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# Biochar and Wood Ash Amendments for Forestry in the Lake States: Field Report and Initial Results

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Soil amendments are common in agriculture but are not widely used in Lake States forestry. Our objectives were to test the efficacy of operational-scale application of soil amendments on marginal sites as a management strategy for adaptation to drier conditions. Wood ash and biochar amendments were applied throughout 50 acres of recently harvested scrub oak stands, and red and jack pine seedlings were planted. Short-term results indicate increased water holding capacity and cation exchange capacity in soils amended with biochar and biochar with manure and significant increases in seedling production with wood ash amendment. Here we report on the feasibility of the application methods and their associated financial costs and present initial data on soil properties after amendment with wood ash and biochar.

**Keywords:** soil amendments, climate change, adaptation, biochar, wood ash

Climate change-mediated drought and rising temperatures are expected to alter the way forest ecosystems function around the world (Allen et al. 2010). Forests in the northern Great Lakes region have experienced widespread drought and are vulnerable to the additional stresses of nutrient-poor soils, forest pests, and deer browse (Janowiak et al. 2014). The interactive effects of these stressors can result in reduced growth, limited regeneration, or mortality, especially with species most vulnerable to climate change. Management strategies that adapt to and mitigate the effects of climate change, such as promoting resilience to drought, are critical for ensuring the desired future state of forested land (Swanston and Janowiak 2012). In agriculture, soil amendments have been used to improve plant productivity, soil nutrient availability, and water-holding capacity (Jeffery et al. 2011). The forestry application of soil amendments to reduce the impacts of drought, specifically wood ash and biochar, has potential as an adaptive management strategy.

Forestry applications of wood ash are common in Scandinavia and the northeastern United States (Reid and Watmough 2014) but have been rarely used in the Great Lakes region. Wood ash is a byproduct from the combustion of wood and contains high concentrations of essential macro- and micronutrients, such as potassium (K), calcium (Ca), and magnesium (Mg) (Pitman 2006). In sandy soils, it can increase soil pH and cation exchange capacity (CEC) (Kahl et al. 1996, Pathan et al. 2002, Reid and Watmough 2014); however, data on its effect on water holding capacity are limited (Demeyer et al. 2001). Wood ash can also improve tree production in soils deficient in K, Ca, or Mg (Augusto et al. 2008); however, application rates must factor in potential heavy metal inputs (Pitman 2006). The use of wood ash could lead to the development of new forest biomass-derived products, increase local demand for biomass to produce the amendments, and improve forest regeneration and restoration (Vance 1996).

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Few studies have used biochar amendments in the field (Jeffery et al. 2011, von Glisczynski et al. 2016). Cost, application methods, and availability factor into the limited use of biochar in forestry. Biochar is produced by the thermal conversion (pyrolysis) of woody biomass and consists of recalcitrant organic carbon with potential for long-term soil carbon stabilization (Lehmann and Joseph 2015). Residues from wildfires, including various types of charcoal, are a significant component in fire-prone forest soils, representing ~5–15% of the total biomass burned (Santin et al. 2016). Residues from fire probably have significant effects on the physical and chemical properties of soil, but little is known about these effects in managed forests, particularly where fire has been excluded through management (DeLuca and Aplet 2008). In greenhouse and mesocosm experiments, biochar has been shown to decrease bulk density and increase water holding capacity, CEC, and soil alkalization (Atkinson et al. 2010, Lehmann and Joseph 2015). Soils with low CEC have a low pool size of available nutrients for plant growth. A soil's CEC is often directly related to its organic matter content, and therefore any organic amendment (e.g., manure) would probably increase CEC. However, biochar might have additional benefits in that it has particularly high reactivity and is probably more persistent in the environment (Ameloot et al. 2013). Greenhouse studies often incorporate biochar into growing medium, and forest applications primarily occur on the soil surface; thus, the short-term benefits of biochar in forestry field trials are often smaller (Scott and Page-Dumroese 2016). There is a need for expanding the operational scale use of biochar in forests to fully evaluate feasibility and methods of application.

