RESEARCH BULLETIN 45 DECEMBER 1983

AN EVALUATION OF FOUR IMPLEMENTS USED TO TILL COMPACTED FOREST SOILS IN THE PACIFIC NORTHWEST

CHARLES W. ANDRUS
HENRY A. FROEHLICH

FOREST RESEARCH LAB

COLLEGE OF FORESTRY OREGON STATE UNIVERSITY

Since 1941, the Forest Research Laboratory--part of the College of Forestry at Oregon State University in Corvallis--has been studying forests and why they are like they are. A staff of more than 50 scientists conducts research to provide information for wise public and private decisions on managing and using Oregon's forest resources and operating its wood-using industries. Because of this research, Oregon's forests yield more in the way of wood products, water, forage, wildlife, and recreation. Wood products are harvested, processed, and used more efficiently. Employment, productivity, and profitability in industries dependent on forests are strengthened. And this research helps Oregon to maintain a quality environment for its people.

Much research is done in the Laboratory's facilities on the campus. But field experiments in forest genetics, young-growth management, forest hydrology, harvesting methods, and reforestation are conducted on 12,000 acres of College forests adjacent to the campus and on lands of public and private cooperating agencies throughout the Pacific Northwest.

With these publications, the Forest Research Laboratory supplies the results of its research to forest land owners and managers, to manufacturers and users of forest products, to leaders of government and industry, and to the general public.

As a research paper, this publication is one of a series that comprehensively and in detail discusses a long, complex study or summarizes available information on a topic.

The Authors

Charles W. Andrus at the time of this study was a graduate research assistant in the Department of Forest Engineering, College of Forestry, Oregon State University, Corvallis.

Henry A. Froehlich is a professor in the Department of Forest Engineering, College of Forestry, Oregon State University, Corvallis.

Acknowledgements

The authors wish to thank Hubert Williams of Rome Industries, Cedartown, Georgia, and Edward Radke of Radke's Repair and Iron, Monroe, Oregon, who supplied parts and ideas vital to the development of a prototype described in this bulletin.

Disclaimer

To Order Copies:

Copies of this and other Forest Research Laboratory publications are available from:

Forest Research Laboratory
College of Forestry
Oregon State University
Corvallis, Oregon 97331

CONTENTS

INTRODUCTION

The use of ground-based logging equipment can have widespread effects on a forest site. Following a single-entry harvest, 18 to 40 percent of the land may be covered by skid trails and landings. Soil compaction within these disturbed areas commonly extends to a depth of 15 inches or more and may persist for decades (Adams and Froehlich 1981). In heavily-used skid trails compaction may be accompanied by displacement of the topsoil.

Conifer seedlings planted in skid trails and landings often exhibit decreased height growth, and, in some cases, increased mortality (Froehlich 1973, Sands and Bowen 1978).[1] Compacted soil also causes growth losses in older stands of trees (Perry 1964, Wert and Thomas 1981), including thinned stands (Froehlich 1979).

Concern over reductions in site productivity has prompted some private and federal timberland managers in the Pacific Northwest to attempt to rehabilitate the soil in skid trails and landings. Tillage of the soil, using available logging equipment and forest tillage implements, provides potential solutions to the problem of soil compaction.

[1]USDI Bureau of Land Management. Influence of soil compaction on tree growth after tractor logging. Unpublished 1972 manuscript. Bureau of Land Management, Eugene, Oregon.

This paper evaluates methods used currently in the Pacific Northwest to till compacted forest soils and presents alternative methods that alleviate soil compaction more effectively and efficiently. This discussion is based largely on recent research conducted by the Department of Forest Engineering of Oregon State University. The paper focuses on tillage as a means of ameliorating soil compaction, although some of the principles discussed may apply to general objectives of site preparation.

The second section of this paper describes four tillage implements -- brush blades, rock rippers, disk harrows and winged subsoilers -- and their respective performances in the field.

The third section compares production rates and costs for each of the four implements and presents guidelines for selecting the most appropriate tillage implement for a variety of site conditions, soil types and tillage tasks.

BENEFITS OF TILLAGE

Undisturbed productive forest soils are highly porous and are penetrated easily by air, water, and roots. The purpose of tilling compacted soil is to break up the soil mass and thus promote the free movement of water and air. The loosened soil allows better tree planting and greater root growth and distribution. Tillage of compacted forest soils has been shown to increase seedling survival rates and height growth for a range of soil types and site conditions (Table 1). The effects of tillage on the growth of older trees are not yet known, although improved soil conditions would be expected to benefit tree growth.

