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Soil and Vegetation Response to Soil Compaction and Forest Floor Removal After Aspen Harvesting

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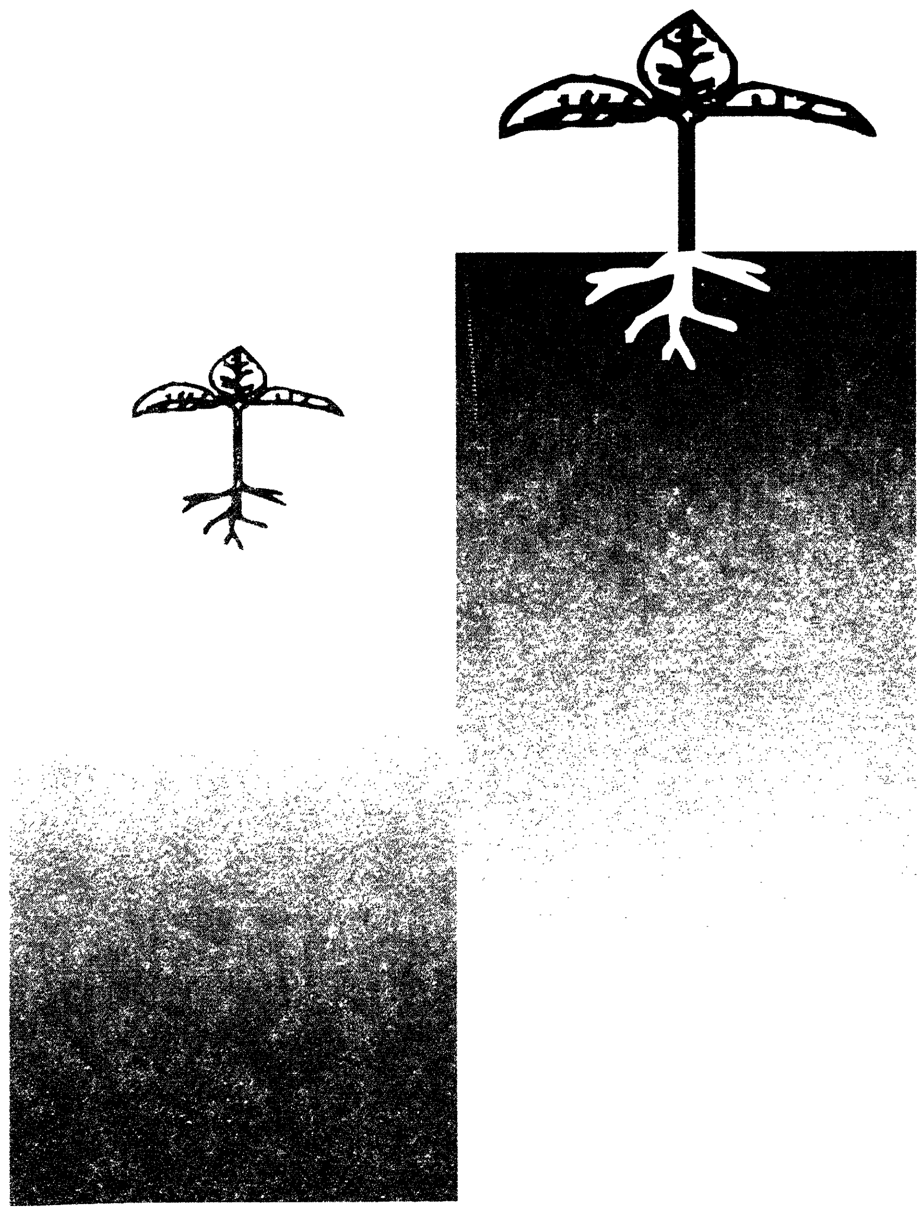

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Reduced soil porosity and organic matter removal have been identified as common factors associated with loss of forest productivity (Powers *et al.* 1990). In both agriculture and forestry, management activities can modify soil porosity and organic matter with resultant impacts on vegetative growth (Agren 1986, Greacen and Sands 1980, Grier *et al.* 1989, Gupta *et al.* 1989, Standish *et al.* 1988, Tate 1987).

As part of a nationwide long-term soil productivity (LTSP) study soil porosity and organic matter are being experimentally manipulated on large plots to determine the impacts of such manipulations on growth and species diversity for a wide range of forest types (Powers 1991). Porosity and organic matter are, of course, surrogates for causal growth factors such as moisture and nutrient availability, aeration, or soil strength. A further objective of the study is to determine how management activities affect the causal growth factors, and how these in turn affect vegetation growth and diversity.