Sandy forest soils in the northern Great Lakes region often exhibit poor fertility and low water holding capacity and as such may require long periods of time for nutrient pools to be replenished if stands are harvested on short rotations (Silkworth and Grigal 1982). These soils tend to support oak/pine forests dominated by white, jack, and red pines (*Pinus strobus, Pinus banksiana*, and *Pinus resinosa*), red and northern pin oak (*Quercus rubra* and *Quercus ellipsoidalis*), and red maple (*Acer rubrum*). Regionally, these low-productivity forests are referred to as scrub oak and are dominated by northern pin oak, which is subject to even-age management on a 70–90 year rotation (Wisconsin Department of Natural Resources 2006). Although scrub oak typically grow in poor soils, the added stresses of widespread drought, increasing temperatures, oak wilt, forest pests, and herbivory can lead to poor regeneration and increased mortality.

Foresters in northern Wisconsin used the Forest Adaptation Resources workbook and menu of adaptation actions (Swanston and Janowiak 2012) to define future management goals of scrub oak; assess climate change vulnerabilities including mortality, disease, and regeneration; evaluate forest management objectives; and identify adaptation strategies (Table 1). A primary component of the site-specific plan was to harvest dying and poorly regenerating scrub oak stands, improve soil water holding capacity with soil amendments, plant drought-tolerant species including red pine and jack pine, and monitor survival and growth of newly planted seedlings. Our goals in this article are to describe and examine the application and feasibility of biochar and wood ash as soil amendments in a large-scale managed forest setting and to present preliminary soil response data after the application of these amendments.

## Methods

The study site is located in the southeastern corner of Florence County, Wisconsin, USA. The dominant soil in the treatment area is the Sarona-Vilas complex (Alfic/Entic Haplorthods) sandy loam/loamy sand, which is well drained, moderately acidic, and nutrient poor (Soil Survey Staff 2016). Before whole tree harvest (2009–2011), the stand was composed of northern pin oak and red maple, with a stocking of 120 $ft^2$ of basal area per acre on an 80-year rotation. In 2015, 50 ac were identified for amendments (wood ash, biochar, and composted manure). Site preparation consisted of disc trenching in the fall of 2014, with trenches 0–8 in. deep and 7 ft apart, with the goal of establishing 900 seedlings $ac^{-1}$. Trench depth was limited by the abundance of rocks and slash, and spacing distance was dictated by the target seedling density.

### Biochar

A 1:1 mix by weight of biochar-composted manure was applied to 16 ac of a 31-ac stand, leaving 15 ac as a stand-level control. The biochar was purchased from Confluence Energy (Cremling, CO) using a feed stock of lodgepole pine (*Pinus contorta*) that underwent pyrolysis at 1022° F for 45 minutes. It had an organic carbon content of 85%, an hydrogen/carbon ratio of 0.67, and a bulk density of 8.3 lb $ft^{-3}$. The composted dairy manure came from a local farm and was 26.6% carbon and 2.1% nitrogen. In May 2015, red pine was planted at seedling densities of 900 trees per acre (TPA) by a contracted planting crew. To apply the biochar, one individual created a planting hole using a hoedad and applied 2.1 pints of the biochar/manure mix in the hole; a second individual placed the seedling in the hole and closed the hole around the seedling (Figure 1). Experimental plots were established within the planting area, consisting of four treatments: biochar only (1.1 pints $seedling^{-1}$), biochar + manure (2.1 pints $seedling^{-1}$), manure only (1.1 pints $seedling^{-1}$), and control (no additions); the same planting/application method was used for the stand treatment and within experimental plots. Each plot was composed of

### Management and Policy Implications

**Drought-induced decline of scrub oak in northern Wisconsin highlights the need for alternative strategies to enable long-term forest soil productivity. Florence County foresters, in cooperation with state, federal, and nonprofit partners, are using this decline as an opportunity to implement unique climate change adaptation strategies for reducing drought impacts. Our study found improvements in soil bulk density, water holding capacity, and cation exchange capacity with biochar and increased pH with wood ash. Long-term monitoring of seedling survival and growth will inform forest managers on the plant growth responses to these amendments. Future work in the region should involve alternative approaches to using biochar in forestry, including broadcast applications or inclusion in containerized stock. Although the financial costs associated with biochar currently limit feasibility at large scales, more efficient application methods and identification of local feedstocks for biochar production could make this financially feasible in the future. Surface application of wood ash was effective for increasing pH in acid soils, and the regional availability and efficient application methods of wood ash make it a viable option for use in Great Lakes forests.**

