# ARE WE MAINTAINING ASPEN PRODUCTIVITY ON SAND SOILS?

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ABSTRACT.—Management activities that decrease soil porosity and/or remove organic matter have been associated with declines in site productivity. We determined effects of soil compaction and organic matter removal (OMR) on soil properties and aboveground productivity of aspen (*Populus tremuloides* Michx. and *P. grandidentata* Michx.) suckers, associated woody species, and herbaceous vegetation on a Rubicon sand in northeastern lower Michigan. Three levels of OMR—(1) merchantable bole harvest (MBH), (2) total tree harvest (TTH), and (3) TTH plus forest floor removal (FFR)—and three levels of soil compaction were applied. Compaction and FFR each increased fourth-year sucker density about 20%. "Heavy" compaction *increased* aspen diameter and height by about 10% and biomass by 20%. FFR *decreased* sucker diameter, height, and dry weight by more than 20%. Total aboveground biomass production (herbs + shrubs + aspen + associated species) decreased with increased OMR. Retention of organic matter appears critical to sustaining long-term productivity of aspen-dominated ecosystems on sand soils. As an interim guideline for aspen harvesting on sand soils, we recommend limbing at the stump and retaining of slash on site.

Maintaining site productivity is a key factor in sustainable forest management. Forest management activities that decrease soil porosity and remove organic matter have been associated with declines in site productivity (Agren 1986, Greacen and Sands 1980, Grier *et al.* 1989, Standish *et al.* 1988). As part of an international network of cooperative studies on long-term soil productivity (LTSP) (Powers *et al*. 1990, *Tiarks et al*. 1993), we are monitoring effects of soil compaction and organic matter removal (OMR) in the aspen (*Populus tremuloides* Michx. and *P. grandidentata* Michx.) forest type across a gradient of soil productivity on four sites across the northern Lake States region and in southeastern British Columbia (Kabzems 1996, Stone and Elioff 1998). The research is designed to determine how changes in soil porosity and organic matter content affect fundamental soil processes controlling forest productivity and sustainability; and secondly, to compare responses among major forest types and soil groups across the United States and Canada. The objective of this installation is to monitor changes in soil properties following forest harvesting and application of soil compaction and OMR treatments on a sand soil, and to measure responses by the forest regeneration and herbaceous vegetation. We use the term "sand" as in the commonly used USDA textural classification scheme i.e., 85% or more sand-size particles (Soil Survey Staff 1975). We report results on aspen stocking and growth and aboveground biomass production of aspen and associated vegetation after four growing seasons and compare them with data from a loamy sand site in northern Minnesota.

## METHODS

### Stand and Site Conditions

The study is on the Harrisville Ranger District, Huron National Forest, Alcona County, in northeastern lower Michigan (44° 38' N, 83° 32' W). The climate is continental with warm (20.5°C, 64.8°F) summers, cold winters (-6.0°C, 22.4°F), and 747 mm (29.4 in.) of precipitation; about 60% occurs during April through September. Winter snowfall averages 125.7 cm (49.5 in.). The site was occupied by a fully stocked, 35-year-old stand of predominantly trembling and bigtooth aspen. Basal area averaged 20 $m^2$ $ha^{-1}$ (87 $ft^2$ $ac^{-1}$); about 90% was aspen and the balance was primarily red maple (*Acer rubrum* L.), northern red oak (*Quercus rubra* L.), and eastern white pine (*Pinus strobus* L.). The most common shrubs on the area were red maple, serviceberry (*Amelanchier* spp. Med.), ironwood, (*Ostrya virginiana* (Mill.) K. Koch), and blueberry (*Vaccinium* spp.); the predominant herbs were bracken fern (*Pteridium aquilinium*), large-leaf aster (*Aster macrophyllus* L.), wild sarsaparilla (*Aralia nudicaulis* L.), wintergreen (*Gaultheria procumbius* L.), and running groundpine (*Lycopodium clavatum* L.). The soils, developed from outwash sands, are acid, relatively infertile, and are classified as transitional between

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Rubicon (Entic Haplorthod, sandy, mixed, frigid) and Grayling sands (Typic Udipsamment, mixed, frigid) (Soil Survey Staff 1975). Depth to the regional water table ranges from 2.5 to 5 m (8 to 16 ft); site index (age 50) for aspen is about 19 m (62 ft).