As part of the national effort, we plan to install 10 to 15 replications in the Lake States in the aspen type. The aspen type was selected because it composed about 49 percent of the pulpwood harvest in the Lake States in 1991 (Hackett 1992) and because it is often whole-tree harvested with large equipment, resulting in large nutrient removals and possibile compaction of soil.

In the Lake States, aspen harvesting can increase water yields (Verry 1987) and accelerate the leaching of nutrients (Mroz *et al.* 1985, Richardson and Lund 1975, Silkworth and Grigal 1982), but the effects of such changes on soil productivity are unknown. Alban and Perala (1990) examined whole-tree vs. bole-only harvesting of aspen on three sites and found no difference in soil organic matter or nutrients, or in vegetative regrowth, between the two harvesting systems. These sites were winter-harvested on frozen ground so that soil compaction did not occur; however, the potential for harvesting to cause soil compaction has been documented in the Lake States (Mace 1971, Shetron *et al.* 1988, Thorud and Frissell 1976). None of these studies reported the impact of the compaction on vegetative growth.

We report here on 2-year results from the first installation of the LTSP study in the Lake States.

THE STUDY SITE

The study plots are located in the Marcell Experimental Forest in north central Minnesota about 25 miles north of Grand Rapids. The climate of the study area is continental with warm summers (mean July temperature 19°C), cold winters (mean January temperature -16°C), and 770 mm of annual preciptation, about half of which occurs during the growing season.

The stand on the study area was well stocked with 70-year-old aspen (*Populus tremuloides* Michx., *Populus grandidentata* Michx.) with a site index of 20.7 m (base age 50). The aspens dominated the site and made up 88 percent of

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Table 1.—*Vegetation on site before harvesting*

Species	Stems	Basal area	Aboveground biomass
	No/ha	*m²/ha*	*t/ha*
Populus tremuloides	355	19.4	91.4
Populus grandidentata	264	16.4	97.5
Acer rubrum	402	2.8	12.2
Betula papyrifera	148	1.9	9.0
Other tree species[1]	16	0.2	0.9
Shrubs	—	—	2.53
Herbs	—	—	0.25
Total	1,185	40.7	213.8

[1] Includes *Abies balsamea*, *Picea glauca*, *Pinus banksiana*, and *Quercus rubra*.

the aboveground biomass (table 1). The predominant shrub on the plots was beaked hazel (*Corylus cornuta* Marsh.). The predominant herbs were *Aralia nudicaulis* L. and *Aster macrophyllus* L. Shrubs and herbs constituted only about 1 percent of the aboveground biomass (table 1).

The soil on the study site is a Cutaway loamy sand (Loamy, mixed, Arenic Eutroboralf (Soil Survey Staff 1975). A brief description taken from the study site and representing an average condition follows:

Oi_5-4cm; relatively undecomposed hardwood leaves and twigs.
Oe_4-2cm; very dark brown (10YR 2/2) partially decomposed hardwood leaves and twigs.
Oa_2-0cm; black (10YR 2/1) well-decomposed forest litter; weak fine and very fine granular structure; very friable; many very fine roots; very strongly acid; abrupt smooth boundary.
E_0-7cm; dark grayish brown (10YR 4/2) loamy sand; weak fine granular stucture; very friable; common fine and many very fine roots; very strongly acid; abrupt smooth boundary.
Bw1_7-25cm; dark brown (7.5YR 3/4) loamy sand; weak fine granular structure; friable; common medium and many very fine roots; medium acid; clear smooth boundary.
Bw2_25-35cm; dark yellowish brown (10YR 4/4) gravelly loamy sand; weak medium subangular blocky structure; friable; few medium and common very fine roots; medium acid; clear smooth boundary.
Bw3_35-75cm; dark yellowish brown (10YR 4/6) gravelly sand; weak medium platy structure; few very fine roots within the horizon and many roots concentrated at the contact between Bw3 and Bw4; medium acid; abrupt smooth boundary.
Bw4_75-109cm; brown (10YR 5/3) loamy sand; common medium distinct brown (7.5YR 4/4) mottles; massive structure, firm; very few roots; strongly acid; clear wavy boundary.
IIB/E_109-140cm; dark yellowish brown (10YR 4/4) and light brownish gray (10YR 6/2) clay loam; strong coarse blocky stucture; very firm; very few roots; slightly acid; clear wavy boundary.
IIC_140-180cm; brown (10YR 5/3) clay loam; massive; very firm; neutral; roots rare.

