Aspen development on similar soils in Minnesota and British Columbia after compaction and forest floor removal

by Douglas M. Stone[1,2] and Richard Kabzems[3]

Forest management practices that decrease soil porosity and remove organic matter can reduce site productivity. We evaluated effects of four treatments—merchantable bole harvest (MBH) with three levels of soil compaction (none, light, or heavy), and total woody vegetation harvest plus forest floor removal (FFR)—on fifth-year regeneration and growth of aspen (*Populus tremuloides* Michx.) growing on soils with similar textures (20–40 cm silt loam over clay loam till) in northern Minnesota (MN) and northeastern British Columbia (BC). Overall mean sucker density was significantly greater in BC than in MN, and mean height was significantly lower. Soil compaction did not affect sucker density in BC, but significantly reduced it in MN, primarily due to late spring treatment. In BC, mean sucker heights generally decreased with level of compaction, but only the differences between non-compacted and the heavy compaction treatments were significant. On the MN plots, sucker heights were reduced significantly by compaction. Treatment responses were similar on both sites: (1) the greatest sucker densities were in the FFR treatment; (2) greatest mean heights were on the non-compacted MBH plots and were significantly greater than those in the FFR treatment; (3) sucker heights generally decreased with level of compaction; and (4) soil compaction decreased the number of suckers that had reached a dbh of 25 mm after five years and will likely delay future stand development and reduce site productivity.

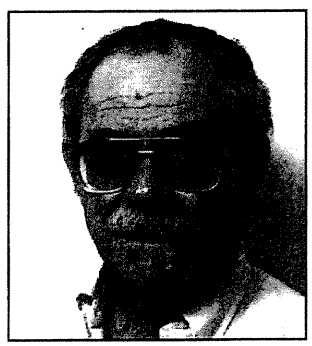
Key words: sustainable management, organic matter removal, soil compaction, aspen sucker density, height growth

Les pratiques d'aménagement forestier qui réduisent la porosité du sol et qui enlèvent la matière organique peuvent réduire la productivité d'une station. Nous avons évalué les effets de quatre procédures de récolte de la tige marchande (MBH) selon trois niveaux de compaction du sol (aucun, léger, important) et la récolte de toute la végétation ligneuse ainsi que l'enlèvement du substrat forestier (FFR) sur la régénération de cinq ans et la croissance du tremble (*Populus tremuloides* Michx.) en croissance sur des sols de texture semblable (20 à 40 cm de silt loameux sur un till d'argile et de loam) dans le nord du Minnesota (MN) et le nord-est de la Colombie-Britannique (C.-B.) La densité totale moyenne des drageons était significativement plus élevée en C.-B. qu'au MN, et la hauteur moyenne était significativement inférieure. La compaction du sol n'a pas affecté la densité des drageons en C.-B., mais elle a été significativement réduite au MN, principalement à cause des opérations effectuées tard au printemps. En C.-B., la hauteur moyenne des drageons diminuait généralement selon le niveau de compaction, mais seul les différences entre les opérations sans compaction et avec beaucoup de compactions étaient significatives. Dans les parcelles du MN, les hauteurs moyennes ont été réduites significativement par la compaction. Les réactions aux opérations étaient similaires sur les deux sites : (1) les plus importantes densités de drageons se retrouvaient dans les traitements FFR; (2) les plus importantes hauteurs moyennes se retrouvaient dans les parcelles non compactées MBH et étaient significativement plus grandes que celles des traitements FFR; (3) les hauteurs des drageons diminuaient généralement en fonction du niveau de compaction ; et (4) la compaction du sol réduisait le nombre de drageons qui avaient atteint un dhp de 25 mm après cinq ans et retardera probablement le développement futur du peuplement et réduira la productivité de la station.