## Design and Treatment

Three levels of harvest intensity and OMR, and three levels of soil compaction, were applied to 50 x 50 m (0.25-ha, 0.62-ac) plots in a complete 3x3 factorial design with three replications. The levels of OMR were (1) merchantable bole harvest (MBH) to a 10-cm (4-in.) top diameter, (2) total aboveground tree harvest (TTH), and (3) total vegetation harvest plus forest floor removal (FFR). The FFR treatment was included to represent those areas in skid trails and landings where most or all of the forest floor materials are removed during harvest. It also could provide an indication of productivity trends following a second rotation of total tree harvesting. The compaction treatments were designed to provide: (1) no additional compaction above that due to harvesting; (2) light, to increase bulk density of the surface 10 to 20 cm of soil by 15%; and (3) heavy, to increase bulk density of the surface soil by 30%. Four non-cut control (NCC) plots were installed in the adjacent stand, for a total of 10 treatment combinations.

The aboveground portion of the stand was harvested in late January 1994 using a tracked Bobcat shear on the non-compacted plots, a Hydro-Ax feller/buncher on the rest of the units, a Caterpillar 518, and a Timberjack 380B grapple skidder. The winter was colder than normal, with several days below -30°C (-20°F); during harvest, the surface 20 to 25 cm (8 to 10 in.) of soil was frozen and covered by 35 to 40 cm (14 to 16 in.) of snow. Tops from the MBH plus compaction treatments were piled adjacent to the plots and replaced after the compaction treatments were completed. In mid-April, the coarse woody debris and forest floor materials were removed using a power-driven sidewalk sweeper with a revolving wire brush head 45 cm in diameter and 90 cm wide; the material was piled outside of a 5- to 10-m-wide buffer zone surrounding each treatment plot. In late April, when the soil was at field capacity, the compaction treatments were applied using a 9.5 Mg (21,000 lb) Hough model 60 front-end loader with 44.4 x 63.5 cm (17.5 x 25 in.) tires, advancing one tire width each pass. The light compaction treatment was accomplished with a single pass of the loader with a tire pressure of 172 kPa (25 psi). The heavy compaction treatment required two passes of the loader with the bucket loaded with sand and tire pressures of 276 kPa (40 psi). This provided a machine weight of 12.7 Mg (28,000 lb); the static pressure exerted by the front tires was not determined.

## Measurements and Analyses

All measurements and sampling were made at eight randomly located sample points located within the interior 40 x 40 m area of each treatment plot. In early August 1996, after three growing seasons, the aboveground herbaceous vegetation was collected from four 1.0-$m^2$ subplots per plot, dried at 75° C, and weighed. In September 1997, after four growing seasons, the basal diameter of all woody plants (> 15-cm height) was measured and recorded by 2-mm diameter classes on eight 5.0-$m^2$ subplots per plot. Mean height of aspen suckers in each diameter class was recorded to the nearest 5-cm class. Aboveground biomass of the woody species was estimated using allometric equations for each species developed by Perala and Alban (1994). The form of the equations is:

Component weight = Constant*D15^b*Age^c*Soil and other treatment multipliers,
where weight = g, D15 = mm, and Age = years.

All subplot data were composited and treatment effects were evaluated by two-way analysis of variance of the plot-level means. First, the overall effects of compaction level and organic matter removal each were evaluated by analysis of the pooled data (n = 9). Then the individual treatment effects and compaction-OMR interactions were evaluated (n = 3). Neither the compaction effects nor the interactions were significant, so the data were stratified by level of compaction and the effects of OMR were evaluated for each compaction level (n = 3). Comparisons among means were made with the Least Significant Difference procedure at the 95% confidence level (Analytical Software 1996).

## RESULTS

Across OMR treatments, both levels of compaction resulted in consistent, although non-significant increases in sucker diameter, height, and dry weight (table 1). Aspen diameter and height were about 10% greater, and biomass was more than 20% greater on heavily compacted plots than on non-compacted plots. Mean sucker density averaged 24% greater on the 18 compacted plots than on those that were not compacted. Across compaction treatments, increased OMR significantly decreased sucker diameter, and height (table 2.) Aspen biomass production also showed a showed a consistent, non-significant decrease with increasing OMR and a slight increase in stand density. Compared to MBH, the TTH plus FFR treatments each reduced mean sucker diameter, height, and dry weight by more than 20% and increased stand density by 19%.

