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# MULTIPURPOSE SUBSOILING EXCAVATOR ATTACHMENTS

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## INTRODUCTION

For several years the Umpqua National Forest, Diamond Lake Ranger District (DLRD), Pacific Northwest Region (R6), of the Forest Service, U.S. Department of Agriculture, has been developing methods and implements to improve soil productivity in areas degraded by previous activity. Previous activities include timber harvest, undeveloped recreation, and temporary or unwanted roads. The objective for improving soil is usually watershed restoration. These new methods were developed to cut the cost of restoration activities and to ensure a satisfactory result. Key to the success of these operations is the return of soil tilth (the physical condition of soil as related to its ease of tillage, fitness as a seedbed, and its impedance to seedling emergence and root penetration) to compacted soil, which was caused by equipment and road use. The failure to adequately treat compaction and retain surface organic material during site restoration will reduce potential soil productivity and overall recovery. The Umpqua National Forest believes that its developed methods and implements fully meet the Forest Service Chief's objectives for land stewardship, the Aquatic Conservation Strategy (Northwest Forest Plan), and the Healthy Forest Initiative.

## BACKGROUND

Ground-based harvest systems can cause the greatest area of detrimental compaction during forest management activities. After a ground-based harvest ends, skid trails and landings may be visible for years or decades. On the Umpqua National Forest, ground-based harvests and related site preparation done before 1990 created more compaction due to loose enforcement of requirements for designated skid trails, landings, and dozer slash piling operations. Current harvest management now requires designated skid trails and the use of low ground-pressure equipment when piling to reduce the total amount of compaction occurring during harvest. The Forest Service manual (FSM) on forest soils directs that activities must create less than a 20-percent increase in detrimental soil conditions (FSM 2521. 1-1 a, R-6 Supplement 2500-96-2). Even if these measures are met, the opportunity to exceed the 20-percent threshold remains if the next entry does not use the same skid trails. This effect is compounded in second-entry harvest areas where dozer slash piling took place in the first entry.

Subsoiling skid trails and temporary roads after each entry will reduce the opportunity for cumulative detrimental soil conditions. Proven to increase the survival and growth of seedlings, subsoiling begins the process of restoring areas of previous compaction when followed by vegetation establishment. However, since there is a high economic cost associated with subsoiling, it is often considered a last resort after multiple planting failures. Prior to restoration efforts, compaction can cause localized surface erosion, which may remove the topsoil and hinder the soil's ability to support vegetation, either planted or desired native vegetation. Organic material lost during the original slash treatments (30-plus-years old) and subsequent erosion of topsoil may have eliminated enough nutrient value to delay vegetative recovery.

The common treatment for compaction is to subsoil with an agricultural subsoiling implement or dozer-mounted ripper system. Although there are problems with dozer subsoiling, the cost of this treatment is often the lowest available. The problems with dozer subsoiling are spotty treatment coverage from maneuvering around obstacles and difficulty in maintaining effective ground cover. Thick brush, stumps, boulders, and standing trees can inhibit the dozer from reaching all compaction in the treatment area. Avoiding live trees and their root systems can also reduce the total treatment area, leaving those trees to survive under isolated poor tilth conditions. The greatest long-term drawback of subsoiling with a dozer-drawn implement is the inability to return organic material (i.e., grass sod and woody material of varying sizes) to the treated surface. Dozer subsoiling can expose the soil by creating bare areas when organic material accumulates under the drawn implement. Additionally, inattention during operation can cause boulders to surface, resulting in a boulder field. Loss of organic material on the surface of exposed soil also can have a detrimental effect, especially on those soils already low in nutrients and moisture-holding capacity. Adequate surface organic material creates a buffer from temperature and moisture fluctuations, increasing plant vigor and growth.

Often associated with ground-based systems, grapple-piling operations provide a means of treating compaction before leaving the harvest unit. To date, the removal of logging residues from the site and treatment of compaction (subsoiling operations) has been accomplished separately in time, and sometimes by different equipment. Multiple entries on the same acreage raise the overall cost of treating an acre of land. Recently, an exception to multiple entries has begun. Excavators used for grapple piling are employed to decommission temporary roads and landings immediately following log haul.