**Table 1. Florence County forest adaptation approaches and actions for this particular project, summarized from using the Adaptation Workbook with project partners.**

| General adaptation approaches | Specific adaptation actions |
|---|---|
| Maintain diversity of native tree species. | Healthy pockets of scrub oak and northern red oak will be identified and reserved. |
| Favor or restore native species that may be better adapted to future conditions. | The sites will be trenched and planted to jack pine and red pine, with a minority component of white pine.<br>Bur oak and juneberry will be in clusters in uplands to provide mast sources for wildlife.<br>Small areas of white pine and swamp white oak will be planted along riparian corridors in the project area to maintain long-lived forest cover and wildlife corridors. The current range of swamp white oak extends just to the south of the project area. |
| Maintain or restore soil quality and nutrient cycling. | On 130 acres within the project site, add wood-based soil amendments (wood ash and biochar) to increase soil water-holding capacity and boost nutrient exchange and soil microbial communities. |

The Adaptation Workbook with project partners is available online at forestadaptation.org/node/529.

**Figure 1. Red pine seedling planted with biochar + manure.**

four treatment transects (each 59 ft long), with 10 seedlings per transect. The plots were replicated 9 times and were randomly stratified across the stand.

## Wood Ash

Wood ash was obtained from a local paper mill (Verso Mill, Quinnesec, MI). It had a neutralizing value of 49.7% and an effective calcium carbonate concentration of 42.2% (Michigan State Extension, Method E-471). Using the Mehlich buffer pH method (Mehlich 1976), we calculated a lime requirement of 1.29 tons $ac^{-1}$ to raise the pH from 4.9 to 6.0. One month before planting, 34 acres in two different stands, one red pine and one jack pine, were amended with the wood ash using a modified salt spreader (Figures 2 and 3). Wood ash was applied at a rate of 5 tons $ac^{-1}$ within the trenches (or 0.635 tons $ac^{-1}$ across the stand). The spreader was made for the back of a pickup truck and had a "live bottom" with a chain to pull salt out the back. The rear spinner on the unit was removed to allow the ash to fall directly on the ground, and there was a sliding gate to control the amount of ash the chain drive would pull through. Wood ash is about one-third the weight of salt, so the hopper on the unit was modified to increase capacity from 1 to 3 cubic yards. The hopper was modified by welding a steel angle iron frame and using plywood for the sides. In May 2015, jack pine and red pine were planted in the trenches of the separate stands at seedling densities of 900 TPA.

## Soil and Seedling Measurements

Soils were sampled to a depth of 5.9 in. In the biochar treatment, one planting hole per transect ($n = 9$) was destructively sampled near the base of the seedling using a soil corer (1.97 in. diameter). Because of the nature of the biochar and/or manure application, a large volume of soil had to be sampled directly from the planting hole. In the biochar control treatments (no amendments), sampling in the planting hole was not necessary, and we instead sampled along the transect using a 0.79-in. diameter soil corer. Pretreatment (December 2014) and posttreatment (July 2015) soils in the wood ash sites were collected with a 0.79-in. diameter soil corer evenly spaced along three 328-ft transects (five cores per transect). All soils were transported to Michigan Technological University (Houghton, MI) and refrigerated before analyses.

Soils were dried at 131° F to constant mass and sieved (no. 10, 0.08-in. mesh) to remove roots, rocks, and woody debris. Wet to dry weights of soils were used to calculate soil water content, and dry weight was divided by soil sample volume for bulk density. Dried, unsieved soils were used in determining volumetric water holding capaci-

Figure 2. Modified skidder with spreader used for broadcast wood ash application.

Figure 3. Trenched site with wood ash top dressing before planting with red pine.

ties (field capacity) by saturating known masses of soil on Whatman qualitative filter paper in Buchner funnels (Kane et al. 2006). A 1:1 soil/deionized water slurry was used for measuring soil pH using an electrode. CEC was determined by KCl extraction (CEC-7 method) (Soil Survey Staff 2014) and colorimetric ammonium ($NH_4$) determination (using the modified salicylate Hach method 8155) with a plate reader (SpectraMax M2 plate reader; Molecular Devices, Sunnyvale, CA).

In the biochar stand, seedlings were measured for diameter and height at annual intervals (2015–2016) nearing the end of the growing season. Seedlings in the wood ash stand were sampled along transects of 20 seedlings. Survival checks (1⁄100 ac, $n = 13$) were conducted outside of the experimental blocks at the stand level.