Table 1.—*Mean basal diameter (15 cm), height, dry weight, and density of aspen suckers by level of compaction*

| Compaction level | Diameter | Height | Dry weight | Density |
|---|---|---|---|---|
| | *mm* | *cm* | *Mg ha*$^{-1}$ | *k ha* $^{-1}$ |
| None[1] | 15.2 | 191 | 3.93 | 25.9 |
| Light | 15.6 | 205 | 4.13 | 33.2 |
| Heavy | 16.6 | 213 | 4.99 | 31.2 |

[1]Each treatment is the mean of nine plots.

Table 2.—*Mean basal diameter (15 cm), height, dry weight, and density of aspen suckers by level of organic matter removal*

| Organic matter removal | Diameter | Height | Dry weight | Density |
|---|---|---|---|---|
| | *mm* | *cm* | *Mg ha*$^{-1}$ | *k ha* $^{-1}$ |
| MBH[1] | 17.6 c | 228 b | 5.01 | 27.0 |
| TTH | 15.9 b | 204 b | 4.20 | 31.2 |
| FFR | 14.0 a | 176 a | 3.83 | 32.1 |

[1] MBH, merchantable bole harvest; TTH, total tree harvest; FFR, total tree harvest and forest floor removal. Each treatment is the mean of nine plots; means followed by the same letter, or without letters, do not differ significantly at P=0.05 level.

Of the nine treatments, the TTH plus light compaction plots had the greatest number of suckers. (table 3). In general, both the level of OMR and degree of soil compaction tended to increase mean sucker density Differences in basal diameter among the nine treatments were significant, although the separation of means was distinct only with the light compaction treatments (table 4). Within each compaction level, the largest diameters occurred in the MBH treatments and decreased with intensity of OMR. For each level of OMR, the smallest diameters occurred on non-compacted plots and increased with compaction.

The differences in height among the nine treatments were significant and showed a pattern similar to those for diameter (table 5). At each level of compaction, the greatest height occurred in the MBH treatments and decreased with intensity of OMR. Likewise, with both MBH and TTH, the lowest mean heights occurred on non-compacted plots and increased with compaction. As with mean diameter and height, the greatest biomass occurred in the MBH treatments with either light or heavy compaction (table 6), and the least in the FFR plus light compaction and on non-compacted FFR treatments.

Table 3.—*Density of aspen suckers (k ha*$^{-1}$*) by level of organic matter removal and soil compaction*

| Organic matter removal | Compaction level | | |
|---|---|---|---|
| | None | Light | Heavy |
| MBH [1] | 24.0 | 28.4 | 28.5 |
| TTH | 26.5 | 36.8 | 30.2 |
| FFR | 27.1 | 34.3 | 34.9 |

[1]Each treatment is the mean of three plots.

Table 4.—*Basal diameter (mm at 15 cm) of aspen suckers after four growing seasons by treatment*

| Organic matter removal | Compaction level | | |
|---|---|---|---|
| | None | Light | Heavy |
| MBH | 16.9 | 18.0 c | 17.8 |
| TTH | 14.8 | 16.1 b | 16.7 |
| FFR | 14.0 | 12.7 a | 15.3 |

Table 5.—*Mean height of aspen suckers (cm) after four growing seasons by treatment*

| Organic matter removal | Compaction level | | |
|---|---|---|---|
| | None | Light | Heavy |
| MBH | 211 | 243 c | 230 |
| TTH | 188 | 207 b | 218 |
| FFR | 174 | 165 a | 190 |

Table 6.—*Mean dry weight of aspen suckers (Mg ha$^{-1}$) after four growing seasons by treatment*

| Organic matter removal | Compaction level | | |
|---|---|---|---|
| | None | Light | Heavy |
| MBH | 4.09 | 5.49 b | 5.45 |
| TTH | 4.10 | 4.19 ab | 4.33 |
| FFR | 3.59 | 2.71 a | 5.20 |

## DISCUSSION

### Soil Compaction

Early results from these LTSP installations provide data to question three commonly held beliefs: (1) sandy soils are not susceptible to compaction, or that compaction is not a problem on sands; (2) where soil compaction occurs, it is detrimental to aspen sucker development and growth; and (3) the effects of compaction are soon alleviated by the normal soil processes of wetting-drying and/or freezing-thawing.