Mots-clés : aménagement durable, enlèvement de la matière organique, compaction du sol, densité des drageons de tremble, croissance en hauteur

Introduction

Maintaining soil productivity is critical for sustainable forest management. Forest management activities that decrease soil porosity and remove organic matter have been associated with declines in site productivity (Greacen and Sands 1980, Agren 1986, Standish *et al.* 1988, Grier *et al.* 1989). 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 evaluating effects of three levels of organic matter removal (OMR) and three levels of soil compaction in the aspen (*Populus tremuloides* Michx. and *P. grandidentata* Michx.) forest type on four sites in the northern Great Lakes region and one site in northeastern British Columbia (Kabzems 1996, Stone and Elioff 1998, Stone *et al.* 1999, Stone 2001). The research is designed to determine how changes in soil porosity and organic matter content affect soil processes controlling forest productivity and sustainability and to compare responses among major forest types and soil groups across the United States and Canada.



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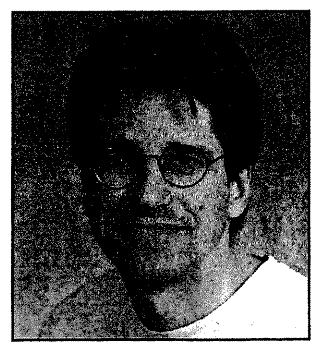

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The objectives of these aspen studies are to monitor changes in soil properties following forest harvesting and application of nine combinations of OMR and soil compaction treatments, and secondly, to measure responses of the aspen regeneration and associated vegetation. Fifth-year results from four

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treatments in a pilot study in north-central Minnesota (MN) and fourth-year results of four treatments in northeastern British Columbia (BC) were reported earlier (Stone and Elioff 1998, Kabzems 2000a). Fifth year results from four treatments—merchantable bole harvest (MBH) with three levels of soil compaction (none [C0], light [C1], or heavy [C2]), and total vegetation harvest plus forest floor removal (FFR) are now available. We report effects on fifth-year regeneration and growth of aspen growing on soils with similar textures (20–40 cm silt loam over clay loam till) on sites in MN and BC separated by approximately 2300 km. Treatment effects on soil properties will be reported when fifth-year data are available for all nine treatment combinations.

Methods

Stand and Site Conditions

Minnesota – The study was installed in the spring of 1993, on the Chippewa National Forest in north-central Minnesota (47°20′ N, 94°30′W). The climate is continental with warm summers (mean July temperature 20°C), cold winters (mean January temperature –17°C), and 640 mm of precipitation; about half occurs during the growing season. The site was occupied by a fully stocked, 70-year-old stand of predominantly trembling aspen; the primary associated species were red maple (*Acer rubrum* L.), basswood (*Tilia americana* L.), sugar maple(*A. saccharum* Marsh.), northern red oak (*Quercus rubra* L.), and eastern white pine (*Pinus strobus* L.). Basal area averaged 37 m^2 ha^{-1}. The predominant herbaceous species were twisted stalk (*Streptopus roseus*), bellwort (*Uvularai sessilifolia*), lady fern (*Athyrium filix-femina*), ostrich fern (*Matteucic struthiopteris*), sarsaparilla (*Aralia nudicaulis*), and bracken fern (*Pteridium aquilinium*). The site is on the Guthrie till plain; the surface soils developed from a silt loam loess cap 30 to 40 cm deep underlain by clay loam till. Site index (age 50) for aspen is about 23 m. The pre-harvest forest floor thickness averaged 6.2 cm with a dry weight of 131 Mg ha^{-1}.

British Columbia – The study was installed in the spring of 1995, in the Dawson Creek Forest District (55°58′N, 120°28′W). The climate is generally continental with moderately warm summers (mean July temperature 15°C), cold winters (mean January temperature –18°C) and 500 mm of precipitation; approximately half of which falls during the growing season. The site is representative of mesic aspen ecosystems in the Boreal White and Black Spruce (BWBS) zone (Kabzems 1996). The site was occupied by a fully stocked, 100-year-old aspen stand with a basal area of 34 m^2 ha^{-1}. The primary associated species were white spruce (*Picea glauca* (Moench) Voss), lodgepole pine (*Pinus contorta* Dougl.), and balsam poplar (*P. balsamifera* L.). The soils are silt loam 20 to 30 cm thick over clay loam till. Site index (age 50) for aspen was 18 m. The pre-harvest forest floor thickness averaged 7.0 cm with a dry weight of 149 Mg ha^{-1}.

