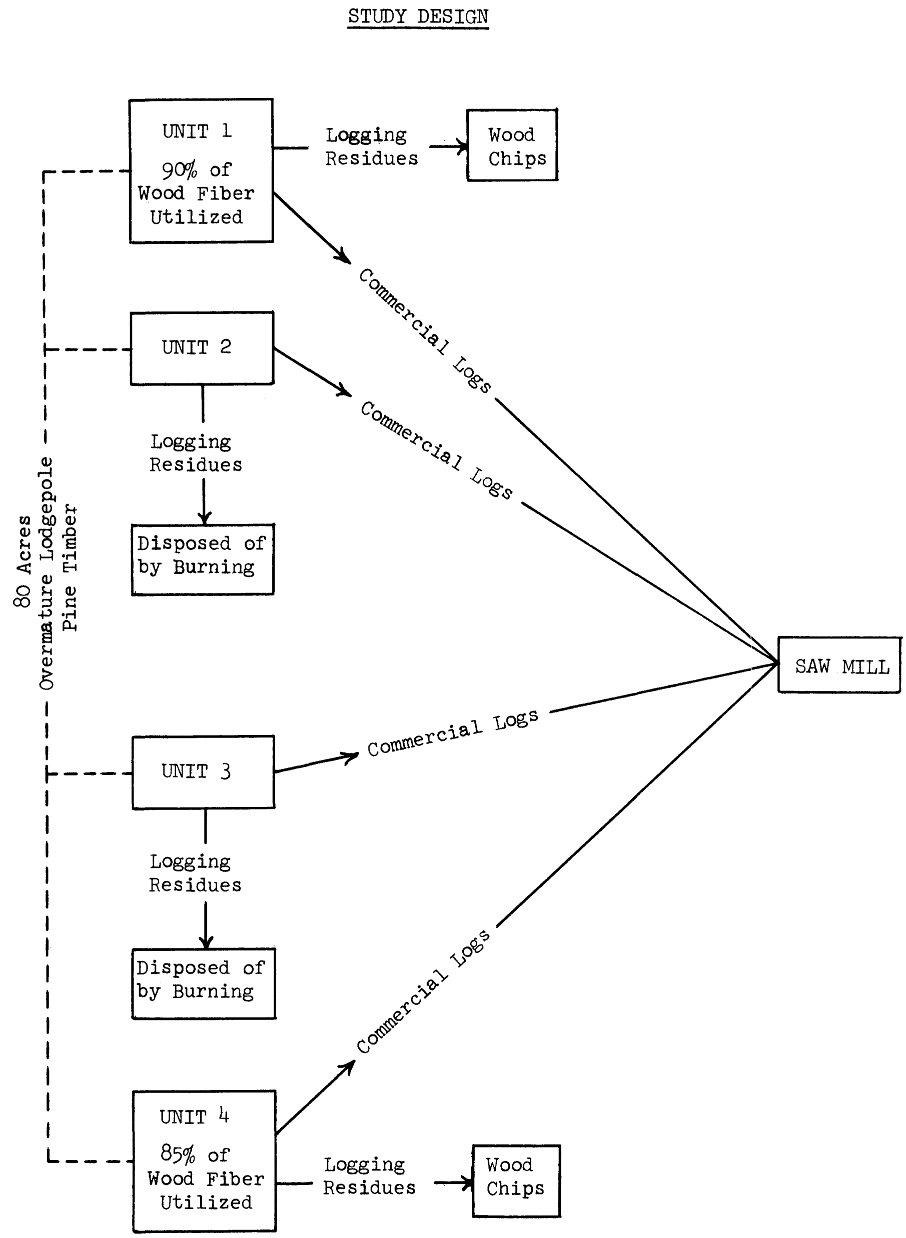

Figure 3

Study Design.

harvesting and "near-complete" harvesting. "Conventional" harvesting standards require only the removal, as logs, of all sound trees to a merchantable top diameter of 6 inches. The "near-complete" harvesting standards required removal of all merchantable trees, as logs, and the conversion of the following to chips at the site:

1. Tops of all merchantable trees.
2. All remaining live and standing sound dead trees 3 inches in diameter ($4\frac{1}{2}$ feet above the ground) and larger.
3. All sound down material over 6 inches in diameter at the large end and over 6 feet in length.

Before the four units were harvested, estimates were made of stand volume, number of trees, site index (site quality), and the volume of wood material lying on the ground. Figure 4 shows the large volume of sound wood fiber in a typical overmature stand of lodgepole pine.

After harvesting, the four units were surveyed to obtain estimates of the volume of wood material left on the ground. A systematic sample grid of twenty 50-foot transects was used in each unit to estimate the volume of remaining material 3.0 inches in diameter and greater.

