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Soil Compaction Reduced the Growth of Lodgepole Pine and Douglas-fir Seedlings in Raised Beds after Two Growing Seasons

C. E. Bulmer*
D. G. Simpson
Research Branch
B.C. Ministry of Forests
3401 Reservoir Rd.
Vernon, BC, CanadaV1B 2C7

Growth of lodgepole pine (*Pinus contorta* Dougl. ex Loud. var. *latifolia* Engelm.) seedlings after two growing seasons was reduced by medium and high levels of compaction in loamy sand and silt loam soils that received one of three compaction treatments (low = 0.70 relative bulk density [RBD], medium 0.79–0.82 RBD, and high 0.84 RBD). Survival was reduced on the loamy sand, but not on the silt loam. Soil water content was adjusted with irrigation to levels associated with plant water stress (near wilting point), reduced aeration (near 10% air-filled porosity), and intermediate conditions. Lodgepole pine survival on loamy sand was increased at high water content, but was unaffected by water regime on silt loam. For both soil types, the best lodgepole pine growth was observed for the intermediate watering level. The detrimental effects of compaction were consistent across all water regimes. We also evaluated the response of Douglas-fir [*Pseudotsuga menziesii* var. *glauca* (Beissn.) Franco] on silt loam and it was similar to lodgepole pine, except that survival was lower on the compacted silt loam, and under dry conditions. For both species, limitations to growth and survival at medium and high compaction levels were consistent with expectations based on the least limiting water range. Our results, however, are also consistent with a continuously declining growth response due to increasing compaction. The RBD was a good predictor of limiting soil conditions for both soil types and species, and substantially reduced survival and growth was observed at RBD levels higher than 0.80.

Abbreviations: AWSC, available water storage capacity; LLWR, Least limiting water range; MBD, maximum bulk density; RBD, relative bulk density.

Soil compaction has been studied for many years in an effort to quantify its effect on forest productivity (Grigal, 2000; Fleming et al., 2006). Soil compaction research also addresses concerns about environmental degradation and greenhouse gases (Soane and Ouwerkerk, 1995). More recently, concern over the ability of forest ecosystems to adapt to climate change has provided renewed incentive to maintain soils in a productive state (Ogden and Innes, 2008).

It is generally acknowledged that soil compaction beyond certain limits is detrimental to forest productivity (Greacen and Sands, 1980); however recent research has shown that moderate levels of compaction can enhance survival and growth of young trees on certain coarse-textured soils in Mediterranean climates while having little effect in cold northern climates (Fleming et al., 2006; Gomez et al., 2002). These results, along with increasing pressure to more accurately predict the effects of a wide array of management options indicate that continued work to evaluate the factors affecting seedling performance in compacted soil is justified.

The work of Letey (1985), and da Silva et al. (1994) have provided a context for the investigation of plant growth response to compaction; by describing how the growth-limiting factors of water availability, aeration, and soil mechanical resistance were affected by compaction, these authors showed that soil water content is a crucial factor in determining the extent to which compaction is

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*Corresponding author (chuck.bulmer@gov.bc.ca).