Treatments

Minnesota – The stands were harvested during January and February 1993. Snowfall during November and December 1992 was somewhat greater than normal and air temperatures were slightly greater than the 30-year mean. Thus, soil frost was thin and discontinuous initially, and ranged from 5 to 10 cm when logging was completed. Snow depth increased from about 30 cm initially to 46 cm during the logging operations. On the non-compacted (MBHC0) plots, the trees were felled with chainsaws and winched off the plots with a cable skidder located outside the plot boundaries. On all other plots, the stems were cut with a Case-Drott model 40 feller-buncher and placed outside the plot boundaries; skidders did not enter any of the plots. The FFR treatment consisted of manually removing all coarse woody material and windrowing the forest floor materials, using a power driven sidewalk sweeper with a revolving wire brush head 46 cm in diameter and 90 cm wide; the materials were piled outside a 5 to 10-m-wide buffer zone surrounding the 50 × 50 m treatment plots. The light compaction treatment (MBHC1) consisted of a double pass, at right angles, across the plots with a model D-7 Caterpillar tractor, advancing one track width (61 cm) each pass. The heavy compaction treatment (MBHC2) included the light treatment followed by a double pass, at right angles, with a Michigan model 75C front-end loader with 52 × 63.5 cm (20.5 × 25 in.) tires, advancing one tire width each pass. There were three replications for each of the four treatments.

The objective of the compaction treatments was to increase bulk density of the surface soil by either 15% or 30% without damaging the root systems by rutting. This was accomplished successfully in previous years on the Marcell Experimental Forest and the Ottawa and Huron-Manistee National Forests. However, spring and early summer rainfall were higher than normal in 1993 and delayed study installation on this site. The frequent rainfall and the desire to avoid rutting caused numerous delays in application of the treatments. Thus, the suckers had begun to emerge by the time the soil had drained sufficiently to complete the compaction treatments, and many were broken by the machine traffic.

British Columbia – The area was harvested in January and February 1995. Winter harvest on frozen ground ensured that no soil disturbance occurred during the harvesting phase (Kabzems 1996). Only the feller-buncher entered the plots during harvest. Cut stems were placed outside the plot boundaries and removed with a grapple skidder. The first group of nine 40 × 70 m treatment plots was established in May 1995. The non-compacted (MBHC0) plots received no post-harvest compaction. The compaction treatments were applied with a vibrating pad mounted on an excavator. The light treatment (MBHC1) compressed the surface mineral soil 1 to 2 cm, and the heavy treatment (MBHC2) compressed the surface soil 4 to 5 cm. The FFR treatment consisted of removing all coarse woody material from the plots and then stripping the forest floor materials with an excavator. There were two replications for each of the three MBH-compaction level combinations. The FFR plots each received one (none, light, or heavy) of the compaction treatments. The effects of compaction on sucker density were not significant (Fig. 1) so we pooled these data and analyzed them as three replications of the main FFR treatment.

Measurements and Analyses

Measurement protocols varied somewhat between sites. On the MN site, all measurements were made within the interior 40 × 40 m area of each 50 × 50 m treatment plot. In September 1997, after five growing seasons, the basal diameter (15-cm height) of all woody species was measured and recorded by 2-mm diameter classes on eight randomly located