Excavators are versatile when piling or subsoiling. Current application of excavator subsoiling has been limited to treating little more than temporary roads and landings. When the need to subsoil more than temporary roads and landings presents itself, the level of versatility and precision must be weighed against the lower cost of equipment and the greater acreage production that a dozer operation can provide. Depending upon the amount of acreage intended for treatment, a grapple-piling operation would have to be "piggybacked" with a dozer subsoiling operation to be economical.

Excavators treat compaction by forcing the machine's grapple rake, or tines, into compacted soil. Although this loosens the soil, it may bury surface organic material, reducing effective ground cover. Though organic material can be lost during subsoiling, the excavator can utilize available slash during piling for effective ground cover. Placing organic material on top of a subsoiled surface has been shown to maintain soil aggregate stability, which can allow for increased natural regeneration and maintain the vigor of planted seedlings (observations on subsoiled temporary roads indicate more than 6 years of soil aggregate stability).

To remedy various detrimental soil conditions and improve the production of excavator subsoiling, two implements were invented on the DLRD.

1. Subsoiling Grapple Rake (SGR). This instrument was designed to treat compaction immediately after it occurs. Activities that cause compaction include temporary harvest roads, skid trails, mechanized fuels reduction, site preparation, and grazing. The SGR can be used to treat legacy compaction thought to be remedied by time and frost heave.

2. Subsoiling Excavator Bucket (SEB). This instrument accomplishes two activities: excavation and subsoiling. It was designed for road decommissioning and resource restoration resulting in improved water quality and fisheries enhancement, and the return of hydrologic function within a given watershed.

## EQUIPMENT DESCRIPTION AND USES

Subsoiling Grapple Rake (SGR). The SGR was created specifically for prescriptions that combine brush disposal/grapple piling with the subsoiling of newly created or legacy compaction. (Legacy compaction is from ground-based harvesting, without designated haul and harvest routes, dozer pile slash treatment, or undeveloped recreation, grazing, or abandoned roads.) The use of the SGR in grapple-piling operations will treat compaction and utilize slash as effective ground cover for the subsoiled areas. This differs from present practices, where slash is disposed of and then subsoiling is introduced years later when legacy compaction is identified as a problem. The SGR may reduce costs of reforestation, while allowing the soil resource to maintain or restart its natural development. The integration of differing project work can reduce potential negative impacts of forest management by treating compaction directly after it is created.

Logical applications for fuel treatment and subsoiling:

1. Grapple piling for post-timber harvest fuel reduction or slash removal.
2. Obliteration of skid trails, temporary roads, and landings.
3. General subsoiling for soil-productivity issues.
4. Placement of organic material on subsoiled areas for effective ground cover.

The SGR combines aspects of fuel treatment and subsoiling, and it effectively eliminates future compaction issues at the close of harvest. These benefits are realized without compromising grapple-piling production rates. In addition, there is an increase in effectiveness of the subsoiling treatment. Dozer subsoiling avoids areas of rock and heavy vegetation. The SGR still avoids the rock, but it can also remove dense brush and subsoil where needed, and then place this material back, as ground cover. The SGR combines the best attributes of grapple piling and subsoiling. The SGR can reduce operational costs while increasing opportunities for soil restoration efforts. Figures 1 and 2 show photos and drawings of the implement in different modes/positions.

Using the SGR on a prescription for subsoiling and grapple piling, such as might be done with funds collected from timber sales for Knutson-Vandenburg (reforestation and rehabilitation), brush disposal (fuel treatments), or a stewardship contract, the DLRD showed an estimated savings of approximately $490 per acre (when compared to past contract costs for doing the work separately). Logging contractors who, under timber sale contract requirements, may be responsible for the disposal of logging slash and the removal of temporary roads and landings at the close of logging operation may benefit by using this equipment.