### Statistics

To measure significance of differences between individual treatments and control soils, *t*-tests were conducted in Sigma Plot 12.5 (Systat Software, San Jose, CA). Significance for all tests was determined at $P \leq 0.05$.

## Results and Discussion

Biochar incorporation into the soil produced significant improvements, lowering bulk density and increasing water volume and water holding capacity (Table 2). This increased water volume is especially important at our study site, because of the excessively well-drained soils and current and expected future drought conditions in the area (Peters et al. 2014). These findings are in agreement with a recent review of biochar amendment impacts on soil physical properties, which showed an 8% decrease in bulk density and a 15% increase in water holding capacities across experiments (Omondi et al. 2016).

Amending soils with biochar and biochar + manure increased soil CEC by 23 and 42%, respectively (Table 2), which is ecologically significant, especially in sandy soils with low pH (Magdoff et al. 1987). The observed increases in CEC greatly increase soil buffering capacity. Whereas there are no forested systems to put these results in context, such an increase in CEC from 15.9 (control plots) to 22.5 (biochar + manure) in sandy agricultural soils of Michigan (pH 4.5–4.9) would resist a change in pH equivalent to approximately 1.5 tons ac$^{-1}$ in lime (Warncke et al. 2010). Although the effects of biochar on CEC were not significantly different from those of manure at 1 year after application, the biochar is likely to persist longer in the soil (Ameloot et al. 2013) and thus will probably have a lasting effect on CEC. Notwithstanding these results, increasing CEC alone without addition of nutrients, such as those supplied in the manure, could effectively tie up plant available nutrients in the short term and negatively affect tree growth (McElligott et al. 2011). Although not significant, we did observe

**Table 2. Soil properties for biochar and wood ash amendments.**

| Treatment | Water volume θv | | Field capacity | | Bulk density | | pH | | CEC | |
|---|---|---|---|---|---|---|---|---|---|---|
| | % | SE | % | SE | lb ft$^{-3}$ | SE | pH | SE | cmol kg$^{-1}$ | SE |
| Biochar | | | | | | | | | | |
| Biochar + manure | 20.3a | 1.4 | 43.5a | 2.7 | 59.74a | 3.81 | 5.1a | 0.1 | 22.5a | 2.0 |
| Biochar | 14.6a | 0.8 | 44.1a | 3.5 | 60.87a | 4.18 | 4.9a | 0.1 | 19.6a | 2.0 |
| Manure | 15.0a | 1.3 | 47.7a | 2.6 | 63.74a | 3.12 | 5.2a | 0.2 | 19.5a | 2.4 |
| Control | 11.7b | 0.7 | 28.8b | 1.1 | 96.20b | 3.31 | 4.8a | 0.0 | 15.9b | 1.6 |
| Wood ash | | | | | | | | | | |
| Pre-wood ash | 24.6a | 2.9 | | | 57.12a | 15.42 | 4.8a | 0.1 | | |
| Post-wood ash | 17.0b | 1.0 | | | 58.62a | 9.80 | 5.4b | 0.3 | | |
| NRCS Soil Survey | | | | | | | | | | |
| Sarona-Vilas (range) | 9–12 | | | | 84.3–106.1 | | 4.5–6.5 | | 5.1–14.2 | |

Pre-wood ash soils were sampled in December 2014 and post-wood ash and biochar soils were sampled in late July 2015. Ranges for dominant soil types at the planting sites are also presented (Sarona-Vilas complex). Different letters denote significant differences in biochar or wood ash treatments.

**Table 3. Average seedling diameter and heights 2 years after amendment.**

| Treatment | Diameter | | Height | |
|---|---|---|---|---|
| | in. | SE | in. | SE |
| Biochar | | | | |
| Red pine (biochar + manure) | 0.32a | 0.05 | 11.72a | 1.85 |
| Red pine (biochar) | 0.30a | 0.04 | 11.54a | 1.63 |
| Red pine (manure) | 0.33a | 0.04 | 12.76a | 1.17 |
| Red pine (control) | 0.33a | 0.04 | 13.08a | 1.58 |
| Wood ash | | | | |
| Red pine (wood ash) | 0.30a | 0.04 | 15.96b | 2.06 |
| Red pine (control) | 0.30a | 0.04 | 12.92a | 1.67 |
| Jack pine (wood ash) | 0.60b | 0.08 | 34.30b | 4.42 |
| Jack pine (control) | 0.40a | 0.05 | 24.00a | 3.10 |

Different letters denote significant differences in biochar or wood ash treatments.

lower diameters and heights in the biochar only (no nutrients added) plots, which could indicate nutrient immobilization in the short term (Table 3). Therefore, it will be necessary to monitor our field trials throughout establishment to fully assess the effectiveness of these amendments.

