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Development and Use of a Commercial-Scale Biochar Spreader

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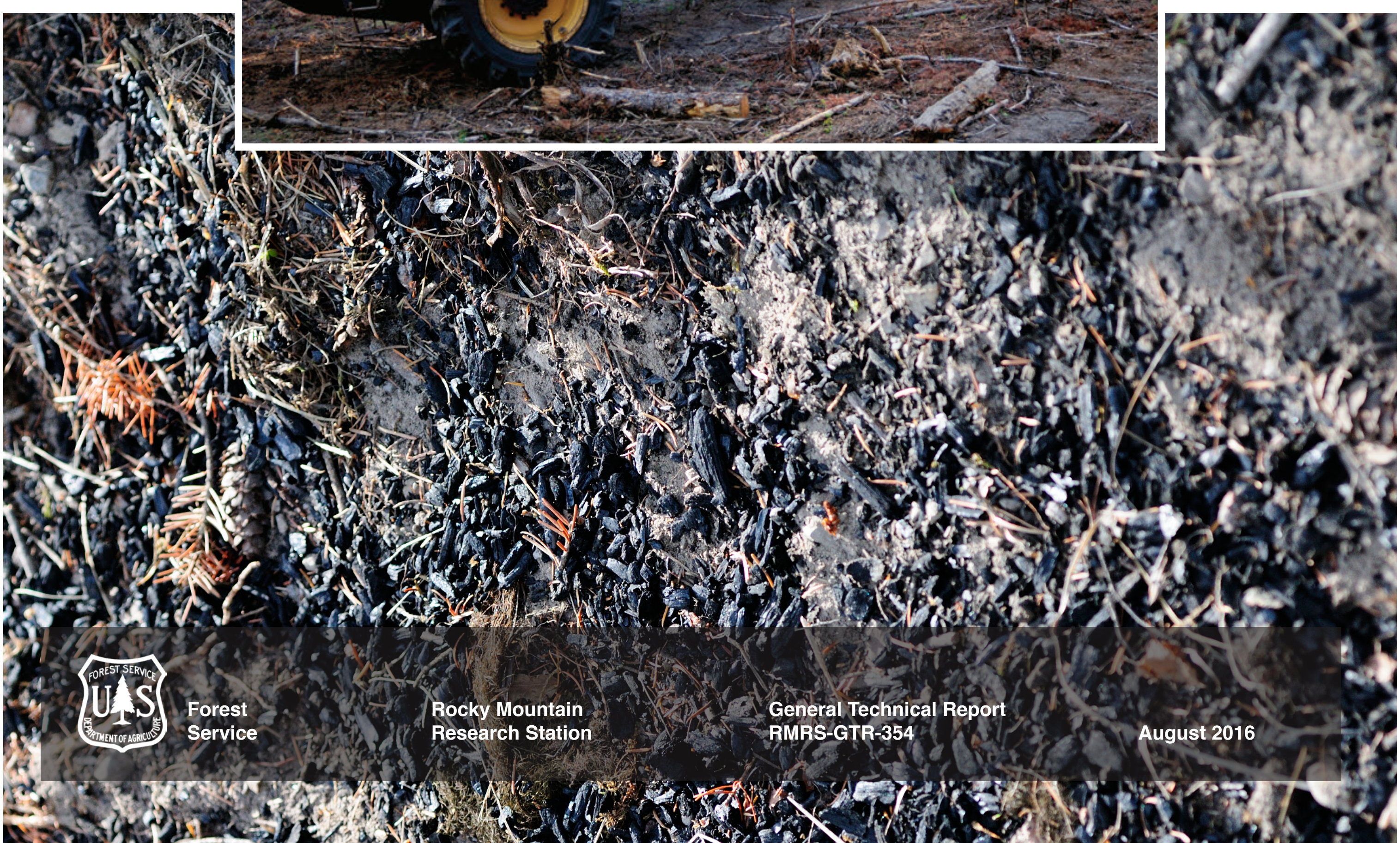