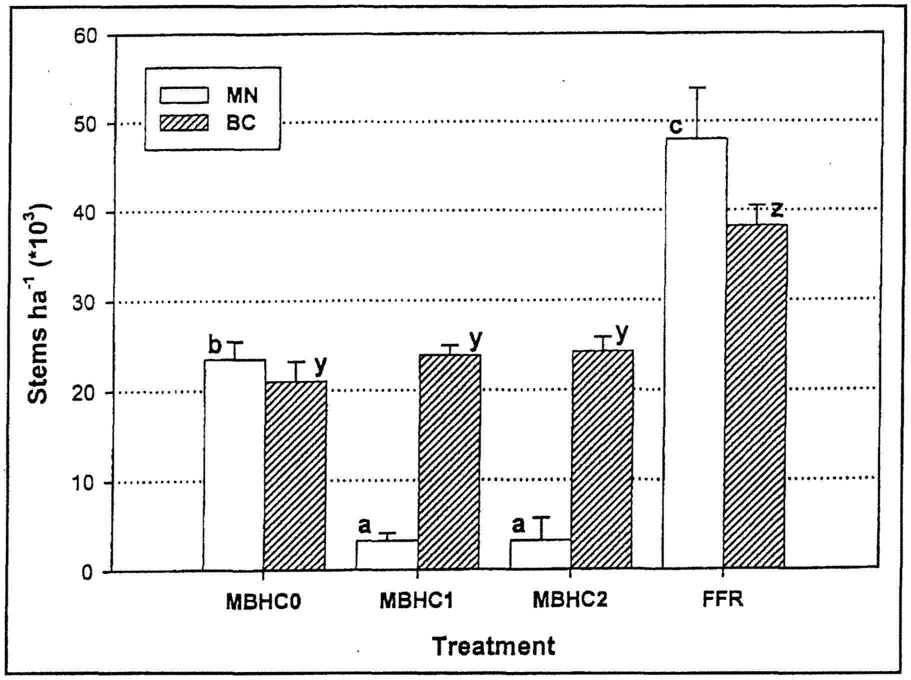

Fig. 1. Mean fifth-year aspen sucker density by treatment. Within sites, means followed by the same letter do not differ significantly at $p \leq 0.05$; error bars = standard error of the means. MBH = merchantable bole harvest; C0 = no compaction; C1 = light compaction; C2 = heavy compaction; FFR = total vegetation harvest plus forest floor removal.

5.0-m^2 subplots per plot. Mean height of aspen suckers in each diameter class was recorded to the nearest 5-cm class. On the BC site, density and height of aspen suckers and associated species were measured on nine randomly selected 50-m^2 subplots per plot in September 1999. On each subplot, average height of the aspen suckers was visually estimated and height of the four tallest suckers was measured. In early June 2000, during the sixth growing season, the basal diameter (15-cm height) of aspen was measured and classified as < 25-mm or > 25-mm diameter on three randomly selected 50-m^2 subplots per plot.

For each site, all subplot data were composited and the site and treatment effects were evaluated by two-way analysis of variance of the plot-level means. First, the data from both sites were combined and the overall effects were analyzed using a site-treatment-site*treatment model (Analytical Software 2000). The data for each site were then analyzed separately with a randomized complete block (treatment-replication-treatment*replication) model. Where main effects were significant at $p \leq 0.05$, comparisons among means were made with the Least Significant Difference procedure at the 95% confidence level.

Results and Discussion

Natural Variation

Trembling aspen is the most widely distributed commercial forest species in North America (Little 1971). Only one other hardwood species, the closely related Eurasian aspen (*P. tremula*), has a wider range. Both species typically exhibit marked phenotypic variability throughout their transcontinental ranges (Harper *et al.* 1985). Because of the greater variation within species than between species, *P. tremuloides* and *P. tremula* have been considered as a single circumboreal superspecies for taxonomic purposes (Harper *et al.* 1985) and from the standpoint of self-thinning rates and stockability (Perala *et al.* 1995, 1999). Considering the geographic differences between sites (Table 1) and the broad genotypic and phenotypic variability between clones (Jones and DeByle 1985), we were not surprised to see significant differences in overall mean sucker density and height between sites (Table 2). Schier and Zasada (1973), for example, found that at any given sucker number (density) and total nonstructural carbohydrate (TNC) concentration, growth of suckers from excised roots of three Utah clones was greater than that from three Alaskan clones.