Several lines of evidence indicate that the first is incorrect; if sandy soils contain a range of particle sizes, they are susceptible to compaction. First, a trial run before the compaction treatment showed that one, two, and four passes of the loader increased bulk density of the surface 10 cm of soil—where most of the aspen suckers originate—from approximately 0.96 Mg m$^{-3}$ to 1.10, 1.33, and 1.40 Mg m$^{-3}$, respectively. These increases are about 15%, 39%, and 46% for the one, two, and four passes, respectively. An increase of 30% was estimated to be the approximate threshold level for root-limiting bulk density, or a soil strength of 3,000 kPa. Secondly, compared to LTSP installations on silt loam and clay loam sites, soil strength on the sand showed the greatest relative increase in cone index and the greatest absolute value, > 2,900 kPa (Mungoven 1996). Moreover, cone index increased to a greater depth (> 50 cm) in the sand relative to the other two sites. Thus, only one or two passes of the loader were required to achieve the light and heavy levels of compaction. We emphasize that these experimental compaction levels are well below those encountered on major skid trails and landings found on conventionally harvested sites. On those areas, we have measured substantial reductions in both sucker density and growth (unpublished data).

The second assumption—that where soil compaction occurs, it is detrimental to aspen sucker development and growth—is not substantiated by the early results on this site. The overall means of growth (table 1) indicate that soil compaction did not decrease ($p \leq 0.05$) basal diameter, height, or dry weight production of aspen suckers during the first 4 years of the study. Although the differences are not statistically significant, the trends in increased growth are consistent. Moreover, if they continue, the differences will increase with time. The increased growth is probably due to changes in the pore space distribution. Low to moderate levels of compaction can convert a portion of the macropore space to micropores, thereby increasing the water-holding capacity of the soil (Campbell *et al.* 1974, Dickerson 1976, Donnelly and Shane 1986), thus decreasing water stress in the regeneration (Powers and Fiddler 1997, Powers 1999).

The third assumption—that the effects of compaction are soon alleviated by normal soil processes such as freezing and thawing—has not occurred on a loamy sand site in northern Minnesota where the soils normally freeze each winter (Verry 1991). Five years after the treatments were applied, neither bulk density nor soil strength on compacted plots has shown any trend toward recovery (Stone and Elioff 1998). We are monitoring soil properties on the sand site in the current study.

### Aspen Development

These data show two opposing responses: first, soil compaction tended to increase growth of the aspen, and secondly, OMR decreased it. Additionally, the lowest density of suckers (24 to 27 k ha$^{-1}$) occurred on the non-compacted plots and increased with TTH, compaction, and FFR. The increase in sucker density with both compaction (table 1) and level of OMR (table 2) was not unexpected; disturbance to the parent root systems and increased soil temperatures are known to favor development of suckers (Schier *et al*. 1985, Peterson and Peterson 1992). The FFR treatment also stimulated sucker density on the loamy sand site in Minnesota; however, compaction decreased it (Stone and Elioff 1998).

The decreased early growth in diameter and height and the trend in decreased dry weight production with increasing OMR were not expected because of the nutrient and carbohydrate reserves reported to be contributed by the parent root systems (Peterson and Peterson 1992). They also suggest that the contribution of parent root systems to regeneration may not be as significant on these kinds of sites as is commonly reported in the literature. This could indicate that stands growing on sand soils do not possess the ecological resilience as would identical clones growing on more productive soils. Most importantly, it illustrates the importance of site organic matter to sustaining the integrity and productivity of ecosystems on coarse-textured soils (Flinn *et al*. 1980, Smethurst and Nambiar 1990, Carlyle *et al*. 1998).