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Abstract

Applying biochar to forest sites can be problematic and costly because of the need to keep the forest floor as undisturbed as possible during and after harvest operations. The Missoula Technology and Development Center of the U.S. Forest Service, working with Rocky Mountain Research Station scientists, developed and tested a high-capacity biochar spreader that can be mounted on a log forwarder and used on skid trails and log landings to distribute either pelleted or bulk biochar. This spreader can be modified to carry a variety of payloads and adjusted to apply biochar at many different spread rates. In our field trials, we detected no change in soil bulk density when using the spreader on sites with an intact forest floor, but found that compaction increased by 11 percent from forwarder ground pressure when using the spreader on a flat area with no forest floor. However, biochar applied to forest sites adds organic matter and helps to retain water, thereby potentially resulting in a decrease in soil bulk density over time. Field trials also demonstrated that biochar can be effectively and efficiently applied to forest sites at commercial scales by using existing and modified logging equipment.

Keywords: forest productivity, soil restoration, compaction, forest operations, skid trails

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Kevin Jump is President of John Jump Trucking, Inc. in Kalispell, Montana, where he has worked to expand opportunities to retrieve and use low-value forest products. He also provided the log forwarder for these trials. He has worked in the timber industry for over 40 years.

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Contents

Introduction

Many forests in the western United States face management challenges related to wildfire, insects, diseases, and invasive species resulting, in part, from overstocked or stressed stands. Climate change, especially drought and associated low soil moisture, exacerbates many of the forest stressors that contribute to tree decline and mortality, such as insects and disease (Dale et al. 2001; Nyland 2007). Commercial forestry in this region also faces problems related to decreased commodity values and increasing operational expenses, such that the costs of biomass removal from silvicultural treatments often exceed revenue (USDA Forest Service 2005). Restoring forest ecosystems can be expensive, but the benefits of restoration may be substantial if wildfire hazards are also reduced (Thompson and Anderson 2015; Zamora-Cristales et al. 2015). This is especially true in areas with high-value infrastructure, timber, municipal watersheds, residential areas (i.e., the wildland-urban interface), rare species, archaeological sites, and other values-at-risk.

Both timber harvesting and restoration treatments produce large quantities of forest residues, including tops, limbs, and unmerchantable logs. These materials are potentially available for the production of energy, fuels, and biochar (a solid, black carbon product from biomass sources). Human beings have used wood for energy for millennia (James 1989). Today products made from biomass are of particular interest because they can decrease consumption of fossil fuels, reduce greenhouse gas emissions, and generate revenue to offset the cost of operations (Anderson et al. 2013). However, increasing harvest intensity to include biomass for bioenergy or other uses risks altering nutrient cycling, soil quality, and other associated ecosystem services and attributes. Researchers have investigated the impacts of whole tree harvesting on soil and ecosystem function (see, for example, Ares et al. 2007; Fleming et al. 2006; Jang et al. 2015; Thiffault et al. 2011) and in general have found few negative responses. On sites that are deficient in nutrients before harvesting, however, some residues should be left (Page-Dumroese et al. 2010).

Biochar

Waste wood from forest operations is frequently burned in slash piles for disposal. Although this is often the cheapest option, it also causes changes to the mineral soil under the slash pile and has negative air quality impacts (Busse et al. 2014; Loeffler and Anderson 2014). One way to reduce the negative effects of burning is to use the unmerchantable material to create energy chips during operations (Jones et al. 2010). Slash forwarding and other methods can potentially be used to recover material that is difficult to reach (Harrill and Han 2010). This is a common practice in areas that use biomass for large-scale power generation.