TABLE 1.
GROWTH RESPONSE OF SEEDLINGS PLANTED IN TILLED (FORMERLY COMPACTED) FOREST SOILS

Soil type[a]	Description of site and tillage	Increased survival	Increase in height
		percentage	
Clay loam (I)	Skid trails and landings ripped 18-24 in. deep	55	36[b]
	Compacted ridge top ripped 18-24 in. deep	17	73[b]
	Logged area ripped 30 in. deep	11	67[b]
Clayey glacial tillite (II)	Eroded area ripped 18 in. deep	66	69[b]
Clay loam (III)	Skid trails tilled with brush blade	--	50
Shallow stony soil (IV)	Ripped 18-24 in. deep	83	13
Gravelly loam (V)	Ripped 39 in. deep	13	17[b]

[a]Sources for information presented in each horizontal column are as follows: (I) Bert 1975; (II) Ritchie 1965; (III) personal communication, 1981, from W.E. Power, USDI Bureau of Land Management soils specialist, Salem, Oregon; (IV) Nichols and Reaves 1958; (V) Craig et al. 1977.
[b]Fertilizer applied to tilled and control plots.

FOUR TILLAGE IMPLEMENTS: THEIR DESIGN AND PERFORMANCE

The conditions left by logging prevent a direct application of agricultural tillage methods to forest land. Large roots, logging slash, rocky soil, and steep terrain can render conventional tillage methods ineffective. This study evaluates the efficiency of four types of tillage implements: brush blades, rock ripper tines, disk harrows and winged subsoilers (Figs. 1, 3, 4, 6).

This study is based on the work of Oregon State University researchers who in 1980 began evaluating tillage methods for loosening compacted forest soils in the Pacific Northwest.[2] Initial observations determined the effectiveness of using rock ripper tines and brush blades over a range of site conditions. Subsequent observations centered on disk harrows and winged subsoilers.

Soil density and strength measurements were, whenever possible, taken prior to tillage to determine the degree and depth of soil compaction. Skid trail profiles before and after tillage provided measurements on the extent of soil shattering. Samples of tilled oil were sieved to determine clod size. A detailed time-study provided information on the productivity of tillage operations.

Descriptions of the four implements and of their respective performances in the field follow.

BRUSH BLADES

DESCRIPTION

The brush blade (Fig. 1) is a common, readily available implement. It can be used to loosen compacted forest soils, although it is designed primarily for other uses. It is easily mounted on a crawler tractor.

Front-mounted brush blades are most often used to pile slash, although the six to ten tines on the underside of the blade have sometimes been used to rip soil. The space between tines ranges from 12 to 30 inches; tine length ranges from 10 to 20 inches.

Andrus, C. 1982. Tilling compacted forest soils following ground-based logging in Oregon. Unpublished Master of Science thesis, Department of Forest Engineering, School of Forestry, Oregon State University, Corvallis.

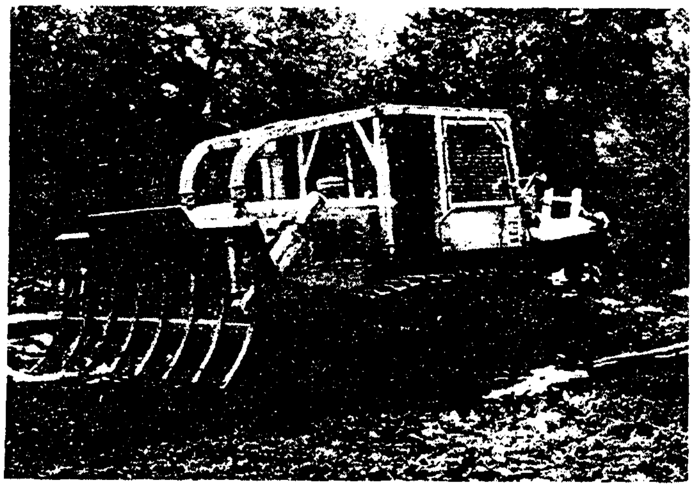

FIGURE 1.
BRUSH BLADE.

As a brush blade tine moves through the soil, it displaces the soil forwards, sideways, and upwards. At shallow ripping depths soil displacement by a tine is primarily upwards, resulting in a desirable V-shaped shattering pattern. However, at ripping depths exceeding some critical depth,[3] most of the soil is displaced to the side of the tine tip (Fig. 2). Undesirable compression occurs, rather than shattering of the soil. Operation of tines below the critical depth is also undesirable because it greatly

[3]The critical depth varies with both tine geometry and the soil conditions. High soil moisture and high soil strength decrease the critical depth, especially in clayey soils. Alternatively, inclining the tine forward (thus creating a smaller rake angle--see Fig. 5, p. 6, for illustration of rake angle) or increasing the tine tip width increases the critical depth.

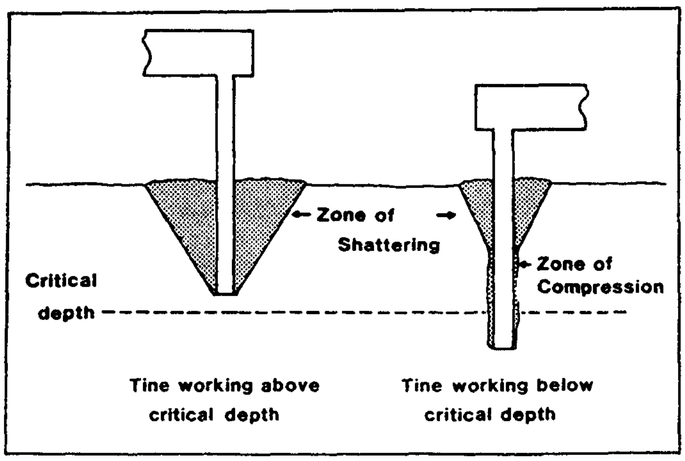

FIGURE 2.