FIGURE 4

Large volume of sound wood fiber on ground in typical overmature stand of lodgepole pine.

The weight of logs removed was obtained by weighing the loaded trucks. The weight of chips was determined by measuring the volume of chip piles by aerial photogrammetric techniques and applying a conversion factor of 14.4 lb./cu. ft.

The results of the study of the volume (weight) of material removed from the test units are as follows:

Average of adjusted tons per acre removed on units "nearly-completely" harvested	= 158
Average of adjusted tons per acre removed on units "conventionally" harvested	= 117
Difference in methods of harvesting	= 41
Percent increase due to "near-complete" harvesting	= 35%

This indicated increased yield of wood fiber is quite significant in terms of extending the wood supply for the Nation. The results of the study of the material remaining on the ground are equally significant. The sample previously referred to indicated that the volume of material over 3 inches in diameter remaining after logging on the units conventionally logged was approximately five times the volume left on the areas where more complete utilization was done.

Opportunities of Marketing Logging Residue

An analysis of utilization potentials of saw log and residue materials will be synthesized from recovered material. Highest potential use will be assumed. Actual utilization and marketing studies will be limited to lumber, logs, and particle boards; however, the cooperator and the Forest Products Laboratory will conduct utilization studies on particle board made up of various mixes of residue material, incorporating tops, limbs, dead wood, and needles. Possibilities of marketing the residue material will be largely dependent upon the cost of picking up and transporting this material to the area of processing and potential market.

A comparison of costs between logging under existing contract provisions (green logs to a 6-inch top), and logging under the specifications of the study will be made. Although actual data can only reflect the method or methods employed on the four study areas, costs will be simulated in the analysis to provide comparisons with other kinds or uses of equipment.

Regeneration and Nutrient Cycling

The objectives of the regeneration phase of the study are to evaluate, under varied utilization standards and residue disposal methods, the germination and survival of lodgepole pine under conditions imposed by the treatments, the growth and vigor of seedlings in relation to nitrogen status of natural and artificial seedlings, and the cost of natural and artificial regeneration methods and how they relate to other research conducted in the area.

The setup and design of studies to accomplish these objectives are quite complex. Each of the four cutting units will be divided into quarters (5-acre plots) for treatment of logging debris or chipped material, whichever is applicable. On the conventionally logged units, two quarters will be randomly selected for windrowed piling and burning. The remaining two 5-acre plots will be broadcast burned in place. On each of the two chipped areas, two randomly selected quarters will be uniformly covered by a volume of chips roughly equivalent to the amount of material originally removed from the area. The remaining two 5-acre plots on the chipped units will be left as they were following logging.

Each 5-acre plot will be further divided to evaluate the effect of treatments: (1) on establishment of natural lodgepole pine seedlings; (2) on seeding of lodgepole pine seed in prepared spots, similar to the method described by Lotan and Dahlgreen;[4] and (3) on planting of lodgepole pine seedlings in accordance with specifications set forth in the Intermountain Region Reforestation Handbook.[5]

Intensive utilization of the logging residue in lodgepole pine stands is a dramatic departure from conventional logging. Therefore, where considerable material remains on the site, additional studies closely related to regeneration will be made of the effects of treatments on soil chemistry and on nutrient cycling. Alternatives to current residue disposal techniques, such as spreading chips on site, may create significantly different conditions for future plant growth than does burning the slash or leaving it intact. Either potential practice—the spreading of chips as mulch, or their removal and utilization—will likely influence the establishment, survival, and growth of succeeding crop of trees. This will be due to changes in the microclimate and in physical and chemical properties of the soil. The greater proportion of plant nutrients removed in the intensive utilization process may temporarily deplete the nutrient supply for subsequent plant growth. In contrast, the spreading of chips on site will mulch the soil and cause a drastically altered microclimate within and immediately above the soil. This alteration plus the decomposition of the chips may cause nitrogen deficiency in newly developing seedlings.

The objectives of this portion of the study are to answer the following questions:

1. Does intensive utilization of lodgepole pine, coupled with selected debris disposal methods, have any measurable effect (compared to "standard" utilization) on the supply of available major plant nutrients in the top 15 cm. of soil?

2. Do any of the above treatments have any effect on the nutrient content of lodgepole seedlings or plantations on the respective sites?

3. Do the measured soil properties and amounts of major nutrients in lodgepole pine seedlings growing on these treated sites have any statistical correlation with seedling establishment, survival, height growth, and total dry-matter production?

Fuller utilization of logging residues could result in significant changes in the chemical components of subsurface waters. Each of the several types of treatment of logging residue embraced in this study may change the status of plant nutrients. These treatments, therefore, may affect the nutrient supply for regenerating stands and change the chemical quality of water yields from the site. Consequently, the effects of the selected residue disposal or utilization method on the chemistry of the soil-water extracts and, in part, on the chemistry of the soil will be evaluated.