More recently, pyrolysis (the thermochemical conversion of wood in a low-oxygen environment) has been used to make products from biomass (Anderson et al. 2013). Pyrolysis transforms biomass into useful and marketable energy products and into biochar. If markets are available, selling these products can help decrease the net costs of operations. The use of in-woods mobile pyrolysis close to treatment sites to create biochar is one method of using “waste” biomass left in log landings or in slash piles (Coleman et al. 2010; Dymond et al. 2010). Biochar can be used to add organic matter to a site and provide greater buffering against droughts or floods by increasing water holding capacity. It can also improve nutrient retention and sequester carbon in the soil.

One major barrier to producing and using biochar has been the lack of an appropriate method for distributing the char on forest sites. Application by hand is both difficult and costly, but mechanized systems have not yet been adequately developed and tested on forest sites. Here we describe a biochar spreader, based on the combination and modification of commonly used machinery that can be used on skid trails and log landings, or to ameliorate abandoned roadbeds.

Development of a Biochar Spreader

The Missoula Technology and Development Center (T and D) of the U.S. Forest Service was tasked with developing a biochar spreader and prime mover that were robust enough to operate on log skid trails, and capable of spreading both biochar pellets and bulk biochar. Log skid trails are a challenging operating environment; the terrain is often steep, uneven, and covered with logs, sharp twigs, and sharp rocks. Further, the design had to protect the operator from many hazards: falling objects, branches and debris penetrating the cab, and rollover. The spreader hopper also had to carry enough biochar payload to minimize the number of times the equipment had to pass over the treated area to spread biochar and refill the hopper. The spreader itself needed adjustments to control the width of the spread pattern and the quantity of pellets that were applied. A method to quickly load the hopper was also required. In summary, the T and D team had to develop a method to safely, effectively, and efficiently apply biochar to forest sites, while minimizing environmental impacts, especially to soil.

The prime mover chosen for the prototype machine was an FMG/Timberjack 910 forwarder. Its large forestry-rated flotation tires and walking beam suspension allow it to survive challenging terrain while minimizing disturbance to the forest floor and mineral soil. The machine itself had a 110-hp diesel engine and an articulated frame with six tires on the ground. Two 700-34 tires were mounted on the front of the forwarder and four 700-26.5 tires were on the back. The articulated frame helped the operator maneuver through the trees. An unmodified FMG/Timberjack 910 forwarder weighs 22,046 pounds (11 short tons) and has a load rating of 24,250 pounds (12.1 short tons).

We removed the forwarder’s log bunks and mounted a Swenson EV-150 spreader with custom-designed protective cage on the forwarder (fig. 1). This spreader is commonly used for spreading salt and sand on roads during the winter. The spreader hopper selected was 9 feet long and could hold 4.9 cubic yards of material. The spreader had a self-contained hydraulic power pack that could be controlled remotely from the cab of the forwarder. This feature eliminated the need for the unit to run off the forwarder’s hydraulic system, making it more versatile for mounting on different types of equipment. The Swenson EVRGH hydraulic power pack was powered with an 18-hp gas engine. The spreader with power pack weighed about 3,000 pounds and the protective cage weighed about 300 pounds, leaving about 10 tons for payload considering other added components. In practice, the density of biochar in both its pellet and bulk form is such that even the largest reasonable hopper volume would be filled before the weight limit was reached. As configured, it would be possible to use a somewhat larger hopper on the FMG/Timberjack 910 or a similar machine.

Figure 1—Forwarder with prototype biochar spreader within a protective cage on test site, Ninemile Ranger District, Lolo National Forest, Montana (photo by U.S. Forest Service).