THE TREATMENTS

Eight plots (30 x 40 m with a 5-m-wide buffer strip) were laid out in the summer of 1990. Six plots were harvested, and two were left as uncut controls. The area (except for the controls) was whole-tree harvested in February 1991 with a John Deere[1] Model 643D feller-buncher (weight=13,000 kg). At the time of harvesting the soil was frozen to a depth of 0.3 m and there was

[1]*Mention of trade names does not constitute endorsement by the USDA Forest Service.*

about 0.4 m of snow on the ground. In April 1991, the forest floor was hand-raked from three of the plots and piled outside of the buffer strip. In May, four plots were compacted by four to five passes of a rubber-tired pneumatic roller ("wobble wheel") weighing about 8,100 kg, pulled by a D-6 Caterpillar tractor. Thus, of the harvested plots, two were compacted, two had compaction plus forest floor removal, one had only the forest floor removed, and one had neither compaction nor forest floor removal.

METHODS

Before harvesting, each tree greater than 2.5 cm d.b.h. on the 30 x 40 m plots was mapped, and its d.b.h. was measured. We also measured the height of about 20 trees per species with a clinometer to develop a height/diameter relation for the stand. The herb layer (herbs and woody seedlings less than 15 cm tall) was clipped at ground line from four 1-m^2 subplots per plot in late August, and bagged. The shrub layer (woody plants greater than 15 cm tall but less than 2.5 cm d.b.h.) was recorded by species and diameter at 15 cm on four 4-m^2 subplots per plot.

After harvesting, we sampled the herb and shrub layers in August 1991 and 1992 after 1 and 2 years of growth. The sampling was as before except that 12 subplots per plot were sampled instead of 4 as previously, and the herb layer subplots were 0.5 m^2. Tree and shrub aboveground biomass was estimated from allometric relationships for each species developed previously (Perala and Alban 1993). The tree equations are of the form WEIGHT = $a(DBH)^b(HT)^c$; and the shrub equations are similar except that height is not included, but age is included where significant. Herb biomass was measured directly for the clipped samples after drying at 75°C to a constant weight.

Ground-flora composition and abundance were measured on four 5 x 10 m subplots in each treatment plot. Percent ground cover was determined for all herbaceous and woody species in the subplot, using a Braun-Blanquet cover-abundance scale (Mueller-Dombois and Ellenberg 1974). Abundance values were determined by traversing the plot several times to record the species present, and then assigning abundance values after species lists were compiled. Abundance estimates were stratified by height class, referred to hereafter as the ground-flora (<0.5 m) and shrub layers (>0.5 m).

Soil samples were collected in April 1991 (T1) just before the forest floor removal and compaction treatments, and in May 1991 (T2) and 1992 (T3) after treatment application. Twelve hand-driven soil cores (6.4 cm diameter) were collected from each plot (Ruark 1985) and divided into the forest floor, 0-10 cm, 10-20 cm, and 20-30 cm mineral soil layers. The forest floor sample was dried at 75°C and weighed; the mineral soils were air dried, and subsamples were dried at 105°C to determine moisture. The core samples were used to calculate soil bulk density, and subsamples were used to determine carbon (C) content by gas chromatography (Carbo Erba carbon analyzer). When soil samples were collected, soil strength (SS) was measured with a hand-held automatic recording penetrometer (Rimik, Model CP10), using a 30° 1-cm^2 conical tip probe.

Infiltration rate was measured in August 1991 and June 1992 with a sharpened PVC pipe of 15.3 cm inside diameter. The pipe was tapped into the ground with a mallet, filled with water, checked for leaks, allowed to drain, then refilled with water. The level was then measured after 3 minutes.

The results were analyzed by two-way analysis of variance using regression to check for interactions between compaction and forest floor removal, and by simple one-way ANOVA (Huitema 1980). All testing of significance was done by the LSD test, and differences were declared significant if P was less than 0.05.

RESULTS AND DISCUSSION

Two-way analysis of variance showed that compaction had a significant impact on soil bulk density (Db), soil strength (SS), and infiltation rate, but forest floor removal or the interaction between the two treatments did not.

Compaction significantly increased Db at all three depths (table 2); Db increased by 22 percent in the 0-10 cm depth and by somewhat less in the deeper layers. On the non-compacted plots, Db did not change significantly over the three sampling times. From T2 to T3, the Db did not change at any depth, indicating that freezing and thawing over winter had not significantly lessened the bulk density during the first year.

