Original scientific paper

The use of a Rotary Asphalt Broom to Groom Aggregate Forest Roads

Kevin Boston, Ben Leshchinsky, Erica Kemp, Robin Wortman

Abstract

Due to the dispersed nature of forestry operations in much of the world, only a subset of a given forest road network are used in any year. Specifically, spur roads are generally only used when harvesting operations are adjacent to roadways; otherwise, they remain unused or only have infrequent administrative traffic. During these periods of light use, a substantial amount of organic litter may build up on the roads. As this detritus accumulates and decays, it creates conditions that encourage the growth of unwanted vegetation in the roadway, accelerating the contamination of the surface aggregate. This organic material can degrade the road by retaining moisture and creating a less tractive road surface. Contemporary forest practices control this unwanted vegetation by using a combination of grading or herbicides, at significant expense. One potential alternative treatment is the utilization of a rotary-mounted asphalt broom for vegetation and debris removal. A series of field trials were performed on wet, contaminated forest roads, in which we evaluated vegetation, debris removal effectiveness, and tire slip on segments of road before and after sweeping. The combined effects of wire and synthetic bristles on the rotary broom proved effective in both increasing traction and removing unwanted debris and vegetation from the road surface. Application of this technique was expedient, and did not result in significant loss of surface aggregate, removing on average less than 1% of the aggregate surface.

Keywords: forest road maintenance, rotary brooms

1. Introduction

Harvesting patterns and systems dictate the use of road systems. Adjacency or »green-up« rules promote the dispersion of even-age harvest activities throughout forested landscapes (Boston and Bettinger 2006). In the western United States, these adjacency rules are commonly included as part of state forest practice regulations, as well in the Sustainable Forestry Initiative and Forest Stewardship Council certification schemes. These rules limit the opening size in a range from as small as 8 hectares in California to as large as 97 hectares in Washington (Boston and Bettinger 2001, Boston and Bettinger 2006). Adjacency rules are not limited to US private forest practices, as they are often a component of both the Forest Stewardship Council and Sustainable Forestry Initiative certification programs. In the Australian state of Victoria, the maximum opening size is 40 hectares (Boston and Bettinger 2006), while in Sweden restrictions limit opening sizes to less than 20 hectares (Carvajal et al. 2013).

These spatial planning rules result in greater dispersion of harvesting activities, causing many roads to be inactive for extended periods of time. During these times of inactivity, the surfaces of forest roads can accumulate a large amount of organic material from a variety of sources. This material can fall from neighboring trees or be deposited by the wind from the surrounding forest. As organic matter accumulates, it facilitates the growth of grasses and other vegetation that can further contaminate the aggregate surfacing. In areas with abundant moisture, such as the Oregon Coast Range, unused roads can become quickly overgrown with vegetation between each use.

Some companies have employed »daylighting« around their roads, which removes the trees near the roads to reduce the amount of material on the road and allow the road to dry more quickly (Kochenderfer 1970). However, the resulting space could support additional wood production, and the tradeoff between width of the buffer strip and the impact on the road has not been explored.

The accumulation of organic material on the roadway can result in a variety of hazards and management issues, notably: loss of traction, loss of drainage capabilities, increased fire risk, and increased grading and maintenance costs.

A slick, thin film of wet vegetation and debris results in a reduction in traction, a driving hazard. When the leaf litter is wet, light vehicles may experience tire spin, which often results in a temporary loss of traction on the steeper grades (personal observation Boston 2015). Furthermore, this vegetation can impair road drainage systems by fouling voids between aggregate surfacing as well as concentrating water in the vehicle wheel-path, creating a preferential flow channel that can facilitate erosion.

Vegetation, especially grasses, can increase susceptibility to fire. In the late summer or autumn in a Mediterranean climate, one characterized by dry summers and wet winters, these grasses dry out and can be ignited by the exhaust systems from vehicles (Wilson 1979). Modern exhaust systems can produce temperatures in excess of the ignition temperature of vegetation commonly found growing on forest roads. The USDA Forest Service recommends that people avoid parking vehicles on dry vegetation (USFS 2014) due to this increased fire risk.