*Figure 1. Pictures show the SGR in positions or modes of use for each operation. (Pictures by D. Morrison)*

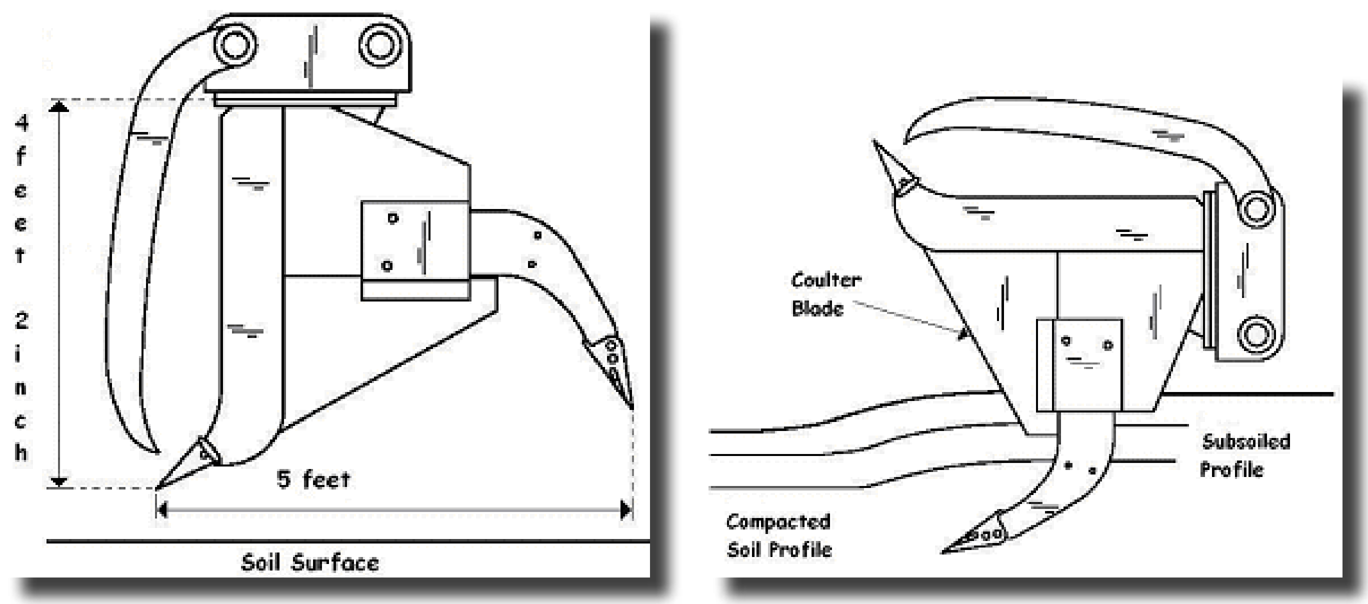


*Figure 2. Drawings show the SGR in grapple mode (left) and subsoiling mode (right).*

## How the SGR Functions

The SGR implement creates a broken pattern for water to enter the soil and eliminates the continuous furrow associated with dozer subsoiling. This can prove beneficial in the decommissioning of skid trails and other compaction on slopes up to 30 percent, or for conditions with a heavy clay horizon buried in the soil. The broken pattern is a beneficial result of the excavator being unable to treat the soil while traveling. Figure 3 shows a conceptualized drawing of a dozer and excavator subsoiling. During regular grapple pile operations the SGR allows for the restoration of compacted areas previously too small for separate service contracts (i.e., landings, skid roads, loader, and temporary roads).

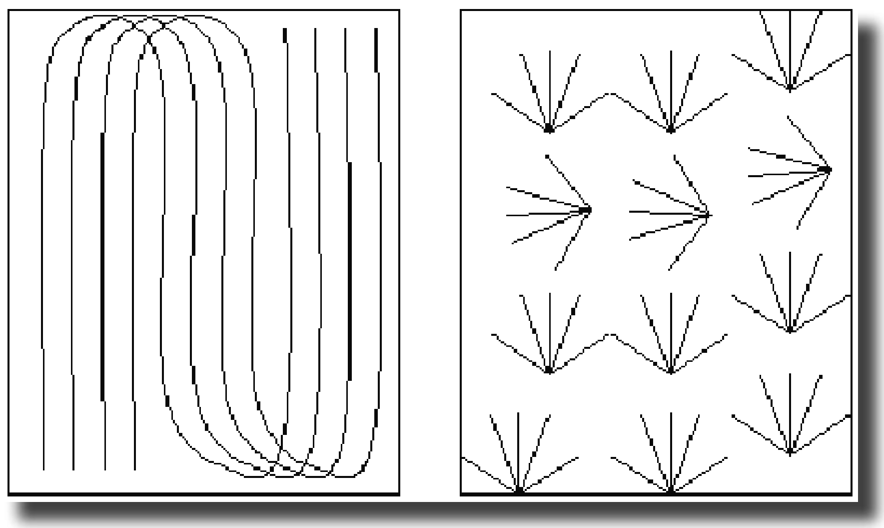

*Figure 3. Conceptual drawings of subsoiling patterns. The left drawing shows the continuous furrow pattern associated with dozer subsoiling. The right drawing shows the broken pattern associated with the SGR.*