MODE OF SOIL LOOSENING AS A TINE MOVES THROUGH THE SOIL.

increases the force required to move the tines through the soil. In addition, tines working below critical depth produce continuous, well-defined slots that can channel water and cause soil erosion along tilled paths in steep terrain.

FIELD PERFORMANCE

The brush blade designs did not effectively loosen compacted forest soils during field studies at three sites of varying conditions. The brush blade loosened only the first 4 to 7 inches of soil in primary skid trails in which pre-tillage measurements showed soil compaction more than 12 inches deep.

The brush blade tines were too short and too close together to allow soil and logging debris to pass readily. Therefore, soil built up in front of the blade and formed berms alongside the trail. The depth of loosening and the amount of soil displacement depended on the care taken by the operator. Frequent lifting of the blade (every 5 to 10 feet) helped disperse the loosened soil more evenly and allowed the operator to keep the tines at a greater depth when tilling. However, frequent stops to raise and lower the blade increased tillage time.

Brush blades with longer tines and greater tine spacing allowed soil to pass between the tines more readily; however, these blades were usually wider than the skid trails. That excessive width, combined with the concave shape of the skid trail, meant that only the outer tines loosened the deepest layers of compacted soil.

At most of the study sites the skid trails were required to be waterbarred as well as tilled. Waterbars were easily constructed with the brush blade as the tillage operation progressed, thereby making it unnecessary for the crawler tractor to travel over the tilled skid trails a second time. However, some recompaction of soil by the machine tracks occurred even after only one pass of the crawler tractor.

ROCK RIPPERS

DESCRIPTION

Rock rippers (Fig. 3) are similar to brush blades. Like a brush blade, a rock ripper is a common, readily available implement that can be used for tillage, although it is designed primarily for other uses. It also is mounted, more or less permanently, on a crawler tractor. Unlike a brush blade, the rock ripper is mounted on the rear of a tractor.

FIGURE 3.
ROCK RIPPER.

Rock rippers observed for this study had two to five tines. Tine spacing ranged from 20 to 48 inches. Tine length varied from 22 to 47 inches.

The rock ripper produces a soil-displacement pattern similar to that produced by a brush blade. As the rock ripper moves through the soil, it pushes soil ahead, to the side and up. At shallow soil depths, the rock ripper produces a desirable V-shaped pattern. However, if tine depth exceeds the critical depth,[4] the rock ripper produces a narrow slot in the soil below a reduced zone of shattered soil.

FIELD PERFORMANCE

Tilling with five different rock rippers was observed at five sites representing a range of site conditions; a different type of rock ripper was used at each site. The tilling at each site was done with one pass of the rock ripper used. In all cases, either spacing between tines was too great or the ripping depth too shallow to loosen all of the compacted soil within skid trails. The rock

[4] See footnote on p. 3 for explanation of critical depth.

ripper tines produced V-shaped areas of shattered soil where seedlings might be readily established. However, 55 to 80 percent[5] of the compacted soil was not loosened. The remaining compaction may limit the growth of seedling roots that venture beyond the V-shaped zones of loosened soil. Root growth of older trees adjacent to tilled trails would also be impeded wherever tillage was incomplete.

The soil between tines that remained compact might have been tilled successfully if the operator had made a second, but offset, pass with the tines. However, this second pass would have been effective only if the tines were kept from following the rip marks made during the first pass.

At one site, poor tine design (small tip width and large rake angle) coupled with high soil strength resulted in minimal soil loosening. The tines produced narrow slots at depths greater than 10 inches with little fracturing above this depth.

High soil moisture at another site caused ripping tines to produce only vertical slots in the soil at depths greater than 10 inches. Although this site was tilled in late summer, the soil within skid trails had a high moisture content (32 percent). This high moisture content was caused in part by a lack of vegetation to extract water from the clayey soil.

At two sites, the rock ripper used had tine spacing of less than 24 inches. As was true with brush blade tilling, this narrow spacing repeatedly caused logging slash and loosened soil to collect in front of the ripping tines. Periodic delays resulted because the operator had to stop to raise and clear the tines.

Existing waterbars within skid trails were avoided easily when tilling with rock rippers. Constructing new waterbars during the tillage operation was accomplished either by leaving short stretches of untilled soil or, on steeper sites, by excavating a waterbar trench with the crawler tractor blade.

[5] Estimate of remaining soil compaction stems from an assumption that original compaction depth was 15 inches. This assumption is based on measurements from soil pits dug on the rock ripper tillage sites and on measurements at other sites that indicate depth of compaction usually is 8 to 24 inches.