Repair and maintenance of roads covered in organic debris often rely on mechanical grading for vegetation removal or resurfacing. Additional aggregate is often placed on top of the road, which can cost as much as $20.00 per cubic yard in regions where high-quality aggregate is scarce (Sessions et al. 2006). Often, an herbicide treatment is used as well to inhibit or kill road vegetation. However, the use of herbicides is largely unavailable for publicly managed land in the United States, due to public concern about the environmental impact of these chemicals. Thus, there is a need for a low-cost means of removing organic debris and vegetation from forest roads while maintaining the aggregate surfacing.

The purpose of this project is twofold:

- ⇒ quantify the amount of material that falls on forest roads from the surrounding forest in the span of one year
- ⇒ determine if a self-propelled, rotary asphalt broom can effectively remove this accumulated organic material without damaging the surface of the aggregate road and therefore offer an alternative to grading roads.

2. Literature review

Aggregate roads are the primary means to access natural resources in much of the world where year-round hauling is required. Grading is the primary means for maintaining these roads, although often at significant cost. Grading has both benefits and disadvantages: it removes ruts and restores road grade, but simultaneously breaks any natural armoring of the surface layer and thus increases sediment movement from the road. Sediment curves show an initial plume of sediment that reduces with time following road grading (Sugden and Woods 2007). Purposeful selection of only those road segments that require grading, rather than grading the entire road, may reduce road maintenance costs and lessen environmental impacts (Thompson et al. 2007).

Street sweeping with a mechanical rotary broom is a proven means of removing debris and litter from paved streets, and is sometimes used to help remove storm water pollution from paved streets. This technique was shown to remove 84.5 kg of sediment from streets, while eliminating the discharge of heavy metals like copper or zinc that accumulate from brake pads, from a 10 meter wide, 260 meter long strip (German and Svensson 2002). However, the impact of sweeping has never been documented for aggregate roads. One goal for this project is to determine the effectiveness of sweeping for the purpose of removing the accumulation of organic material on aggregate roads in a forested environment.

2.1 Litter accumulation

Litter accumulation can vary significantly by tree species and site index, as both influence the efficiency of biomass production. Fried et al. (1990) collected tree litter from the Oregon coast range, finding that sites dominated by big-leaf maple (*Acer macrophyllum*) produced the most biomass, with a range between 40 to 276 grams of dry matter per square meter. They found that big-leaf maple leaves were the most common element found per unit of biomass during the year. In winter, the litter traps contained a mixture of big-leaf maple and Douglas-fir (*Pseudotsuga menziessii*), comprised of a material that was a combination of leaves, needles, and small branches (Fried et al. 1990). There are no known estimates for litter fall when a road divides the plot, as the opening may alter wind patterns.

2.2 Traction

Wheel slip is defined as 1 minus the ratio between the linear speed of the tire and rotational or angular velocity of a wheel, which is the product of the wheel radius and angular speed, Eq. 1 (Wong 2001). As the resisting forces increase, the tractive effort will need to proportionally increase. Thus, there will be a resulting increase in wheel slip under steady-state conditions to produce that slip (Wong 2001). The maximum tractive effort is often produced when the wheel slip is between 15 and 20%. Wheel slip beyond 20% can result in an unstable condition (Wong 2001). Thus, wheel slip will increase with increasing grade if the truck is a constant speed, as greater thrust is needed to overcome resistance from steeper grades. This will continue until the tire spins and the vehicle stalls. One method to reduce necessary slip is to increase the adhesion between the tire and road surface. The accumulation of leaves has been identified as a major cause in loss of adhesion between the wheel and rail for trains in the United Kingdom (Gallardo-Hernandez and Lewis 2008), but no study has evaluated the impact of this material on vehicle performance on aggregate roads. Roads that have high slip or wheel spin when a vehicle passes are a safety hazard. Slip is defined as:

$$Slip = 100 \times (1 - V/r_{\omega}) \qquad (1)$$

Where:

V linear velocity of the vehicle at the tire center

r rolling radius of the tire, and ω angular speed of the tire.

3. Methods

A series of field tests were performed along a 650 m (2000 foot) segment of single-lane, aggregate-surfaced forest road in the Oregon State University Dunn Forest. This road was selected because it had new surface aggregate placed on the road in 2006, but had not yet experienced hauling or heavy truck traffic at the time of the study. This lack of traffic, as well as grades between 2% and 16% and surrounding plant communities of Douglas-fir and big-leaf maple, presented a scenario representative of unused forest roads found in western Oregon. No attempt was made to generate a sample from the larger population of roads in western Oregon, as further research is needed to infer a larger range of site conditions.