As a fully operational grapple rake and/or subsoiling implement, the SGR utilizes the thumb (a feature available on most excavator models) and rake to grasp slash and build piles for burning at a later time. Depending upon the amount of material available, a portion of this debris is either left as ground cover or piled. Once the area retains the prescribed effective ground cover, the SGR is repositioned to subsoil. This change in position can be seen in figure 1, which shows the two operational modes and a picture of each action. The SGR has incorporated into its design a coulter blade with each subsoiling shank to deal with surface or subsurface organic obstructions, such as roots. These coulters have the same application as coulter wheels (standard on many agricultural implements), which cut roots and surface material, thus parting the soil for the implement's passage. This feature is seen in figure 2 (right drawing). When a sizeable obstruction, such as a large root or tree branch, is encountered during subsoiling, the SGR obtains optimal function of the coulter blades by tilting towards the excavator. It is with this tilting action that the coulter blade acts as a guillotine, severing the object and allowing the subsoiling pass to continue.

In the case of a first-entry harvest, subsoiling will not be needed outside of skid trails or temporary harvest roads. In a second-entry situation, subsoiling may be needed outside of skid trails and temporary roads to treat legacy compaction. After the area is subsoiled, oversized organic material (slash, logs, or brush), if moved, are returned to their former locations. Subsoiling with this implement is done to a maximum depth of 30 inches or to the operational depth of whatever subsoiling shanks and wing tips are used. The act of subsoiling, regardless of the method, creates a tortuous path for the infiltration of water vertically through the soil profile.

## Subsoiling Excavator Bucket (SEB)

The success of the SGR provided the incentive for the DLRD to undertake the development of another implement. This concept to build the SEB prototype was supported by staff from San Dimas Technology and Development Center's Recreation and Watershed/Soil/Air program. The SEB was specifically created for total road-obliteration prescriptions and is shown in figure 4. The prescription where this implement is most important is in the obliteration of midslope roads that can impact fish-bearing streams. The economic and production rate benefits of this implement are similar to those of the SGR.

*Figure 4. Side view of the prototype SEB.*

These are the tasks that can be completed by the SEB:

1. Removing culvert.
2. Installing water-bars.
3. Subsoiling of the roadbed.
4. Outsloping of the road prism or complete obliteration of the road.
5. Removing fill from small and large draws.
6. Returning fillslope material to near original slope position.

Currently, road obliteration projects can be accomplished either by an excavator alone or in concert with a large dozer (e.g., Caterpillar D8, with rear ripper). During an outslope recontouring of the road prism with a dozer, it rips the road, then spreads fill material from the road edge to the ditchline. This process can cause a return of compaction in the ripped road prism when the dozer spreads the fill material, since it is unlikely to rip and spread in a concurrent operation. On roads requiring culvert removal, the equipment will travel across the newly outsloped prism, causing new compaction.

In small operations, high equipment costs and equipment logistics can reduce the final project to culvert removal and slope recontouring over the existing compacted roadbed and ditchline. This project would still leave a condition that might cause slope failure at some future time.

Another treatment example simply may be to subsoil a road for the objective of reducing watershed road densities. Usually, this project is accomplished with a dozer pulling an agricultural subsoiling implement or dozer-mounted ripper system. This method will improve water infiltration, but the placement of organic material, if applied to the treated area at all, is left to hand crews spreading straw mulch. If the site was deficient in organic matter, the subsoil treatment area would be left exposed to the elements, which provides an opportunity for further degradation of surface aggregates with rain splash and soil crusting that could lead to erosion. (Luce1997). When using an SEB, large bales of hay can be positioned along the road prior to subsoiling. The SEB can be used to spread the mulch as it exits the road.