Table 1. Stand and soil characteristics of aspen LTSP sites in north-central Minnesota and northeastern British Columbia

Parameter	Minnesota	British Columbia
Installation date	Spring, 1993	Spring, 1995
Latitude	47°20′N	55°58′N
Longitude	94°30′W	120°28′W
Mean January temperature	−17°C	−18°C
Mean July temperature	20°C	15°C
Mean precipitation (mm)	640	500
Stand age (years)	70	100
Basal area (m^2 ha^{-1})	37	34
Site index (m)	23	18
Silt loam cap (cm)	30–40	20–30
FF thickness (cm)	6.2	7
FF dry weight (Mg ha^{-1})	131	149

Table 2. Overall mean fifth-year density and height of aspen suckers in north-central Minnesota and northeastern British Columbia

Site	Density [a] (10^3 ha^{-1})	Height (cm)
Minnesota	19.5 a	210 b
British Columbia	26.9 b	122 a

[a]Means followed by the same letter do not differ significantly at $p \leq 0.05$.

Stand and Site Conditions

Despite the geographic differences between the sites, mean January temperature, stand basal area, and soil conditions are surprisingly similar (Table 1). Mean annual precipitation is 140 mm less at the BC site; however, the 5°C lower mean July temperature may compensate for the lower precipitation, resulting in sim-

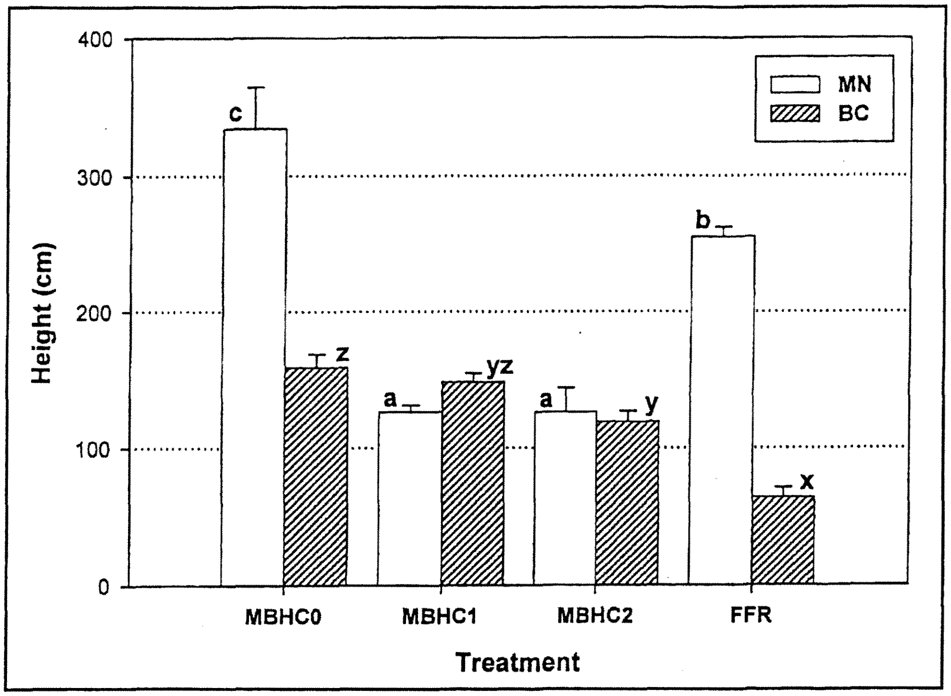

Fig. 2. Mean fifth-year aspen sucker height by treatment; within sites, means followed by the same letter do not differ significantly at $p \leq 0.05$. Treatment codes as in Fig. 1.

ilar growing season evapotranspiration and water balances on the two sites. The somewhat greater basal area and site index on the MN site can be attributed, at least partially, to the thicker silt loam cap. The slightly higher basal area on the MN plots presumably supports a higher leaf area index and provides greater litter production. However, the warmer growing season temperature and greater precipitation favour more rapid decomposition resulting in the lower forest floor thickness and dry weight.

