Forest Ecology and Management 278 (2012) 35–54

Contents lists available at SciVerse ScienceDirect

Forest Ecology and Management

journal homepage: www.elsevier.com/locate/foreco

Effects of organic matter removal, soil compaction and vegetation control on 10th year biomass and foliar nutrition: LTSP continent-wide comparisons

Felix Ponder Jr.[a,1], Robert L. Fleming[b,*], Shannon Berch[c], Matt D. Busse[d], John D. Elioff[e,2], Paul W. Hazlett[b], Richard D. Kabzems[f], J. Marty Kranabetter[c], David M. Morris[g], Deborah Page-Dumroese[h], Brian J. Palik[e], Robert F. Powers[d,2], Felipe G. Sanchez[i], D. Andrew Scott[j], Richard H. Stagg[k], Douglas M. Stone[e,2], David H. Young[m], Jianwei Zhang[d], Kim H. Ludovici[i], Daniel W. McKenney[b], Debbie S. Mossa[b], Paul T. Sanborn[l], Richard A. Voldseth[e,n]

[a] USDA Forest Service, Northern Research Station 202 Natural Resources Building, University of Missouri, Columbia, MO 65211-7260, USA
[b] Canadian Forest Service, Great Lakes Forestry Centre, 1219 Queen St. E., Sault Ste. Marie, ON, Canada P6A 2E5
[c] British Columbia Ministry of Forests and Range, Research Branch Lab, 4300 North Road, Victoria, BC, Canada V8Z 5J3
[d] USDA Forest Service, Pacific Southwest Research Station, 2400 Washington Ave., Redding, CA 96001, USA
[e] USDA Forest Service, Northern Research Station, 1831 East Highway 169, East Grand Rapids, MN 55744, USA
[f] British Columbia Ministry of Forests and Range, Prince George Region, 8808 72 Street, Fort St. John, BC, Canada V1J 6M2
[g] Ontario Ministry of Natural Resources, Centre for Northern Forest Ecosystem Research, c/o Lakehead University, 955 Oliver Road, Thunder Bay, ON, Canada P7B 5E1
[h] USDA Forest Service, Rocky Mountain Research Station, 1221 S. Main, Moscow, ID 83843, USA
[i] USDA Forest Service, Southern Research Station, Forestry Sciences Laboratory, P.O. Box 12254, Research Triangle Park, NC 27709, USA
[j] USDA Forest Service, Southern Research Station, 4900 Meridian St., Normal, AL 35762, USA
[k] USDA Forest Service, Southern Research Station, 4472 Highway 133 South Crossett, AR 71635, USA
[l] University of Northern British Columbia, 3333 University Way, Prince George, BC, Canada V2N 4Z9
[m] USDA Forest Service, Pacific Southwest Region, 2400 Washington Ave., Redding, CA 96001, USA
[n] Department of Soil Science, North Dakota State University, Fargo, ND, USA

ARTICLE INFO

Article history:
Received 16 November 2011
Received in revised form 6 April 2012
Accepted 7 April 2012
Available online 31 May 2012

Keywords:
Stand productivity
Long-Term Soil Productivity
Stem-only harvest
Full tree harvest
Forest floor removal
Climatic regions