## How the SEB Functions

The SEB combines two dissimilar management activities, excavation and subsoiling. The SEB-equipped excavator can either replace the need for a dozer on small jobs or enhance the overall result of road decommissioning on large projects. The SEB-equipped excavator will be the last machine out of the project area, subsoiling the footprint of all equipment to a depth of 24 to 30 inches. This added effort could enhance the growth and vigor of vegetation in the newly created seedbed.

The SEB is an excavator bucket, modified by adding subsoiler shanks with coulter blades to enter the soil and loosen road fill (figures 5 and 6). The shanks extend downward below the bucket and curve forward toward the bottom of the bucket, allowing a single implement to be used for both excavating and subsoiling. Rotating the implement while attached to an excavator boom can allow the use of either mode.

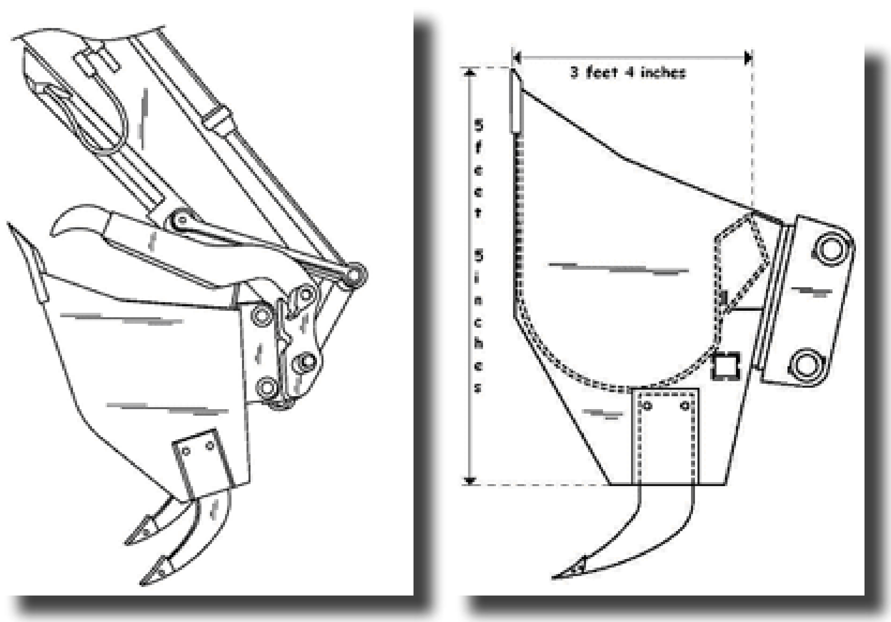


*Figure 5. Left is a view of the mounted SEB. Right is a side view showing the bucket and dimensions of the implement.*

**Operational views of the SEB**

*Figure 6a. Road obliteration using the SEB.*


*Figure 6b. Subsoiling using the SEB.*

The bucket mode is obtained through the normal range of operation of the excavator. The subsoiling mode is obtained by rotating the bucket toward the closed position and bringing the subsoiling shanks into a vertical position for movement through the soil, typically beneath the compacted layer and parallel to the soil surface. In coarse-textured sandy soils, the bucket can attain full range of motion. This range of motion allows the implement to do some subsoiling during excavation, loosening the next bucket scoop. This benefit is diminished in heavy, clayey soils and rock substrate, to the point where a single mode is suggested. Subsoiling results with this implement are similar to that described for the SGR.

## Similarities between the SGR and SEB

No new mechanized parts were added to the common grapple rake or excavator bucket designs. Alterations to both implements were the additions of sockets and coulter blades for the two subsoiling shanks. Standard components were used wherever possible to allow local procurement of worn parts. These implements are intended for operation on any excavator, not less than 44,000 pounds and up to 50,000 pounds gross vehicle weight rating. This allows for adequate hydraulic power and excavator stability necessary for full functional capability. The shanks used for subsoiling are standard John Deere part number A24206. The subsoiling shanks can be standard commercial parts or similar fabricated steel shanks, typically having a curvilinear profile. It is this curvilinear shank that acts like a wedge to lift the compacted soil profile. The momentum of lift energy moves in front of and across the wings, sending fractures through the plate-like structure of the compacted soil profile. The estimated amount of fracture (leading and lateral) can be as much as 7 to 12 inches. With experience, an operator can easily adjust the depth of decompaction by visual control of the shank penetration into the soil.