Treatment Effects

On non-compacted plots, fifth-year sucker density was similar on the two sites (Fig. 1).The compaction treatments drastically reduced sucker density on the MN plots, primarily due to treatment after they had emerged. On this site, effects of compaction on reducing sucker density were dramatic, and not unlike many conventional logging operations in the northern Great Lakes region (Bates *et al.* 1990, 1993). These results indicate that managers should plan harvesting activities to minimize the area covered by machine traffic (Stone 2002), and avoid traffic in the spring after suckers have begun to emerge. The compaction treatments initially tended to increase first-year sucker density in the BC study, but by the fourth-year the differences by level of compaction were no longer apparent (Kabzems 2000a). Presumably, these initial increases were due to minor root injury during compaction. Disturbance of aspen root systems and increased soil temperatures are known to stimulate sucker production (Schier *et al.* 1985, Peterson and Peterson 1992). On fine textured (clay) soils, however, the more severe effects of rutting can be highly detrimental to both aspen sucker density and early height growth (Stone and Elioff 2000).

The differences in sucker density may be due to inherent differences in suckering capacity of the clones on the two sites as suggested by initial results from BC and another site in northern MN. The FFR treatment resulted in a first-year sucker density of >260 000 ha^{-1} on a loamy sand site in MN (Alban *et al.* 1994), and about 220 000 ha^{-1} in BC (Kabzems 1996), most likely due to increased soil temperatures and removal of competing vegetation (Kabzems 2000b). By the fourth year, sucker density had declined to about 55 000 ha^{-1} in BC (Kabzems 2000a), and by the fifth year, to about 40 000 ha^{-1} in MN (Stone and Elioff 1998).

In both MN and BC, the greatest height growth occurred in the non-compacted treatment (Fig. 2). As with sucker density, the late spring treatment on the MN site also greatly reduced sucker height. Compared to the non-compacted plots, the lower height growth with the FFR treatment most likely is due to the two-fold greater sucker density on those plots. In BC, soil compaction generally decreased sucker height; however, only the differences between the non-compacted and heavily compacted treatments were statistically significant (Fig. 2).The lower early height growth in the FFR treatment likely is due to a combination of water relations and carbohydrate reserves in the parent root systems. First, removal of the forest floor would have reduced the amount of available soil water over the growing season, creating less favorable growing conditions. The intact forest floor would have provided both a reservoir of soil water and a mulch that reduced evaporative losses (Powers 1999). Secondly, the exposure of aspen roots after forest floor removal stimulated the production of multiple suckers from each bud. Thus, the available carbohydrates were distributed over a larger number of stems, limiting the height growth of individual suckers and may have decreased dry weight per sucker (Schier and Zasada 1973). Stone *et al.* (2001) provided additional evidence for an inverse relation between sucker density and early growth; they found that retaining 18 to 37 mature aspen ha^{-1} decreased sucker density approximately 40% and increased first-year diameter and height growth by about 30%.

At the BC installation this depression of sucker height in the FFR treatment has continued into the seventh growing season (unpublished data on file). In the first year, mean height of aspen