ABSTRACT

We examined 10th year above-ground planted tree and total stand biomass, and planted tree foliar N and P concentrations across gradients in soil disturbance at 45 North American Long-Term Soil Productivity (LTSP) installations. While ranging across several climate regions, these installations all share a common experimental design with similar measurement protocols. Across all installations planted tree biomass with stem-only harvest (OM_0), no compaction (C_0) and chemical vegetation control (VC), ranged from 2 to 90 Mg ha^{-1}. When compared with the OM_0, full-tree harvest (OM_1) had little consistent effect on any response variable. Full-tree harvest plus forest floor removal (OM_2) also demonstrated few consistent effects on planted tree biomass, although Boreal – Great Lakes conifers showed some positive effects, reflecting high survival, but also negative effects on foliar nutrition. Compaction (C_2), regardless of OM treatment, increased planted tree stand biomass consistently in Warm Humid climates, and compaction with intact forest floors (OM_0C_2) did so across all regions. However, most installations had medium – or coarse-textured soils and compaction did not achieve theoretical growth-limiting bulk densities. Combining OM_2 with C_2 resulted in lesser gains in planted tree biomass. Planted tree biomass gains with the OM_0C_2 were attributed largely to changes in physical soil characteristics, not to vegetation control or nutrient availability. Total stand biomass (Mg ha^{-1}) was either unaffected or, with aspen, reduced by compaction. Vegetation control (VC) consistently enhanced planted tree biomass, regardless of climate, and also enhanced foliar nutrient concentrations on Warm Humid and Mediterranean sites. VC also increased total stand biomass on sites without abundant woody competitors, but decreased it on shrub-dominated Mediterranean sites. For many of the site types and species investigated, harvest-related organic matter removal and soil compaction (excepting aspen vegetative reproduction) have not resulted in large losses in stand biomass 10 year after harvest. Most stands, however, have not yet reached canopy closure, and treatment effects may continue to evolve.

* Corresponding author. Tel.: +1 705 541 5632; fax: +1 705 541 5700.
E-mail address: rob.fleming@nrcan-rncan.gc.ca (R.L. Fleming).

[1] Deceased.
[2] Retired.

0378-1127/$ - see front matter Crown Copyright © 2012 Published by Elsevier B.V. All rights reserved.
http://dx.doi.org/10.1016/j.foreco.2012.04.014

1. Introduction

The North American Long-Term Soil Productivity program (LTSP) addresses short- and long-term effects of harvest-related disturbance on fundamental soil productivity (i.e., the capacity to capture carbon and produce biomass). Manipulative treatments focus on site organic matter and soil porosity, two key properties affecting productive capacity which are influenced by harvesting and silvicultural activities (Powers, 2006). Additionally, vegetation control is considered because it influences both target tree and total biomass production (Wagner et al., 2006). This network of over 100 core and affiliate installations provides rigorous empirical evidence regarding short- and long-term treatment effects and their interactions, features lacking in most chronosequence, retrospective and modelling studies (Powers and Van Cleve, 1991; Morris and Miller, 1994).

Harvest and related regeneration treatments often have different impacts on seedling establishment than on longer-term growth. In particular, treatment effects on microclimatic conditions and competition from lesser vegetation may have large initial impacts, but diminishing effects following stand establishment (Mason and Milne, 1999; Proe et al., 2001). In contrast, increased post-harvest nutrient availability may provide adequate seedling nutrition, regardless of treatment (cf. Smethhurst and Nambiar, 1990; Vitousek et al., 1992; Sanchez et al., 2006). Subsequent reductions in nutrient availability, however, combined with increased nutrient demands as the newly-established stands build leaf area (Switzer and Nelson, 1972; Miller, 1995) may impose substantial productivity constraints related to organic matter removal (Proe et al., 1996; Egnell and Valinger, 2003; Mendham et al., 2003).

Impacts of harvest-related soil compaction often vary with soil conditions. For drier coarse-textured soils compaction can increase water holding capacity, root/soil contact and resource uptake whereas for moister, finer-textured soils compaction often restricts soil aeration, with soil strength and possible rooting restrictions increasing on many soil types (Greacen and Sands, 1980; Kozlowski, 1999). Further, the combined effects of these soil impacts may or may not affect stand productivity (Froehlich et al., 1986; Miller et al., 1996; Gomez et al., 2002a). Over time bulk densities and aeration porosities are likely to recover, but recovery rates can vary greatly, reflecting frost action, soil rock and water content, plant rooting, shrink-swell activity, and the action of soil fauna (Greacen and Sands, 1980; Corns, 1988; Powers et al., 2005; Eisenbies et al., 2007).