Twenty one-square meter litter traps were installed in September 2013 with 30 meter spacing along the margins of the road to measure the litter fall on the road. Adequate clearance was created to allow managerial traffic access without disturbing the traps. Litter trap installation was timed to begin monitoring prior to significant autumn litter fall, with monitoring continuing until June 2014. Material was collected at approximately monthly intervals. The northwest corner of each litter trap contained a plot center, and a 4.52 square meters per hectare (20 square feet per acre) BAF prism was used to measure the basal area surrounding the plots. The tree species, diameter, and total height were measured for each tree located in the variable radius plot.

In April 2014, sweeping of the roads was performed. Three passes were used with a 2.4 m (8 foot) self-propelled rotary asphalt broom. The broom condition was nearly new, with less than 25 hours of cumulative use. The 18,642 watt (25 horsepower) engine was able to turn the 2.4 m broom at 3000 rpm. The broom had a mixture of nylon and metal bristles. During the sweeping, the bristles were in contact with the road surface.

Changes in the road surface were evaluated post-sweeping for each of the seven five-meter road segments with constant grades. Each road segment was further divided into one-meter segments and marked using paint on the edge of the road, in order to better view the tire slip while the vehicle motion was being recorded.

The effectiveness of the sweeping was evaluated using two methods. The first method estimated the change in the vegetation cover. A sampling guide composed of six 7.5 cm squares was randomly assigned to a location within each 5 m test strip. Photographs were taken before and after sweeping at the same location. The change in the vegetative debris cover of the road following sweeping was evaluated using ocular estimates. Results were compared with plant-density guides of known coverage to support these estimates.

The second method measured treatment efficacy for traction improvement, and involved vehicle testing to evaluate wheel slip before and after sweeping. The ve-