The modified logging residue disposal or utilization practices in the lodgepole pine likewise may affect the biochemistry of the soil. Of particular interest is the effect of returning the logging residues to the soil as a chip mulch. This will probably influence the microbial flora of the soil and in turn influence the nitrogen available for plant growth. The planned biological examination of the soils will be geared towards study of organic matter, and especially to the changes in fluxes of nitrogen compounds. The principal objective of this cooperative research is to determine the kinds and levels of microbiological activity in the soil before and after several logging residue disposal treatments.

This program of full utilization of lodgepole pine will be conducted within the context of present requirements for multiple use coordination and protection of the environment.[6] Yet, within this context it is necessary to appraise the effects of alternatives in extending the use of lodgepole pine residues and the impact of their harvesting and transport on air, water, wildlife, fuel hazard reduction, and esthetics. An interdisciplinary team of specialists in ecology, air pollution, watershed management, wildlife management, and esthetics will evaluate results of alternatives proposed. The environmental assessment will be made by visiting test areas, observing results, and visually evaluating effects.

Cost-Benefit Analysis

This analysis will provide a measure of the feasibility and desirability of more complete utilization of available wood in lodgepole pine stands. The appraisal will be a combination of data comparisons and judgments with regard to values that are not measurable in dollars and in some cases not measurable at all. For each set of raw material physical inputs and for each set of physical product outputs, there are matching costs and values. In addition to those costs and values normally associated with consumer products, there are those costs and values associated with social benefits. Such things as the value of beauty will need to be compared with the value of a ton of wood chips; the costs of nutrient depletion, if any, will need to be compared with the value of essential oils; or the grinding of logging slash into the soil will need to be compared with burning, from a cost and value basis.

Some Preliminary Results

The problems of residue disposal and utilization associated with timber harvesting are not simple. They are generally linked with ecological, environmental, and economic factors pertaining to the management of the timber resource and to coordination complexities related to other resource uses and values. As such, identification and evaluation of a number of alternatives are essential; however, the alternatives do not lend themselves to easy differentiation. Many values are affected and, as this study illustrates, answers to "what are the consequences?" and "what is the optimum solution?" often take a long time to assess.

This study will not solve all of the problems. Even though the methods used in the study may provide some of the answers, namely, land management alternatives and information on harvesting techniques, a major unresolved problem is one of adequate markets.

The apparent gain in total fiber yield is a technological one; the economic feasibility of capturing it is another matter. Will consumers learn to accept more products processed from fiber as substitutes for the more scarce products made from solid woods? In the interest of forest conservation, will people be willing to use a slightly lower quality of paper for much of their paper needs?

The results of this study, while useful in comparable situations, cannot be reliably extrapolated and applied to other situations. There are a multitude of forest land conditions, some quite different from the lodgepole pine areas of the Rocky Mountains, and different methods may be needed.

The timber harvest and data collection portion of this study was completed in October 1971. Additional observations and analyses of onsite effects of the overall chipping treatment are expected to continue for some time.

As yet, it is too early to give definitive answers to the many questions that the study was designed to answer. However, preliminary observations provide the following indications as to the efficiency and overall practicability of "near-complete" utilization in lodgepole pine timber harvest operations in the Rocky Mountains:

1. On the type of area treated in this study, it appears that the yield of wood fiber in timber harvest operations can be increased by at least one-third if logging residues can be utilized.
2. Performance of special equipment used in this study indicates their effectiveness and efficiency in "near-complete" utilization operations.
3. Costs of skidding whole trees to landings appear to be no greater than costs of skidding only the merchantable portions.
4. Visual evaluation of the areas where utilization was "near-complete" indicates that such utilization practices will tend to reduce some regeneration costs.
5. The scattered amount of material remaining on the ground following "near-complete" utilization appears to be insufficient to constitute a potential fire hazard or to require additional disposal.
6. Overall, the practice of "near-complete" utilization indicates significant environmental benefits in the way of protection of esthetic values, reduced air pollution (through elimination of residue burning), and perhaps a shorter period of time between harvest of one crop of trees and establishment of a new crop.

Until cost data are completed and dollar and non-dollar benefits are more accurately assessed, and accurate appraisal of the environmental benefits and the technical and economic feasibility of complete residue removal cannot be made. At the present stage of the study, however, complete removal appears to offer some important advantages over current timber harvest methods and practices.

FOOTNOTES

* Assistant Regional Forester, Intermountain Region, United States Forest Service.

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[6] FOREST SERVICE MANUAL, ch. 2130, United States Department of Agriculture Forest Service.