We designed a custom 24-inch-diameter spinner disk (fig. 2) that allowed biochar to be spread up to a width of about 40 feet. The distribution chute funneling the biochar from the hopper to the spinner disk was shortened so that we could mount the spreader closer to the forwarder frame, thereby lowering the center of gravity of the machine for increased stability on side slopes. The hopper's floor is a moving rubber conveyor belt. A hydraulic valve controlled the speed of both the spinner disk and conveyor belt. A manual crank handle controlled a vertical gate at the end of the hopper to better control material

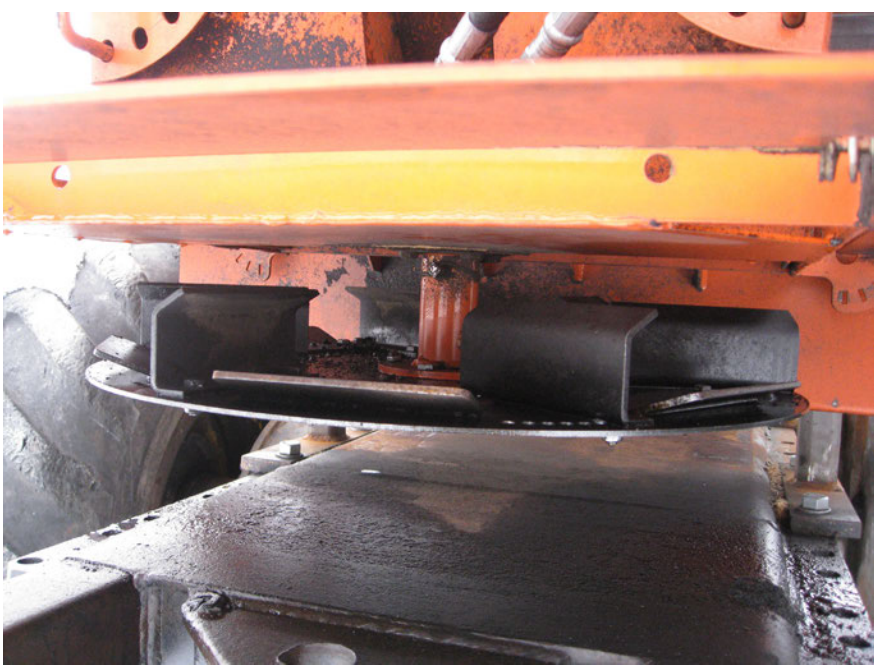

Figure 2—Custom 24-inch-diameter spinner disk with adjustable wings (photo by U.S. Forest Service).

Figure 3—Attendant filling the spreader hopper with a bulk bag full of biochar (photo by U.S. Forest Service).

flow. Two manually adjusted internal baffles were used to direct where the biochar landed on the spinning disk. Three external flaps could also be manually adjusted to control the width of the spread pattern. The final adjustment for biochar coverage was to control the forwarder's groundspeed. The spread pattern and density of deposited material were controlled by the combination of disk speed, belt speed, gate position, baffle and flap position, and forwarder groundspeed. The relatively wide range of application pattern and rate gave us the ability to configure the spreader for operational and soil conditions.

We removed the grapple on the forwarder's boom and replaced it with a hook. This hook was used to pick up bulk load bags full of biochar and suspend them over the hopper. Larger bulk bags contained up to 2,000 pounds of pellets each. The hopper could hold the contents of up to three larger bulk bags. In these trials, an attendant would climb up a ladder and cut the bottom of the bag open to empty its contents into the hopper (fig. 3). However, if the bags are to be reused, they can be emptied by untying and opening a reusable chute on the bottom of the bag. Alternatively, a front-end loader could load the hopper from a pile of biochar.

Depending on how it is manufactured, biochar may shed water to some degree (in other words, it is hydrophobic). But we expect wet biochar not to move as fluidly through the system and to potentially cause bridging and clogging problems. Although not needed for the field trial discussed in this report, a rain tarpaulin system was developed for use

Figure 4—Custom rain tarpaulin system that can be actuated from ground level (photo by U.S. Forest Service).

on rainy or snowy days (fig. 4). A hydraulic vibrator was also installed to keep material that might absorb moisture from clogging the hopper. A backup camera was added to the rear of the spreader's protective cage to give the operator a better view of application rates and to allow safe operation in both the forward and backward directions. The ability to drive backward for long periods is a function built into the forwarder, and adds to its versatility and maneuverability. In addition, there might be some advantage in spreading biochar in the backward direction because the forwarder's tires press the biochar into the forest floor or surface of exposed soil.