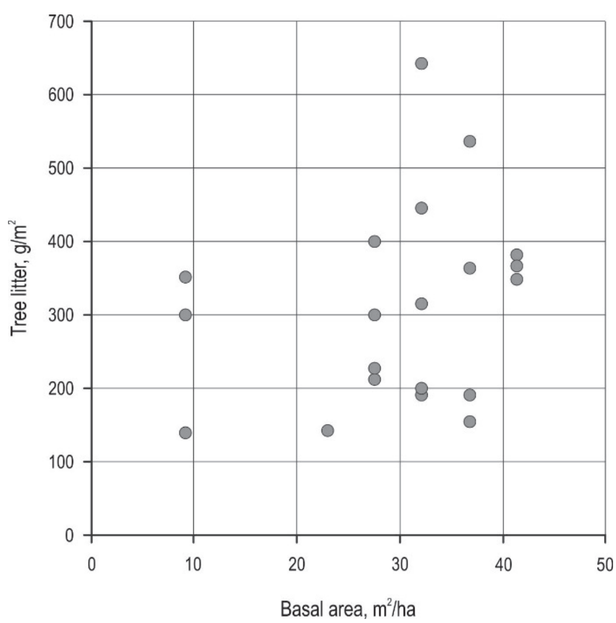

Fig. 1 Litter in leaf trap based on basal area of surrounding forests

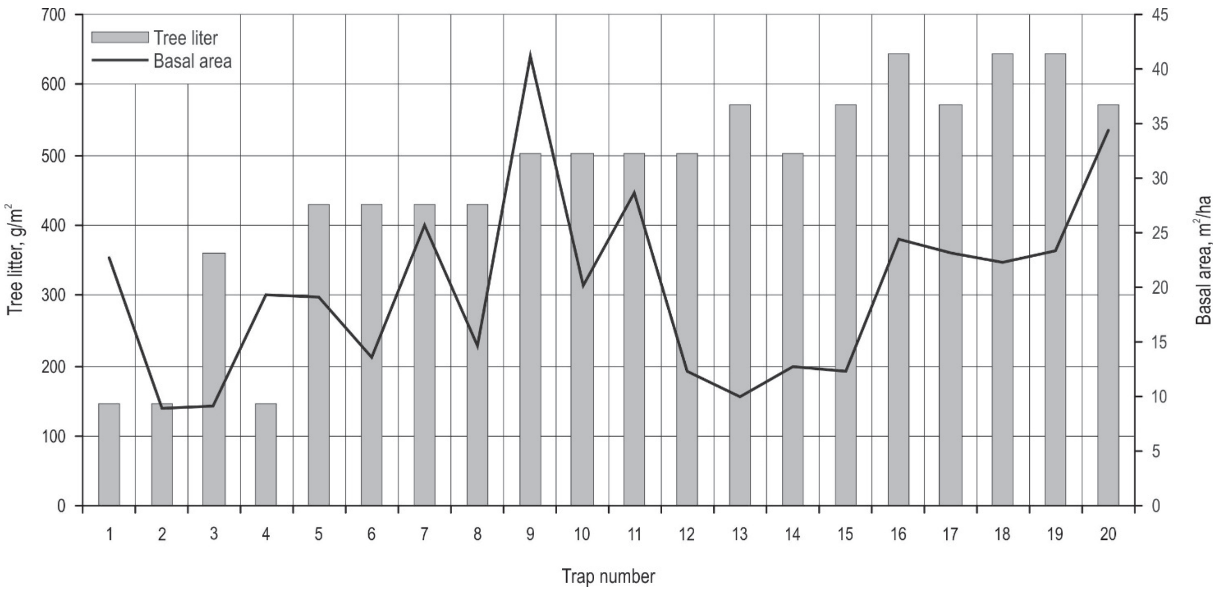

Fig. 2 Amount of litter from leaf traps

hicle, a 750 kg two-wheel drive pickup truck with 76 cm (30-in) diameter tires, was driven at constant speeds of 5 and 10 mph. Three passes were made at each speed. The tire pressure was constant for all four tires at 379 kPa (55 psi). The right rear tire had unique marks placed on it to clearly identify the number of rotations of the tire. Each pass was recorded using timed video recordings (accurate to milliseconds), which evaluated quantification of wheel rotations and longitudinal velocity of the vehicle across the 5 meter test strip; thus, wheel slip could be calculated for each pass. These evaluations were performed before and after sweeping to determine the change in wheel slip due to sweeping.

4. Results

4.1 Litter accumulation

The leaf litter deposited in the litter traps was a combination of leaves from the broadleaf trees, needles from the conifer trees, seeds, cones, and small branches. The bulk of the autumn litter consisted of big-leaf maple leaves, with more conifer needles and branches being deposited in the winter (see Fig. 1). The average dry mass of the material deposited on the trap was 309 grams per square-meter with a standard deviation of 133 grams per square meter (Fig. 2). The minimum dry weight was 138 grams of dry litter per square meter and the maximum dry weight was 640 grams of dry litter per square meter. A linear regression was performed, but no significant relationship was shown between total or conifer basal area and leaf litter deposited in traps with a *p*-value of 0.482; furthermore, this relationship explains only 8% of the variation in the amount of litter captured by the traps. Thus, there is a poor relationship between dry material collected on the traps and total basal or conifer basal area near each trap.

4.2 Cover changes

There was a statistically significant difference in the percent cover between the swept and non-swept sections with a *p*-value of 0.0023. The pre-swept cover