Not surprisingly, wood ash application increased soil pH (Table 2), similar to the results of Kahl et al. (1996) in an acidic northeastern United States forest soil application. We did not measure CEC in the wood ash-amended soils because the ash was not incorporated into the soil, but future soil analysis will include CEC. Increasing soil pH can improve soil nutrient availability, and the significant increase in pH we observed is promising, as we have observed significant short-term responses to wood ash in both diameter and height of seedlings (Table 3). In particular, these results suggest that wood ash amendment in addition to biochar would have a lasting effect on increasing soil nutrient availability.

Whereas positive plant growth responses with the addition of biochar and biochar with fertilizer have been documented in the literature (Robertson et al. 2012, Spokas et al. 2012), we did not measure significant differences in seedling growth after two growing seasons (Table 3). It is likely that the effects of biochar on seedling growth in the natural environment will require more time to evaluate than has been observed in greenhouse studies, because the effects of shading or microsite variability probably impose greater limitations to growth and establishment than do short-term changes in soil structure or nutrient availability. As such, long-term monitoring of seedling survival and growth is planned. Shortly after planting, we measured a 9% mortality rate in the biochar-amended section (638 TPA surviving) and 7% in the remainder of the stand lacking amendments (820 TPA surviving). Because of low stocking due to competition by stump sprouts with no herbicide treatment, this site was subsequently restocked. It is important to consider any long-term success of the treatments, with respect to costs and benefits, in the context of how challenging it is to maintain desired stocking in these droughty soil types; any increased establishment of desired species in these challenging soil complexes is ecologically significant.

Biochar application proved more challenging than wood ash application. The biochar application method used in this study was estimated to have doubled the planting time, compared with that for other areas planted with no amendments. The contractors stipulated that future biochar applications will be $1 per tree instead of their normal rate of $0.05 per tree, owing to the additional effort required. Therefore, planting 1 ac using biochar would cost $900.00 compared with the standard $45.00, which is not a sustainable cost increase for the Florence County Forest. In addition, the regional availability of biochar is limited, with the biochar used in this study being purchased from Colorado. If a local source of biochar were to become available, the feasibility of this amendment would greatly increase. Other application methods of biochar include broadcasting using a spreader similar to that used in the wood ash application. A biochar spreader prototype is currently under development by the US Department of Agriculture Forest Service (Page-Dumroese et al. 2016). The application of wood ash did not require as much additional time or resources as the biochar application. Although the modified spreader (Figure 2) was effective in dispersing wood ash, the motor powering the spreader was inadequate on the uneven terrain, and additional labor was required to keep the spreader functioning. With a larger spreader and/or a motor and hydraulic pump, the application would be more efficient. By addressing these concerns, modified salt spreaders should prove to be an efficient way to broadcast wood ash in forestry applications. Moreover, the supply stream of wood ash in Northern Wisconsin is consistent, owing to the proximity of the Verso Paper Mill and an added incentive in reducing the material being landfilled. Future research focused on identifying sources of biochar (either as feedstock for pyrolysis or as a finished product) and evaluation of the efficacy of broadcast surface application methods for both biochar and wood ash is still needed, but we see these as viable strategies for the management of droughty and nutrient-poor forest soils in the future.

## Conclusions

We have demonstrated how biochar and wood ash amendments might be applied in even age forest management. Biochar significantly improved the soil structure, which greatly increased its water holding capacity and ability to retain nutrients and buffer against changes in acidity (increased CEC). Wood ash amendments significantly increased soil pH and resulted in increased diameter and height growth in seedlings 2 years after application. Methodological constraints to the application of these amendments included the following: lack of a readily available source of biochar in the Lake States, which increased its associated cost; increased cost associated with biochar dispersal (by hand); and lack of refined methods for wood ash dispersal. Wood ash is readily available in the region, and its promising effects on seedling growth suggest that this could be an effective means for enhancing establishment in soils with poor fertility. We propose a potential method of incorporating biochar into the growing medium of containerized stock in combination with wood ash application.

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