DISK HARROWS

DESCRIPTION

The use of disk harrows for tillage of agricultural soils has been widespread for many years. However, disk harrows are not often used on compacted forest soils in the Pacific Northwest. Conventional disk harrows (Fig. 4) are not designed to till irregular terrain, cut through wood debris, penetrate heavily-compacted soil and maneuver tight turns. However, design changes that adapt the disk harrow to these difficult site conditions are possible.

A

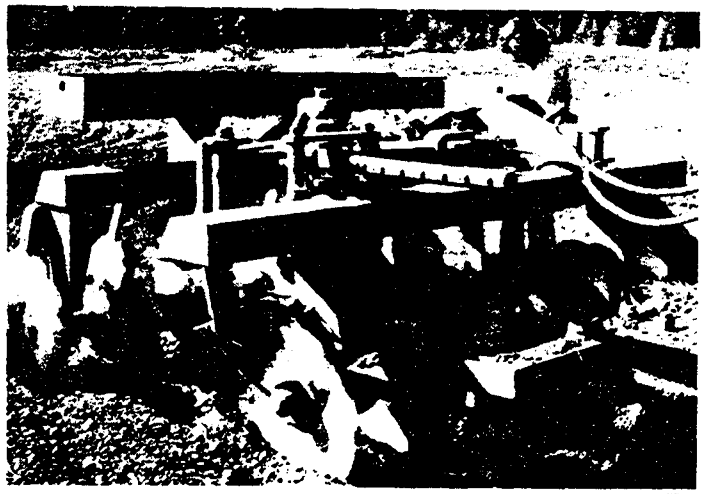

FIGURE 4. B

DISK HARROWS WITH OPPOSED GANGS (A) AND OFF-SET GANGS (B).

After observing a number of disks being used on skid trails, we believe that arranging the disks so that they act independently of each other can improve tillage of irregular terrain or rocky soil. This design allows disks to operate smoothly if adjacent disks encounter a high spot, rock, or piece of wood. Equipping the disk harrow with large heavy-duty disks and increasing the weight of the harrow also allows somewhat deeper tilling of heavily compacted soil. Finally, arranging the disks in opposed gangs rather than in an offset fashion shortens the implement length and increases maneuverability. Designs allowing the disk to be lifted off the ground by a winch line or a hydraulic frame offer even greater mobility. No manufacturer incorporates these important features in one implement. This current unavailability contributes to the limited use of disk harrows on forest sites in the Pacific Northwest.

FIELD PERFORMANCE

Disk harrows were tested at five sites, despite expected design limitations of the implements used. Three disk harrows used at one or more of the sites are described in Table 2.

Skid trails at two sites, both with moist clayey soil, were tilled with Disk Harrow A (Fig. 4b and Table 2). Disk penetration averaged less than 4 inches deep across the skid trails. The average disk weight was too light to overcome the high strength of the compacted soils at these two sites. In addition, large pieces of logging slash occasionally caused the disks to ride on top of the trail surface. The disk harrow was wider than the skid trails and therefore the outer disks also rode along the trail berms, thus preventing the center disks from penetrating the soil. The length of this harrow prevented the operator from making tight turns or backing up.

TABLE 2.

DISK HARROW SPECIFICATIONS

Disk Harrow	Disk diameter (in.)	Disk thickness (in.)	Number of disks (gang arrangement)	Average disk weight[a] (lbs)	Swath width (ft.)
A	36	1/2	16 (offset)	1,250	11-1/2
B	32	1/2	6 (opposed)	600	8-1/2
C	30	3/8	24 (offset)	500	11

[a]Weight of disk plus added weight (if any), divided by number of disk blades.

Tillage depth was also insufficient at two sites where Disk Harrow B (Fig. 4a and Table 2) was tested. At one site, large rocks within the soil kept disks from penetrating the soil. At the other site, insufficient average disk weight limited the depth of soil loosening to 2 inches. The short length of Disk Harrow B (about 12 feet) allowed easy maneuverability even on steep trails. The harrow was lifted off the ground easily by a winch line from the crawler tractor (Fig. 4a). This feature was particularly important in avoiding damage to waterbars during the tillage operation.

Area-wide tillage (within and outside of the skid trail) was performed on a fifth site using Disk Harrow C (Fig. 4b and Table 2). The purpose was to eliminate brush on 80 percent of the site as well as to loosen compacted soil in skid trails. The disks on this agricultural harrow were thin and many broke when they struck rocks in the soil. The few stumps and residual trees on this site did not hamper the maneuverability of the offset disk harrow. Two to three passes of the harrow were required to loosen soil to a depth of 8 inches.

WINGED SUBSOILERS

DESCRIPTION

Adding wings to the sides of a tine (Fig. 5) increases the amount of soil loosening accomplished by the tine and increases the critical depth at which the tine can work.