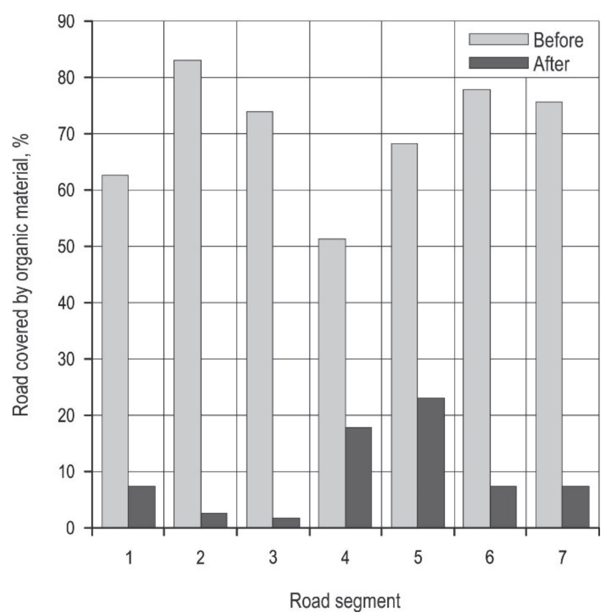

Fig. 3 Changes in percent of road covered by organic material

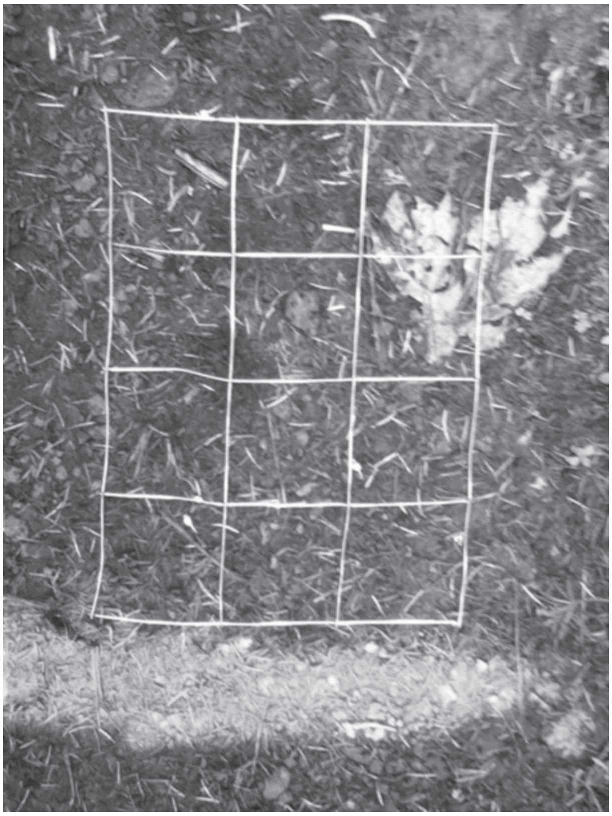

Fig. 4 Pre-treatment condition

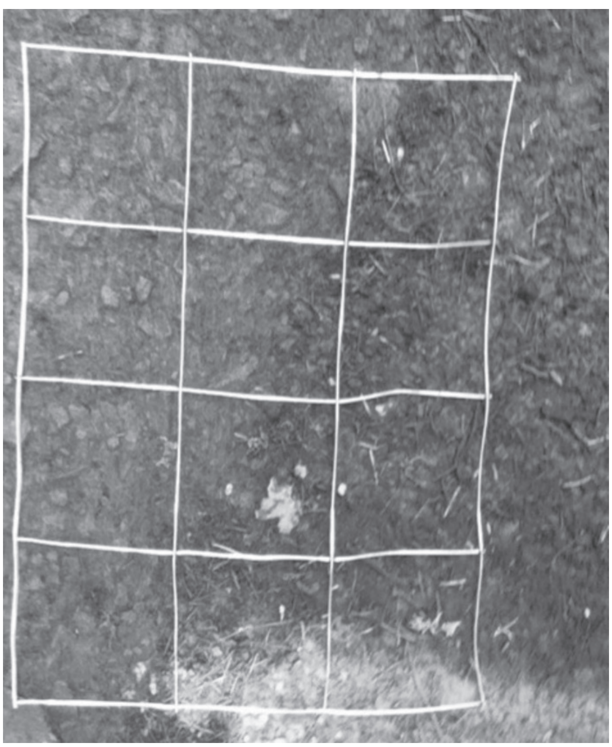

Fig. 5 After treatment condition

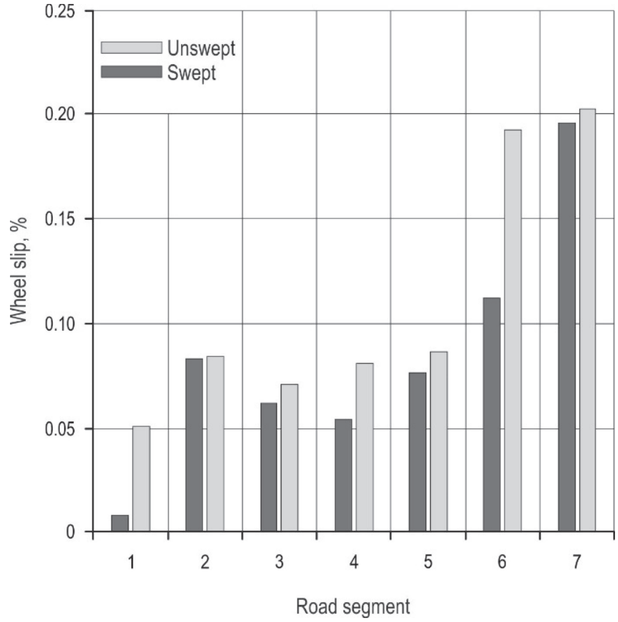

Fig. 6 Comparison of slip between treated and untreated sections from the seven road grade categories

analysis documented the accumulation of organic material on the road. Seventy percent of the roadway was covered in organic matter before treatment, with a standard deviation of 10.6%. Following the treatment, the percent cover was reduced to 9.4% with a standard deviation of 7.87% (Fig. 3).