### Maintaining Site Productivity

Sustaining the long-term productivity of our nations's forests is an ethical and economic aim of forest management (Powers 1990). By law, the Forest Service must monitor the effects of management practices to ensure sustained productivity. Land productivity is defined as a soil's capacity to support plant growth as determined by some index of biomass accumulation. A significant change in productivity is defined as the minimum level of reduced growth that is detectable using current technology. Soil Quality Standards are being developed to detect a decline in potential productivity of 15% (Powers 1990).

We used third-year biomass of herbaceous vegetation plus fourth-year biomass of woody species as an index of net primary productivity. At each compaction level, one or more of the OMR treatments reduced site productivity by 15% or more. Compared to MBH, the FFR treatment reduced biomass productivity by 24% on non-compacted plots (fig. 1a) and by 32% with light compaction (fig. 1b). With heavy compaction, the reduction averaged 15% on the TTH plots and 5% in the FFR treatment (fig. 1c). It is not clear whether the dry weight values in the most extreme treatment are due to sampling variation, if the increase due to compaction compensated for the decrease due to OMR, or a combination of the two. Future measurements should clarify the question. The relative effects of OMR on nutrient availability and water-holding capacity are uncertain; however, the results indicate that retention of organic matter is critical to sustaining long-term productivity of aspen-dominated ecosystems on soils like these.

In soils with low proportions of silt and clay, the amount of soil organic matter becomes increasingly important. Pre-treatment samples indicated the forest floor averaged about 2.0 cm in thickness and 48 Mg ha$^{-1}$, approximately half that on the loamy sand site at Marcell (table 7). Thus, these Michigan sands have a relatively small reserve of soil organic matter to sustain future productivity. Because of the small organic buffer, sustained productivity on these kinds of sites may be at risk. This raises concerns regarding the ability of these sites to maintain productivity of aspen harvested by the total tree