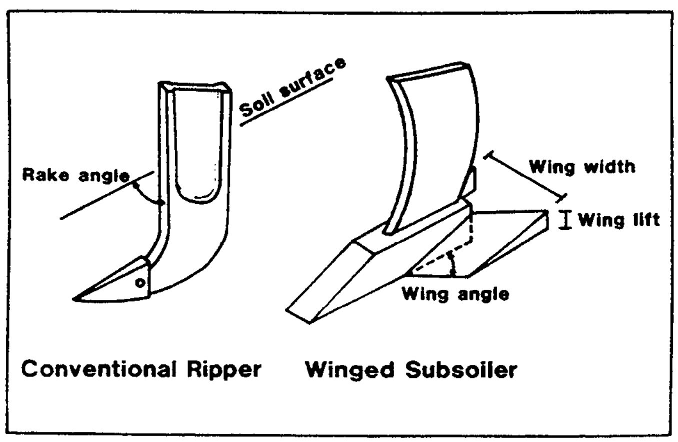

FIGURE 5.
GEOMETRY OF CONVENTIONAL AND WINGED RIPPING TINES.

Spoor and Godwin (1978) reported that adding 12-in.-wide wings to a tine increased shattering in an agricultural soil 80 to 280 percent. Similarly, the addition of 20-in.-wide wings to a tine increased shattering in a forest soil 138 percent for a tine working at a depth of 22 inches (Forest Research Institute 1977).

The use of winged subsoilers for the tillage of forest soils has been limited to date, and no manufacturer makes winged tips that can be adapted to conventional rock ripper tines. We wished to test the efficiency of a winged subsoiler in tilling compacted forest soils. However, no suitable implement existed; therefore, we developed a prototype. Rome Industries (Cedartown, Georgia) provided subsoiler tines and winged shoes. Radke's Repair and Iron (Monroe, Oregon) formed the tool bar and frame needed to adapt the tilling system so that it could be attached easily to conventional logging tractors.

The tilled volume (per winged subsoiler tine) produced by this prototype was significantly greater than that produced by conventional ines. We then added a third winged sub-soiler tine to the implement and tested the altered implement under operational conditions. This version of the winged subsoiler prototype has since successfully tilled more than 100 miles of skid trail.

Because the wings increase the amount of soil shattered per tine, spacing on winged subsoilers can be greater than on wingless tines. Logging slash and loosened soil are less likely to accumulate in front of the tines when tine spacing is increased. Also, winged tips often use less power to loosen a given volume of soil than do conventional tips (Forest Research Institute 1977, Spoor and Godwin 1978).

FIELD PERFORMANCE

Skid trail tillage using winged subsoilers mounted on a towed frame (Fig. 6) was observed at five sites. Two tines were fitted with wings that were 19 inches wide and had a wing lift of 2-1/4 inches. We compared tillage accomplished by conventional nes and by winged subsoilers at two sites. .n a moist clayey soil, a pair of winged subsoilers loosened 64 percent more soil than did the two conventional tines (tines spaced 54 inches; ripping depth equal to 18 inches). The winged subsoilers usually left a broad (48-in.) U-shaped soil shattering pattern; the conventional tines usually left a V-shaped pattern (Fig. 7).

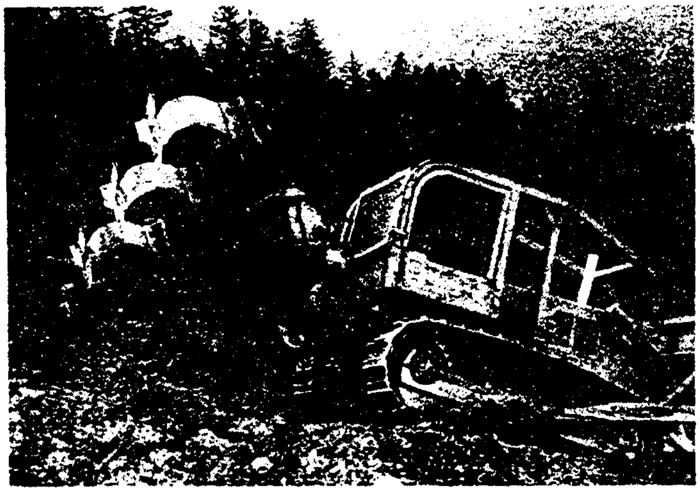

FIGURE 6.
WINGED SUBSOILER.