Field Test

The prototype biochar spreader was tested on the Ninemile Ranger District of the Lolo National Forest, Montana, on October 6, 2015. The objectives were to: (1) determine which slopes the equipment could safely navigate with a full payload, (2) evaluate the uniformity of pellet and bulk biochar distribution on slopes and flat ground, and (3) measure ground disturbance and soil compaction caused by the forwarder during application. It was a clear, sunny day and there had been no rain on the site for several days. Both pelletized and bulk biochar were delivered to the site in super-sack bags. The pellets were manufactured from bulk biochar at the Composite Materials and Engineering Center at Washington State University, Pullman, Washington. They were 7/32 inch in diameter and ¼ to 3/4 inch long (fig. 5). The bulk biochar spread had a flaky, chunky consistency, reflecting its parent material—wood chips (fig. 6). Both forms of biochar flowed freely through the spreader system. It is worth noting, however, that the biochar pellets are denser due to compression during manufacturing, meaning that the same application rate by volume results in a higher application rate by mass.

Figure 5—Close-up view of pelletized biochar (photo by U.S. Forest Service).

Figure 6—Close-up view of raw biochar flakes and chunks (photo by U.S. Forest Service).

Because skid trails and log landings often remain clear of trees for extended periods after harvesting, we used these already compacted areas to test the biochar spreader. The machine spread biochar on several skid trails and log landings within a recently harvested timber sale. The soil on the test sites was classified as a sandy loam. The steepest hillside on which the forwarder spread pellets was a 27-percent slope.

Pre- and post-biochar application soil compaction was measured by using a slide hammer bulk density sampler with a core volume of 180.99 cm^3. Samples were collected on a log landing and a skid trail in the tire path, between the tracks, and off-trail before and after the forwarder spread the biochar (fig. 7). Three replicate soil samples at three sample depths (0–4, 4–8, and 8–12 inches) were collected from each location. Collected samples were taken to the laboratory, dried at 225 ºF for 24 hours, and weighed; the results were averaged. A portion of the biochar spread on the site was collected on tarpaulins and weighed to determine the application rate (fig. 8). For this trial, application rate of pellets averaged 3 tons per acre and bulk biochar application averaged 3.5 tons per acre. During the trials, plots were established to measure long-term effects of biochar on the soil structure.

Figure 7—Soil scientist using a slide hammer corer to collect samples for measurement of soil compaction (photo by U.S. Forest Service).

Figure 8—Soil scientists collecting and weighing biochar spread on a log skid trail as part of a long-term soil restoration study on the Ninemile Ranger District, Lolo National Forest, Montana (photo by U.S. Forest Service).

Results

Performance of the Spreader

The machine was able to turn completely around on the 27-percent slope, head back downhill, and successfully spread biochar going uphill or downhill. It was also able to spread biochar effectively while driving forward or backward. However, dust from the biochar covered the backup camera during the trial, rendering it useless to the operator. When driving backward, he had to peer around the sides of the hopper.

Table 1—Changes in soil bulk density associated with the biochar spreader. Values in parentheses are standard error of the mean.

Location	Bulk density before using spreader	Bulk density after using spreader
	-------------------- Mg/m^3	--------------------
Undisturbed forest	1.10 (0.04)	1.10 (0.04)
Log landing	1.12 (0.08)	1.25 (0.07)
Wheel track	1.17 (0.04)	1.17 (0.05)
Skid trail center	0.96 (0.08)	0.96 (0.08)

Soil Impacts from the Spreader

After we used the spreader, soil bulk density increased on the log landing area by 11 percent compared to preapplication values (table 1). This result is particularly noteworthy because soil from the wheel tracks on the skid trail did not show a similar increase in bulk density. In addition, there was very little forest floor disturbance related to the spreader trafficking the skid trail.