Table 2.—*Soil bulk density*

Treatment[1]	Time	Bulk density 0-10 cm	10-20 cm	20-30 cm
		- - - - - - g/cm^3 - - - - - -		
Compaction	T1 (4/91)	0.98a[2]	1.21a	1.32a
	T2 (5/91)	1.20b	1.37c	1.53d
	T3 (6/92)	1.20b	1.31bc	1.48cd
No compaction	T1 (4/91)	1.01a	1.29b	1.40b
	T2 (5/91)	1.01a	1.26ab	1.44bc
	T3 (6/92)	0.98a	1.28ab	1.45bc

[1] The compaction treatments were applied between times T1 and T2.
[2] Values in a column followed by the same letter do not differ significantly.

Soil strength increased far more dramatically than did Db after compaction (table 3). The change was strongly depth-dependent, the increase ranging from 165 percent in the 0-10 cm layer to 41 percent in the 20-30 cm layer. In the two uppermost soil layers, SS significantly decreased over the first winter (table 3). SS is dependent on soil moisture; however, we found no significant difference in soil moisture over the three sampling times (19, 13, and 11 percent for depths 0-10, 10-20, and 20-30 cm, respectively), suggesting that the partial recovery from time T2 to T3 is, in fact, real.

Infiltration rate was greatly reduced by the compaction treatment (table 4). Somewhat surprisingly, harvesting without compaction reduced the infiltration rate by about one-half from the unharvested controls despite the fact that during harvesting the ground was frozen and snow covered. The difference in infiltration rates between the treatments was even greater the following year (table 4), probably reflecting a filling of soil pores with fines leached in by rainfall and snowmelt.

Table 3.—*Soil strength*

Treatment[1]	Time	Soil strength (k Pa) 0-10 cm	10-20 cm	20-30 cm
Compaction	T1 (4/91)	623a[2]	1,015b	1,383abc
	T2 (5/91)	1,653c	2,090d	1,951d
	T3 (6/92)	1,274b	1,656c	1,862cd
No compaction	T1 (4/91)	649a	798ab	1,180ab
	T2 (5/91)	667a	913ab	1,620bcd
	T3 (6/92)	571a	761a	1,029a

[1] The compaction treatments were applied between times T1 and T2.
[2] Values in a column followed by the same letter do not differ significantly.

Table 4.—*Infiltration rates*

Treatment	Infiltration August 1991	June 1992
	----- cm/min -----	
No harvest, no compaction	5.76a[1]	4.94a
Harvest, no compaction	2.84b	1.09b
Harvest, compaction	0.81c	0.23c

[1] Values in a column followed by the same letter do not differ significantly.

Litter raking reduced the forest floor thickness from 4.4 cm to 0.9 cm (an 80-percent reduction). Similarly, forest floor weight was reduced from 99 t/ha to 27 t/ha (a 73-percent reduction).

Total soil carbon (forest floor plus 0-30 cm) decreased by about 9 t/ha after forest floor removal with little or no change in mineral soil carbon (table 5). Over the next year (from T2 to T3), soil carbon in the forest floor and the 0-10 cm layer increased (table 5), probably because of root death. If we assume that the roots are 20 percent of the aboveground biomass and consist of 50 percent carbon, about 21 t/ha of root carbon would exist in the soil after harvesting. As this material decays, it becomes part of the soil C pool. In our study, roots added enough soil C to more than compensate for any possible accelerated loss of soil C due to decomposition after harvesting and treatment, at least for the first year.

The numbers of species in the ground-flora layer increased after harvest on all plots (table 6), probably because of increased light and amount of exposed soil at the forest floor. The new taxa were primarily species that colonize disturbed habitats, such as *Anaphalis margaritacea* L., *Geranium bicknellii* Britt., *Plantago major* L., *Tanacetum vulgare* L., *Chenopodium album* L., and several species of Aster. Numerous grasses were also recorded in the treated plots. *Populus grandidentata* and *P. tremuloides*, which were poorly represented in the lower structural layers before harvest, formed most of the biomass in the ground-flora and shrub layers in the second year.

The greatest increase in the number of species occurred in plots with both forest floor removal and compaction treatments (table 6). Plots with only litter removal or only compaction had similar increases in species 10 and 11, respectively. Plots with no treatments showed an increase of six species. The number of species is thus strongly correlated with the magnitude of disturbance. The implication in this early phase of analysis is that more heavily disturbed stands will require a longer recovery period to return to pre-disturbance composition than other stands.