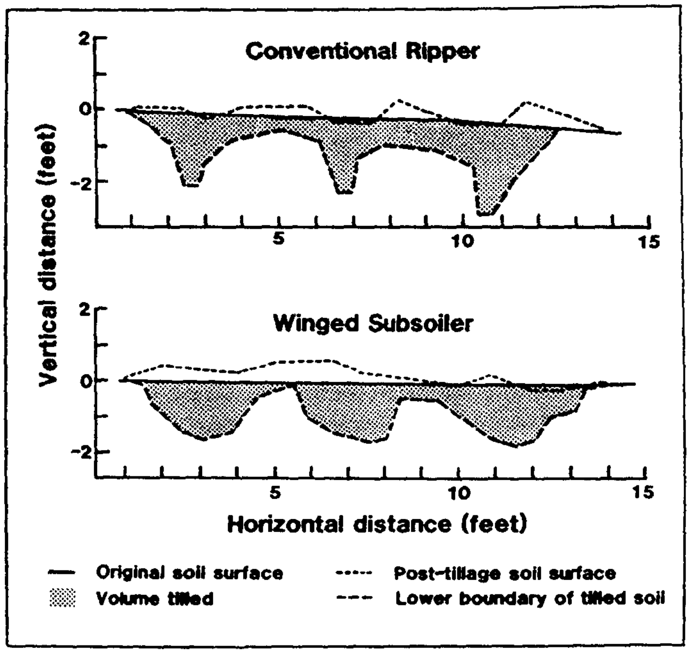

FIGURE 7.
SOIL LOOSENING PATTERNS PRODUCED BY CONVENTIONAL TINES AND BY WINGED SUBSOILERS.

Both the conventional tines and winged subsoilers produced tilled soil that was composed largely of clods; 43 percent of the clods were more than 2 inches in diameter.

These clods remained intact after one season of heavy rains, but had broken down, for the most part, after a second season of rain. The clods had formed primarily in the 8 inches of soil that had composed the original surface layer and was also the layer with the highest density.

A comparison of the two types of tines when used in a rocky granular soil showed that the winged subsoilers loosened 35 percent more soil than did the conventional tines; this increase is about half that observed in the clayey soil. Differences between the conventional and winged subsoilers were masked by the presence of numerous large rocks. Both implements snagged and pulled these rocks to the surface, which caused widespread loosening of the soil. Consequently, in rocky soil the tilling operation may serve not only to loosen compacted soil but also, by bringing subsurface rocks to the surface, help tree planters choose spots where seedling survival and growth may be good. However, large unearthed rocks may be obstacles to future logging operations.

A third winged tine, identical to the first two, was added to the frame before tilling skid trails at two additional sites. The third tine reduced tine spacing. The loam soils at these sites were dry and shattered easily. A single pass of the three winged tines loosened 80 to 90 percent of the compacted soil. As was true with all dry non-clayey soils, the proportion of loosened soil consisting of large clods was small.

Finally, a moist clayey soil was tilled with the three winged tines to determine if subsequent tillage with a disk harrow might substantially reduce the size of clods formed and increase the extent of soil loosening between tines. Disking was done with a 18,000-lb. disk harrow, which tilled an 11 1/2-ft-wide swath. Ripping alone loosened 70 percent of the compacted soil mass within the skid trails; 44 percent of the tilled material consisted of clods greater than 2 inches in diameter. When ripping was followed by disking, the percentage of tilled soil that consisted of clods greater than 2 inches in diameter dropped to 23 percent. However, disking did not increase the amount of soil loosened. The irregular trail surfaces and insufficient disk weighting may have been responsible for the failure of the disk harrow to improve uniformity of tillage depth across the trails. After one winter, it became apparent that disking was not essential because clods that had formed during tillage had, for the most part, broken down.

PRODUCTION RATES AND COSTS FOR TILLING

The cost of tilling at these sites varied greatly with the type of tillage implement, size of crawler tractor used, and site conditions. Some differences may also have been attributable to variations in the operators' skills.

Production rates and costs for skid trail tillage at selected sites are presented in Fig. 8. Skid trail gradients encountered by each implement were: disk harrow, 20 percent (average gradient) and 40 percent (maximum gradient); rock ripper (two tines), 5 percent and 15 percent; brush blades, 20 percent and 50 percent; rock ripper (five tines), 30 percent and 70 percent; winged subsoiler (200 hp), 15 percent and 40 percent; winged subsoiler (140 hp), 20 percent and 50 percent.

Production rates were highest when tilling with one pass of the machine and when both uphill and downhill tilling were possible. Uphill tilling in steep terrain, however, required a large crawler tractor, which increased the cost per hour.

Heavy accumulations of logging slash at the site slowed production because the operator had to stop to clear ripping tines of the debris. These delays were most common when tine spacing was less than 24 inches.

Fig. 8 summarizes observed results of tillage accomplished by disk harrows, rock rippers, brush blades and winged subsoilers. The figure shows that the first three implements loosened less than 45 percent of the compacted soil within skid trails. It is questionable whether such a minimal level of soil loosening can provide enough growth improvement to justify the expense of tillage. Tillage results for these sites probably would have improved if the tillage implement had made additional passes along the skid trails. However, tillage-cost-per-acre would then be markedly greater than those listed in Fig. 8. The winged subsoiler loosened more than 80 percent of the compacted soil in a single pass and appears to be the most cost-effective tillage method tested.