Discussion

The spread patterns created by the machine were acceptable in both application rate and pattern. Pattern widths ranged up to 40 feet. The relatively wide range of application rate and pattern allows the application of biochar to be tailored to soil characteristics and site conditions. Biochar can reduce soil compaction, but on forest sites it may take several years for rain and snow to move the biochar from the top of the forest floor into the mineral soil.

Traffic levels and soil compaction are key issues on forest sites during and after harvest operations. Use of the spreader resulted in compaction only on the log landing area—not on the skid trail. Several factors could help to explain these results. First, the flat log landing area had a higher soil moisture content (8.2 percent) than the surrounding forest (5.1 percent). The log landing area also had less than 0.5 inch of forest floor to protect the mineral soil and no coarse wood or branches on which to drive. In contrast, the skid trail had more than 7.5 inches of forest floor and numerous twigs, branches, and downed logs to drive on, minimizing equipment impacts.

Conclusions

Using waste wood to create biochar rather than burning the wood in slash piles has many advantages. Local air quality impacts of smoke and particulates are reduced, fewer greenhouse gases are emitted (especially methane), and there is less damage to the soil. Biochar in turn can serve a variety of purposes. Adding biochar to forest sites can help mitigate climate change by sequestering carbon. It can also help to improve soil function by enhancing water holding capacity and nutrient retention. But one drawback of applying biochar on a widespread basis has been our inability to spread the char by using conventional logging equipment. We were able to modify a log forwarder to accommodate a high-capacity biochar spreader. Using the spreader, we could spread both bulk biochar and pellets on steep and flat slopes. In field trials on a sandy loam soil, this machine did not compact the soil on sites with an intact forest floor.

This equipment can also be useful in restoring decommissioned roads because abandoned roadbeds are often similar to skid trails.

Management Implications

The spreader developed in this study works well on slopes and flat ground and easily navigates difficult ground conditions. It can spread pelleted or bulk biochar and can carry a variety of payloads. It also offers a variety of settings to accommodate different application requirements. The U.S. Forest Service is looking for opportunities to use this equipment in forest applications in both research and land management projects. If you would like to use this equipment, contact Nate Anderson (406-329-2122, nathanielmanderson@fs.fed.us).

References

Anderson, Nathaniel; Jones, J. Greg; Page-Dumroese, Deborah; McCollum, Daniel; Baker, Stephen; Loeffler, Daniel; Chung, Woodam. 2013. A comparison of producer gas, biochar, and activated carbon from two distributed scale thermochemical conversion systems used to process forest biomass. Energies. 6: 164–183.

Ares, Adrian; Terry, Thomas; Harrington, Constance; Devine, Warren; Peter, David; Bailey, John. 2007. Biomass removal, soil compaction, and vegetation control effects on five-year growth of Douglas-fir in coastal Washington. Forest Science. 53: 600–610.

Busse, Matt D.; Hubbert, Ken R.; Moghaddas, Emily E.Y. 2014. Fuel reduction practices and their effects on soil quality. Gen. Tech. Rep. PSW-GTR-241. Albany, CA: U.S. Department of Agriculture, Forest Service, Pacific Southwest Research Station. 156 p.

Coleman, Mark; Page-Dumroese, Deborah; Archuleta, Jim; Badger, Phil; Chung, Woodam; Venn, Tyron; Loeffler, Dan; Jones, Greg; McElligott, Kristin. 2010. Can portable pyrolysis units make biomass utilization affordable while using bio-char to enhance soil productivity and sequester carbon? In: Jain, Theresa B.; Graham, Russell T.; Sandquist, Jonathan, tech. eds. Integrated management of carbon sequestration and biomass utilization opportunities in a changing climate: Proceedings of the 2009 National Silviculture Workshop; 2009 June 15–18; Boise, ID. Proceedings RMRS-P-61. Fort Collins, CO: U.S. Department of Agriculture, Forest Service, Rocky Mountain Research Station: 159–168.