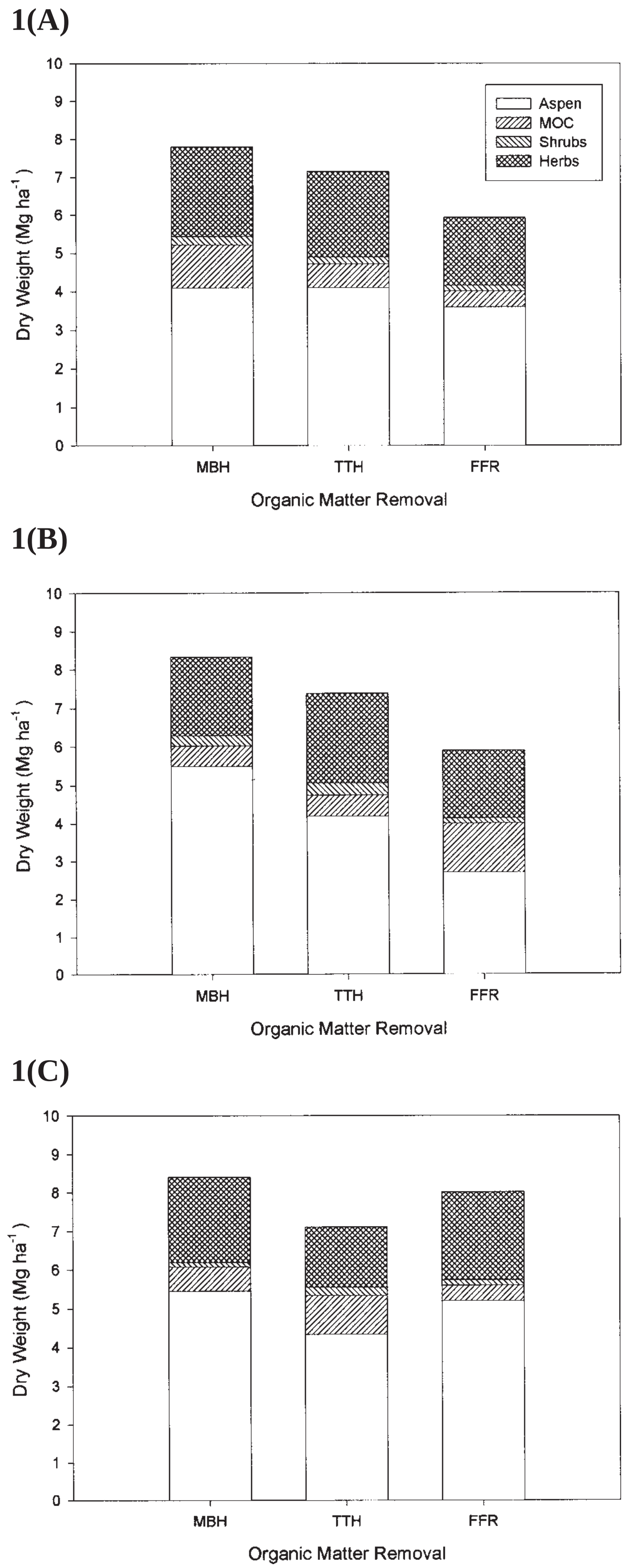


Figure 1.—*Aboveground biomass of aspen suckers, associated species (predominantly red maple, red oak, and black cherry [MOC]), shrubs, and herbaceous species by level of organic matter removal with no compaction (A), and following light (B), and heavy (C) compaction of a Rubicon sand.*

Table 7.—*Site characteristics and productivity of aspen and associated species following total tree harvest of aspen on the Huron-Manistee National Forest (Rubicon/Grayling sand) and the Marcell Experimental Forest (Cutaway loamy sand)*

| Variable | Rubicon sand | Cutaway loamy sand |
|---|---|---|
| Aspen site index - m (ft) | 19.0 (62) | 20.7 (70) |
| Basal area - $m^2$/ha ($ft^2$/ac) | 19.0 (87) | 40.7 (177) |
| FF thickness - cm | 2.0 | 4.0 |
| FF dry weight - Mg $ha^{-1}$ | 48 | 100 |
| Sucker age - years | 4 | 5 |
| Density - k $ha^{-1}$ | 26.5 | 40.4 |
| Basal diameter - mm | 14.8 | 19.4 |
| Height - cm | 188 | 271 |
| Dry weight - Mg $ha^{-1}$ | 4.1 | 12.9 |
| All vegetation - Mg $ha^{-1}$ | 7.1 | 16.5 |

method. Grigal and Bates (1992) coined the term "nutrient mining" to describe nutrient removal at rates greater than natural rates of replenishment. We believe that the concept applies to site organic matter as well; we use this term in the broad sense to include both soil organic matter and the forest floor materials. If removal plus natural losses exceed rates of accumulation, the organic matter pool will decline and productivity may not be sustained (Morris *et al*. 1997).

On national forest lands, the aspens occur predominantly in the Lake States (Eastern region), the Rocky Mountain region, and Alaska. In the Rocky Mountain region, the threshold values for organic matter management are: "Less than 90% retention of fine logging slash following clearcutting or seedtree cutting on soils rated severe. Less than 50% retention following shelterwood or group selection cuttings." Those for the Alaska region are: "Less than 85% litter retention on slopes under 35%; less than 95% on slopes greater than 35%." The Eastern region has no Soil Quality Standard for organic matter retention. These results indicate that harvesting methods should be adapted to increase the amount of organic matter retained on site. As an interim guideline for aspen management on sand soils, we recommend that silvicultural prescriptions and timber sale contracts specify limbing at the stump.

## SUMMARY AND MANAGEMENT IMPLICATIONS

The sand soils on this site contain a range of particle sizes and were easily compacted. Relatively low levels of compaction can increase water-holding capacity and plant growth. Both diameter and height growth of aspen and total biomass production were reduced by OMR. This raises the question of whether the additional biomass yield from total tree harvesting is worth the cost in soil resources—nutrients, organic matter, and water-holding capacity. Grigal and Bates (1992, 1997) recommended limbing at the stump and retaining of logging slash on site to decrease nutrient removal. Equipment is available to fell and limb at the stump, and its suitability and productivity have been demonstrated in summer harvest of aspen up to 75 years old on well-drained sites. It also has been used successfully for winter harvest of mature aspen on poorly drained clay soils, resulting in little visible site disturbance and excellent regeneration of aspen and associated species. As an interim guideline for aspen harvesting on sand soils, we recommend limbing at the stump and retaining of slash on site.

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