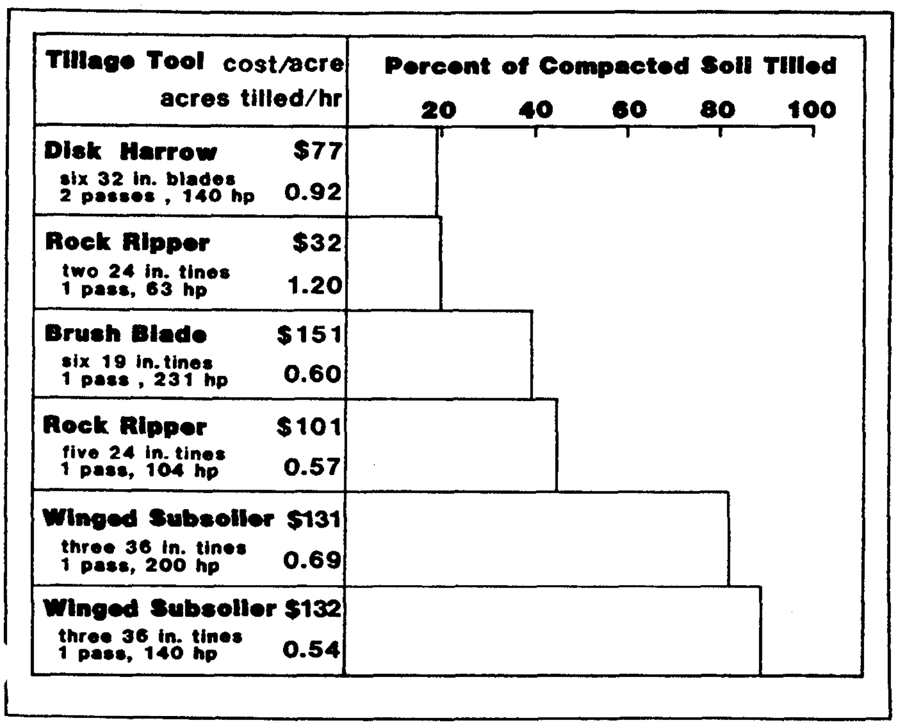

FIGURE 8.

TILLAGE COSTS AND RATES FOR VARIOUS IMPLEMENTS.

GUIDELINES FOR TILLING COMPACTED FOREST SOILS

An ideal tilling method for skid trails is one that yields complete soil loosening of compacted soil across the skid trail and throughout the entire depth of compacted soil. The method should not displace loosened soil to the trail edges and should leave only a minimal amount of the tilled material in the form of large clods. Furthermore, the tillage implement should be rugged enough to operate on surfaces with some woody debris and in soils containing large roots and rocks. Finally, cost would be minimized by prescribing a tillage method that employs available logging or road-building equipment and requires only one pass of the machine along the skid trails.

Table 3 gives guidelines for the selection of the tillage implement most appropriate for a given site. The table indicates site conditions in which disk harrows, brush blades, rock rippers and winged subsoilers are capable of operating effectively. Table 4 outlines design recommendations for certain tillage implements.

Proper supervision and training of equipment operators equal the importance of proper equipment design to the success of a tillage operation. The equipment operator should know how much of the skid trail system is to be tilled, what the tillage depth should be, and how waterbars should be treated or constructed. Particular care is needed to assure that tilling with brush blades or ripping tines is done only when soil moisture is low. Slash piling for the site, if conducted, should precede tillage of the skid trails.

TABLE 3.

TILLAGE IMPLEMENTS RECOMMENDED FOR VARIOUS SITE CONDITIONS.

Tillage implement	Site conditions allowing effective tillage: Soil moisture	Soil type	Rocks	Logging debris within skidtrail	Maximum skidtrail gradient (downhill)	Maximum skidtrail gradient (across trail)
					percent	
Disk harrow	Dry to moist	All soils	None	Minimal amounts	20	10
Brush blade	Dry	All but clayey soils[a]	None, to cobbles	Minimal to moderate amounts	30	10
Winged subsoilers and rock rippers	Dry	All but clayey soils[a]	All conditions (none, to boulders)	All conditions (minimal to heavy amounts)	40	15

[a]Clayey soils shatter into large, persistent clods.

TABLE 4.

SELECTED RECOMMENDATIONS FOR DESIGN OF TILLAGE IMPLEMENTS USED TO TILL SKID TRAILS.

Implement	Implement feature	Design recommendation
Brush blade	Tine spacing	22-26 in.
	Tine length	>20 in.
	Blade width (distance between outer tines)	110-130 in.
Ripping tines (conventional tip)	Number of tines	3 (if two offset passes made) 5 (one pass)
	Tine spacing	40-48 in. (two passes) 24-30 in. (one pass)
	Tine tip width	3-4 in.
	Ripping depth	20-24 in.
Winged subsoilers	Number of tines	3-4
	Tine spacing	30-45 in.
	Wing width[a]	12-24 in.
	Wing lift[a]	3-6 in.
	Wing angle[a]	40-60 degrees
	Ripping depth	18-22 in.
Disk harrow	Disk diameter	40-50 in.
	Disk thickness	1/2-3/4 in.
	Number of disks	6-12
	Average disk weight	>1800 lbs
	Swath width	8-10 ft
	Disk arrangement	Offset gangs[b]; independent disks

[a]See Fig. 5.
[b]See Fig. 4b.