Dale, Virginia H.; Joyce, Linda A.; McNulty, Steve; Neilson, Ronald P.; Ayres, Matthew P.; Flannigan, Michael D.; Hanson, Paul J.; Irland, Lloyd C.; Lugo, Ariel E.; Peterson, Chris J.; Simberloff, Daniel; Swanson, Frederick J.; Stocks, Brian J.; Wotton, Michael. 2001. Climate change and forest disturbances. Bioscience. 51(9): 723–734.

Dymond, Caren C.; Titus, Brian D.; Stinson, Graham; Kurz, Werner A. 2010. Future quantities and spatial distribution of harvesting residue and dead wood from natural disturbances in Canada. Forest Ecology and Management. 260: 181–192.

Fleming, Robert L.; Powers, Robert F.; Foster, Neil W.; Kranabetter, J. Marty; Scott, D. Andrew; Ponder, Felix Jr.; Berch, Shannon; Chapman, William K.; Kabzems, Richard D.; Ludovici, Kim H.; Morris, David M.; Page-Dumroese, Deborah S.; Sanborn, Paul T.; Sanchez, Felipe G.; Stone, Douglas M.; Tiarks, Allan E. 2006. Effects of organic matter removal, soil compaction, and vegetation control on 5-year seedling performance: A regional comparison of long-term soil productivity sites. Canadian Journal of Forest Research. 36: 529–550.

Harrill, Hunter; Han, Han-Sup. 2010. Application of hook-lift trucks in centralized logging slash grinding operations. Biofuels. 1: 399–408.

James, Steven R. 1989. Hominid use of fire in the Lower and Middle Pleistocene: A review of the evidence. Current Anthropology. 30(1): 1–26.

Jang, Woongsoon; Keyes, Christopher R.; Page-Dumroese, Deborah S. 2015. Long-term effects on distribution of forest biomass following different harvesting levels in the northern Rocky Mountains. Forest Ecology and Management. 358: 281–290.

Jones, Greg; Loeffler, Dan; Calkin, David; Chung, Woodam. 2010. Forest treatment residues for thermal energy compared with disposal by onsite burning: Emissions and energy return. Biomass Bioenergy. 34(5): 737–746.

Loeffler, Dan; Anderson, Nathaniel. 2014. Emissions tradeoffs associated with cofiring forest biomass with coal: A case study in Colorado, USA. Applied Energy. 113: 67–77.

Nyland, Ralph D. 2007. Silviculture: Concepts and applications. 2d ed. Long Grove, IL: Waveland Press, Inc. 682 p.

Page-Dumroese, Deborah S.; Jurgensen, Martin; Terry, Thomas. 2010. Maintaining soil productivity during forest or biomass-to-energy thinning harvests in the western United States. Western Journal of Applied Forestry. 25: 5–11.

Thiffault, Evelyn; Hannam, Kirsten D.; Paré, David; Titus, Brian D.; Hazlett, Paul W.; Maynard, Doug G.; Brais, Suzanne. 2011. Effects of forest biomass harvesting on soil productivity in boreal and temperate forests—A review. Environmental Review. 19: 278–309.

Thompson, Matthew P.; Anderson, Nathaniel M. 2015. Modeling fuel treatment impacts on suppression cost savings: State-of-the-art. California Agriculture, Special Issue on Forests and Bioenergy. 69(3): 164–170.

USDA Forest Service. 2005. A strategic assessment of forest biomass and fuel reduction treatments in Western States. Gen. Tech. Rep. RMRS-GTR-149. Fort Collins, CO: U.S. Department of Agriculture, Forest Service, Rocky Mountain Research Station. 17 p.

Zamora-Cristales, Rene; Sessions, John; Boston, Kevin; Murphy, Glen. 2015. Economic optimization of forest biomass processing and transport in the Pacific Northwest USA. Forest Science. 61(2): 220–234.