Fig. 4 and 5 are representative pictures of before and after sweeping, which show respectively the accumulation of moss, grasses, and tree debris found on these unused roads and the effectiveness of the sweeper at removing this material from the road bed.

Aggregate loss from sweeping was approximately 4.5 kg per linear meter of road (with an average road width of 3 meters that is less than 1% of the aggregate amount on a typical road section). Of this material, a grain size distribution was collected for each section (Fig. 7), demonstrating a mean grain size of 0.5 cm, notably smaller than the aggregate surfacing material (5 cm in diameter). Attrition (i.e., material removed) was primarily comprised of material between 0.07 and 1.27 centimeters in diameter.

4.3 Changes in slip

The average slip was measured from the video recording of the truck driving each of the seven sections of the road. The pre-treatment slips measured between 5 and 20%. Slip increased, as expected, with increasing grade. Following the sweeping, the average slip was reduced in all cases. It ranged between 2 and 19% (Fig.

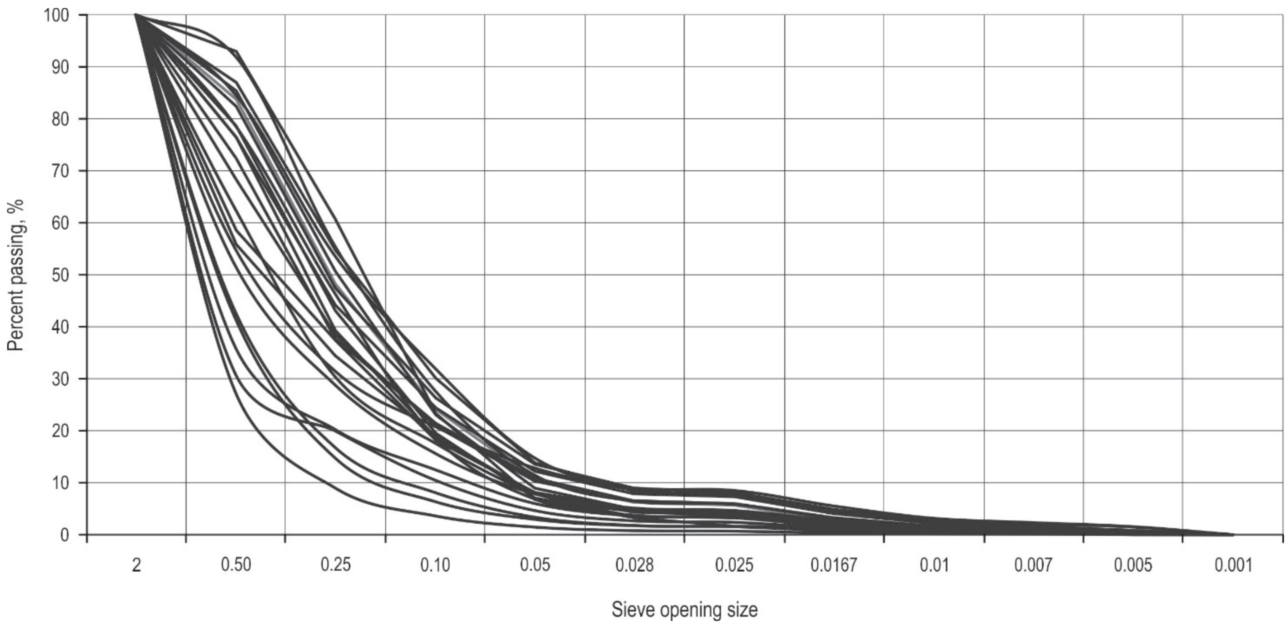

Fig. 7 Grain size distribution of material lost during sweeping

6). The greatest reduction of slip occurred at the 16% road grade, where the post-treatment slip was lowered by nearly 50% (Fig. 6). Other sections show a lesser reduction of slip, potentially due to free water left on the aggregate surfacing post-sweeping. The result was a statistically significant difference between the swept and non-swept sections of road with a *p*-value value of 0.013.