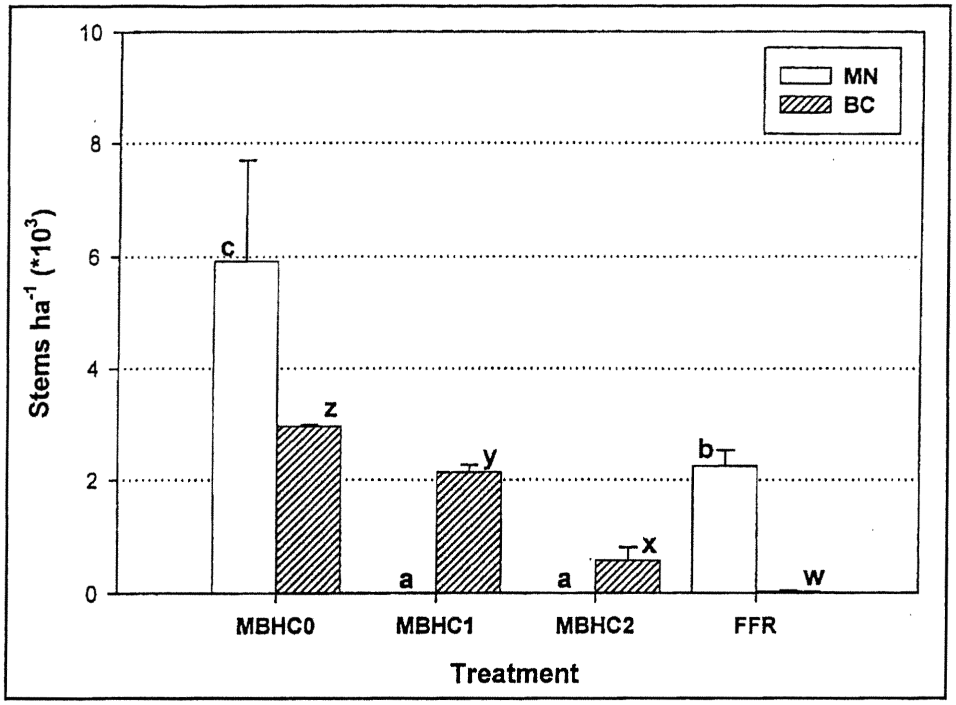

Fig. 3. Mean density of five-year-old aspen suckers ≥25 mm dbh. Treatment codes as in Fig. 1.

on the FFR plots was 82 cm vs. 129 cm in the non-compacted treatment. After the seventh growing season, suckers in the FFR treatment were 139 cm in height, having increased only 57 cm from the first year. Those on the non-compacted plots grew 186 cm over the same time period, reaching 315 cm on average.

Stone and Elioff (1998) suggested that the density of five-year-old aspen suckers that have reached a breast height diameter (dbh) of 25 mm may be a useful index of stand development and future productivity. That number may reflect differences in soil conditions due to experimental treatments or those resulting from conventional harvesting operations. On a loamy sand site in MN, non-compacted plots had 5000 ha^{-1} in this size class and less than 1000 ha^{-1} in compacted, FFR, or compacted plus FFR treatments (Stone and Elioff 1998). This compares with the 5900 ha^{-1} on non-compacted plots on the MN silt loam site, and where no suckers in either compaction treatment had attained this size (Fig. 3). In BC, the density of suckers in this size class declined progressively with severity of compaction. On both sites the lower numbers in the FFR treatment most likely are due to the greater sucker density (Fig. 1) combined with less favourable growing conditions.

Conclusions

Opportunities to compare data from widely separate geographic regions using a similar study design frequently do not exist. Because of this we can make explicit comparisons between early aspen sucker development and responses to experimental soil compaction and organic matter removal treatments. Despite potentially large genetic variation and the geographic differences, treatment responses and aspen development were similar on sites in northern MN and northeastern BC. The compaction treatments decreased sucker height on both sites. In MN the decreased sucker density on compacted plots can be partially attributed to the late treatment application. Managers should plan harvesting activities to minimize the area covered by machine traffic and avoid traffic after suckers have begun to emerge. To date, the compaction treatments applied in BC have not significantly affected total numbers of aspen suckers. Compared to non-compacted plots, the FFR treatment significantly increased sucker density and decreased their height on both sites. Likewise, soil compaction decreased the number of suckers that had reached a dbh of 25 mm after five growing seasons and will likely delay future stand development and reduce site productivity.

Acknowledgements

We thank David H. Alban (retired), North Central Research Station for installing, and John D. Elioff for maintaining the LTSP studies in the Lake States. Dave Alban, Dan Gilmore, University of Minnesota; Doug Maynard, Canadian Forest Service; Bob Powers, Pacific Southwest Research Station; and John Zasada, North Central Research Station, provided helpful comments and suggestions on an earlier version of the manuscript.

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