CONCLUSIONS

Brush blades observed in this study failed to loosen the deeper layers of compacted soil. These blades also transferred some of the loosened soil to the trail edges. Loosening of the entire depth of compacted soil was achieved with rock ripper tines and winged subsoilers at some sites. However, tine spacing was often too great to produce complete loosening of soil between tines. Winged subsoilers produced more soil-loosening-per-tine than did conventional ripping tines. Tines operated most effectively in dry granular soils. Numerous large clods formed when tines operated in compacted clayey soils. Disk harrow designs observed in this study proved ineffective for loosening compacted forest soils when the soil contained large rocks or heavy accumulations of logging slash and when the trail surface was irregular.

Not all compacted soils will necessarily benefit from tillage. Sites with a shallow topsoil over a sterile subsoil may be less productive following tilling. Even the best tillage is unlikely to return a compacted soil to its original condition and productivity. The objective, however, should be to recover as much productivity as is economically possible.

Clayey soils, often the most productive in Oregon, present special problems. These soils often remain moist year-round and often shatter into large persistent clods when tilled with tines. Disk harrows that are designed properly for use on forest sites may offer the best alternative for tilling compacted clayey soils.

Winged subsoilers till effectively in many soil and site conditions. Winged subsoilers allow greater spacing between tines, thereby minimizing logging slash build-up problems. Power requirements per unit volume of loosened soil are less for winged subsoilers than for conventional tines.

Tillage is only one of several tactics for alleviating the impacts of soil compaction caused by logging activities. Other tactics include the use of cable logging methods or the designation of a small percentage of the land to a semi-permanent skid trail system. Ground-based logging followed by skid trail tillage is economically desirable only if it keeps the combined cost of harvesting and of lost site-productivity as low as possible.

Proper design, selection and operation of tillage implements are required to assure that a tillage operation adequately improves the structure of compacted soil. Shop-built tillage implements may provide an excellent combination of proper design and low operating cost in cases where commercially-made equipment is not suitable for conditions encountered at forest sites.

There are many other improvements that could be made on tillage implements; however, those improvements have not yet been devised. The task of devising further improvements for tillage implements used on compacted forest soils offers ample opportunity for ingenious, innovative and challenging work.

LITERATURE CITED

ADAMS, P.W. and H.A. FROEHLICH. 1981. Compaction of Forest Soils. Pacific Northwest Extension Publication PNW 217.

BERT, P.J. 1975. Developments in the establishment of second rotation radiata pine at Riverhead Forest. New Zealand Journal of Forestry 29(2):272-282.

CRAIG, F.G., L.J. GREN, and P. HOPMANS. 1977. A study of establishment techniques for Pinus radiata at Heywood. Forestry Technical Papers. Forests Commission, Victoria 26:45-51.

FOREST RESEARCH INSTITUTE. 1977. Improving the efficiency of ripping. Rotorua, New Zealand. Forest Industries Review 8(8):28, 31-32.

FROEHLICH, H.A. 1973. The impact of even-age forest management on physical properties of soils. P. 199-200 in Symposium Proceedings: Even-age management (R.K. Hermann and D.P. Lavender, eds.). Oregon State University, Corvallis.

FROEHLICH, H.A. 1979. The effect of soil compaction by logging on forest productivity.

Final report to the USDI Bureau of Land Management for Contract 53500-CT4-5(N). School of Forestry, Oregon State University, Corvallis.

GUILD, D.W. 1971. Windrowing and ripping a comparative study with other site preparation techniques. New Zealand Journal of Forestry 16(1):88-97.

NICHOLS, M.L. and C.A. REAVES. 1958. Soil reaction: to subsoiling equipment. Agricultural Engineering 39(6):340-343.

PERRY, T.O. 1964. Soil compaction in loblolly pine growth. USDA Forest Service, Tree Planters' Notes 67:9.

POWER, W.E. 1974. Effects and observations of soil compaction in the Salem district. USDI Bureau of Land Management. Technical Note No. 256.

RITCHIE, R.J. 1965. Establishment of Pinus radiata D. Don in contour rip lines in a low rainfall area. Forestry Technical Papers, Forests Commission, Victoria 15:610.

SANDS, R. and G.D. BOWEN. 1978. Compaction of sandy soils in radiata pine forests. II. Effects of compaction on root configuration and growth of Radiata Pine seedlings. Australian Forest Research 8:163-170.

SPOOR, G. and R.J. GODWIN. 1978. An experiment mental investigation into the deep loosening of soil by rigid tines. Journal of Agricultural Engineering Research 23:243-258.

WERT, S. and B.R. THOMAS. 1981. Effects of skid roads on diameter, height, and volume growth in Douglas-fir. Soil Science Society of America Journal 45:629-632.

Conversion Table

1 foot (ft) = 0.3048 (m)
1 inch (in.) = 2.54 centimeters (cm)
1 pound (lb.) = 0.4536 kilogram (kg)
1 acre (A) = 0.4047 hectare (ha)
1 horsepower (hp) = 745.7 watts (W)
1 mile (mi) = 1.6093 kilometers (km)