Several species were lost from the plots. Among these were woody species, such as *Acer spicatum* Lam., *Dirca palustris* L., and *Rubus alleghaniensis* Porter., and herbaceous species such as *Pyrola rotundifolia* L., *Polygonatum pubescens* (Willd.) Pursh., and *Lycopodium lucidulum* Michx. Plots with both compaction

Table 5.—*Soil carbon weight*

Treatment	Time	Forest floor	0-10 cm	10-20 cm	20-30 cm	Forest floor + 0-30 cm
		----------- Carbon weight (t/ha) -----------				
Forest floor removed	T1 (4/91)	16.6d[1]	15.8ab	8.6a	5.9ab	46.9bc
	T2 (5/91)	5.1a	16.7ab	8.9ab	6.8b	37.5a
	T3 (6/92)	8.5ab	20.6b	10.4b	4.4a	43.9abc
Forest floor not removed	T1 (4/91)	13.4cd	15.5ab	7.7a	5.6ab	42.2abc
	T2 (5/91)	11.1bc	14.7a	8.4a	5.6ab	39.8ab
	T3 (6/92)	15.2d	19.8b	8.0a	4.8a	47.8c

[1]Values in a column followed by the same letter do not differ significantly.

Table 6.—*Changes in species richness (number of species) in the ground-flora layer from pretreatment to the second year*

Treatment	Number of species 1990	1992	Difference
Compaction	23.00a[1]	36.62ab	13.62ab
Forest floor removal	22.00a	32.00ac	10.00ac
Compaction and forest floor removal	23.75a	41.00b	17.25b
No treatment	24.50a	30.50c	6.00c

[1] Values in a column followed by the same letter do not differ significantly (P = 0.05).

and litter removal lost the most species (seven), compared with an average of four for all other plots. The magnitude of disturbance influences not only colonization, but also the persistence of selected woody and herbaceous species. Continued monitoring of the plots will help determine the relation between the magnitude of disturbance and the time required for recovery to pretreatment composition.

The number of aspen suckers was increased greatly by removing the forest floor (table 7). Disturbance of aspen root systems is known to stimulate suckering (Schier *et al.* 1985). By the end of the second growing season, the number of aspen suckers decreased as much as by half for the forest floor removal treatment.

The least total aboveground biomass was on the plots that had either compaction or forest floor removal (table 7). The treatment differences in total biomass largely reflect differences in aspen biomass because the herb and shrub biomass did not differ significantly by treatment. The plot with no compaction or forest floor removal had the greatest aspen and total vegetation biomass as well as the tallest aspen trees (table 7). Surprisingly, the plots with the second best growth were those that had both compaction and forest floor removal. The reason for this is not apparent, but may be a result of the compaction reducing the number of suckers, allowing those remaining to grow under less competition.

Table 7.—*Vegetation after harvesting*

Treatment	Aspen Number 1991	1992	Average ht of tallest 2,000 trees/ha 1992	Biomass 1992 Aspen	Herbs	Shrubs	Total
	- - *#/m²* - -		*cm*		- - - - - *t/ha* - - - - -		
Compaction	6.6a[1]	5.8a	218a	3.43a	0.85a	0.95a	5.23a
Forest floor removal	26.4b	13.3a	227ab	4.05a	0.40a	1.12a	5.57ab
Compaction and forest floor removal	14.0ab	9.8a	244b	5.29b	0.83a	0.80a	6.92bc
No treatment	9.7ab	8.6a	282c	6.17b	0.76a	0.90a	7.83c

[1] Values in a column followed by the same letter do not differ significantly.

Froehlich and McNabb (1984) found that conifer seedling growth was reduced in direct proportion to the increase in surface soil bulk density for a wide range of sites and species. In our study, surface soil bulk density was increased by 22 percent, which, according to the relationship developed by Froehlich and McNabb, should result in a height growth decrease of 17 percent. The tallest aspen trees in our study were reduced 23 percent by compaction. Aspen biomass was reduced much more than height growth by compaction and forest floor removal (table 7).

It appears that a relatively mild level of soil compaction and a rather severe level of forest floor removal have had similar major impacts on aspen growth. Within several years, we should be able to make our first estimates of soil recovery rates and the treatment effects on long-term vegetative growth and composition.

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Reports that both forest floor removal and soil compaction significantly reduced biomass and height of 2-year-old aspen suckers in plots in northern Minnesota.

KEY WORDS: *Populus tremuloides*, soil bulk density, soil strength, infiltration rate, ground flora