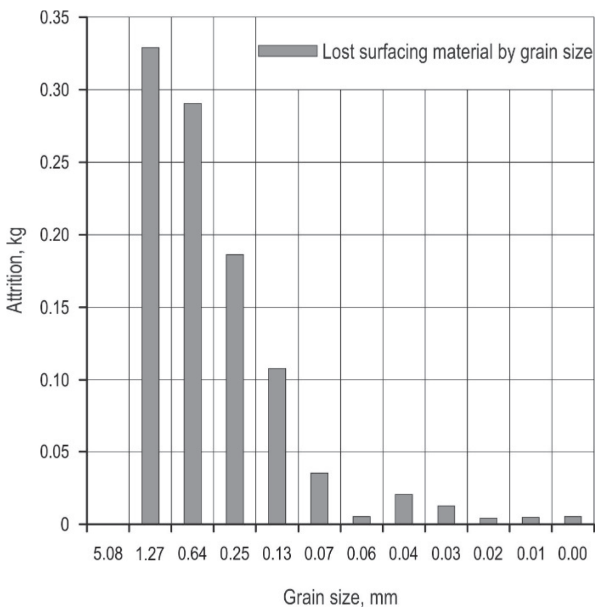

Fig. 8 Distribution of weight of material lost during sweeping (per kg lost)

5. Discussion

The litter deposition along the road showed similar quantities to those described by Fried et al. (1990), who reported between 40 and 276 grams per square meter of litter in plots that were not bisected by a road. Our results showed a mean value of 138 grams per square meter. This suggests that roads with a basal area between 9 and 41 m^2/ha will result in litter falls that are similar to full forests. However, basal area or percent crown closure were not good predictors of the litter accumulation on this site. The high variability of the material in the traps makes prediction difficult, as small branches from windfall constituted the majority of material in the litter traps by weight. These traps appeared to be influenced by the complex wind pattern from the forest, with the variety of nearby openings that tend to occur in a working landscape.

The differences in the percent road surface following the treatment demonstrated the effectiveness of rotary brooms at removal of the organic material, including rooted grasses and moss, from forest roads. Saturation of the surface material may have facilitated easier removal of this material due to increased adhesion between the bristles of the broom and the litter. Further testing is needed to determine if the broom is equally effective during dry soil conditions.

Few stones were dislodged from the surface during sweeping, typically about 4.5 kg of material per linear meter of road were moved. The majority of material removed was smaller grains, falling within the range of fine to coarse sand. The surface of the road was therefore firm when sweeping was completed. Future research should monitor the sediment production from the road and changes in water flow patterns, to determine if sweeping modifies these processes.

There was a significant reduction in slip on the forest roads after sweeping, especially on the moderately steeper grades. The cleaned aggregate road provides a more tractive surface with greater friction for tires than the saturated vegetation that usually covers the roads in western Oregon during the winter. During one of the pre-treatment test drives on the 16% grade section, the vehicle exhibited a loss of the traction with high tire spin and rear-end fishtailing. Following treatment, this temporary loss of control was not observed.

6. Conclusion

A road in mature forested surroundings can accumulate large amounts of organic material, which can cover much of the road's surface. Total basal area and basal area by conifer were not satisfactory predictors of biomass accumulation on this road for these tree species. Sweeping with a rotary asphalt broom, with a combination of wire and synthetic fibers, proved to be an effective treatment for removal of vegetation and organic material from the surface of the road. It removed a majority of moss, grasses and debris on the road surface. Additionally, it did not remove larger stones from the road surface. The result was a road with clean aggregate that offered an improved driving surface, demonstrated by a reduction in the wheel-slip needed to travel on seven test sections. This test demonstrates that sweeping may be a useful treatment for remediating forest roads that are covered in organic debris, as it offers a cost effective and safe alternative to expensive conventional grading or the controversial application of herbicides.

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Received: July 31, 2015
Accepted: September 05, 2016

Authors' address:

Assoc. prof. Kevin Boston, PhD. *
e-mail: Kevin.Boston@oregonstate.edu
Assist. prof. Ben Leshchinsky, PhD.
e-mail: Ben.Leschinsky@oregonstate.edu
Erica Kemp, MsC.
e-mail: Erika.Kemp@oregonstate.edu
Robin Wortman
e-mail: Robin.Wortman@oregonstate.edu
Oregon State University
Corvallis, OR 97331
USA

* Corresponding author