These observations were made in field trials and practical application using John Deere 5- to 7-inch wing tips. The current designs for each tool incorporate adapter plates for standard John Deere and Caterpillar excavator-connection hardware. The tools can be readily disconnected and reconnected by quick-disconnect attachments, as shown in figure 7. This quick-disconnect feature facilitates rapid change of excavator tools (as needed) at the worksite.

*Figure 7. Close-up of coupling assembly and uncoupling from the SGR*

The DLRD has associated the need for overlapping passes with conditions of strongly cemented to indurated soil. This overlapping method is also indicated when working in very bouldery conditions and road decommissioning. In the deep pumice soils of DLRD, custom-made mild steel wing tips up to 10 inches have proven reliable for projecting lateral and forward fractures while subsoiling.

Subsoiling has proven to increase vegetation survival and growth in areas previously compacted. It is the return of organic material that stabilizes the subsoiling treatments. Returning organic material to soil treated for compaction has been shown to enhance vegetative response (field observations made during the soil organic amendment restoration study, Umpqua National Forest, North Umpqua Ranger District). The SGR and the SEB are working well to restore soil tilth and provide optimum seedbeds for revegetation.

## CONCLUSIONS

The SGR and SEB are not intended to replace traditional dozer subsoiling. These implements should be considered an alternative or an additional method to use when developing a land-restoration prescription. Now fully developed, these two implements are part of a planned suite of three subsoiling implements. The third (being developed and tested) will apply to another area of forest management. The inherent economic benefit of the SGR and SEB to the Forest Service will be a reduction in contract costs. These costs are reduced by eliminating multiple entries with different equipment and objectives, having one equipment-transportation cost, reducing the probability for replanting or interplanting due to plantation failure, and having an operation that treats the soil without leaving an equipment footprint.

When compared to subsoiling using an unimproved grapple rake, the production of road decommissioning within temporary roads and skid trails was 3.5 times faster using the SGR.

The greatest benefit of the SGR is the project cost savings. Two operations can be done by one piece of equipment for less than the cost of operating the two pieces of equipment previously required.

While both implements bridge similar gaps in forest management practices, each creates its own potential benefit. The SGR spans the previously large gap between treating harvest-related fuels and treating harvest-related soil impacts. The SEB makes it possible to implement road obliterations as commonly envisioned. Ultimately both implements increase the opportunity for treating legacy compaction and concurrent treatment of new compaction while treating other results (such as fuels) of forest management activities. Other applications of these implements include wildland fire suppression efforts and rehabilitation and burned area emergency rehabilitation work.

Through field trials on the Umpqua National Forest, and in practical application, these implements have shown that forest management and restoration projects can attain new levels of proficiency and quality for the land being treated while ensuring the greatest economic benefit.

Using AutoCAD drawings from the Umpqua National Forest, a duplicate of the SGR was built for the Idaho Panhandle National Forest at a cost of $6,850. An estimated cost for the SEB is $6,000. These costs are presented only as estimates and are not quotes from fabricators.

## PRODUCT INFORMATION

To find out more about the tools discussed in this report, please contact the Umpqua National Forest. For information on the pricing and availability of the implements, contact the companies listed below.

Subsoiling Grapple Rake (SGR)
Kilkenny Machine Company
4380 North Umpqua Highway
Roseburg, OR 97470
541–672–5147

Subsoiling Excavator Bucket (SEB)
Shamrock Steel Fabricators Inc.
4125 McDougal Lane
Eugene, OR 97470
541–688–5994

For further information regarding this project or other forest management projects at the USDA Forest Service's San Dimas Technology and Development Center, San Dimas, CA, contact Bob Simonson, Forest Management Program Leader, at 909–599–1267.

SDTDC's national publications are available on the Internet at http://www.fs.fed.us/eng/pubs/.

Forest Service and U.S. Department of the Interior, Bureau of Land Management employees also can view videos, CDs, and SDTDC's individual project pages on their internal computer network at http://fsweb.sdtdc.wo.fs.fed.us/.

## REFERENCES

Luce, C. H. 1997. Effectiveness of road ripping in restoring infiltration capacity of forest roads. Restoration Ecology 5(3): 265-270.