Effects of vegetation control on productivity are likely to vary with vegetation type, soil conditions, climate regime, and time (South et al., 2006). Further, results often depend on the productivity measure used (e.g., biomass production of crop trees vs. that of the entire plant community). Herbaceous competition is often severe initially but effects can diminish markedly with canopy closure and understory shading (Mason and Milne, 1999; Miller et al., 2003a,b). Larger woody competition often produces greater decreases in planted tree biomass as time proceeds, but effects on total stand biomass vary greatly, depending on site and time frame (Glover and Zutter, 1993; Miller et al., 1999, 2003a,b; Rose et al., 2006).

In earlier synthetic papers we addressed treatment effects on 5th year seedling establishment (Fleming et al., 2006), soil C and N (Sanchez et al., 2006) and soil physical properties (Page-Dumroese et al., 2006), and 10th year effects on soil C and nutrient availability, soil bulk density and stand biomass at 18 installations (Powers et al., 2005). Briefly, forest floor removal improved seedling establishment at Mediterranean (Medit) sites but reduced it at Warm Humid (WmHd) sites (Fleming et al., 2006). Overall, Powers et al. (2005) found 10th year total above-ground biomass (without vegetation control) was not significantly affected by organic matter removal. Compaction generally improved seedling establishment, particularly with intact forest floors (Fleming et al., 2006) whereas effects on 10th year total stand biomass (no forest floor only) varied with soil texture and were present (negative) only with vegetation control (Powers et al., 2005). Vegetation control benefited seedling establishment (Fleming et al., 2006), but general effects on subsequent biomass production were not assessed.

Here we analyze 10th year planted tree and total standing (above-ground) biomass across 45 installations, using additional analytic approaches, and consider both regional and transcontinental trends, as well as foliar N and P concentrations. In particular, we consider the following questions: (1) is there a consistent or regionally-based trend of decreased biomass production and/or foliar nutrition with increased organic matter removal?; (2) are compaction effects on biomass production or foliar nutrition evident at year 10, and if so, to what degree do such effects interact with vegetation control and forest floor removal?; and (3) what is the relative importance of vegetation control compared to other treatments in terms of planted-tree and total stand response?

2. Methods

2.1. Site location, forest description, experimental design

This paper draws on 10th year results from a broad spectrum of locations representing a range of climates, soil conditions and species, and organized into 29 replicated studies for most analyses (Table 1 and (Fig. 1). Studies and installations were assigned to four broad climate groupings based on principal components analysis of modeled climate variables (McKenney et al., 2006) (Table 1). We chose four groupings based on geographic location and general climate (e.g., Fig. 2): Warm Humid (WmHd) encompassing studies in the southeast U.S.; Mediterranean (Medit) for studies in California; Western Montane (WtMt) for studies in the higher-elevation western interior with cool temperate – boreal climates; and Boreal-Great Lakes for studies in northern cool temperate and boreal climates adjacent to the Great Lakes. The full LTSP factorial experimental design involves three organic matter removal levels (stem-only harvest (OM_0), full-tree harvest (OM_1) and full-tree harvest plus forest floor removal (OM_2)), and three soil compaction (Comp) levels (none (C_0), moderate (C_1), and severe (C_2)) (Table 2) (Powers et al., 1990). The organic matter removal levels encompass the extremes in removal levels apt to occur with clearcut harvesting and produce a step series in biomass and nutrient removal (see Powers et al., 2005, Table 1). For the C_0, large mechanized equipment was usually excluded from the plots, but in some cases (e.g., black spruce, jack pine and certain aspen installations (Stone, 2001; Stone and Kabzems, 2002)) dry-weather or winter harvesting was conducted with mechanized equipment crossing the plots. Compaction was accomplished with a variety of mechanical means when soils were near field capacity with the goal of the C_2 treatment to increase soil bulk density to 80% of that proposed by Daddow and Warrington (1983) as limiting root growth. In the event, however, both C_1 and C_2 compaction treatments increased root zone densities by similar amounts (averaging about 18% or 011 Mg m^{-3}) (Powers et al., 2005). As a result we only consider the C_0 and C_2 treatments in this paper. Greater increases in bulk densities were associated with lower initial bulk densities, but at all installations the C_2 treatment never achieved $\geqslant$80% of Daddow and Warrington's (1983) proposed growth-limiting values (Powers et al., 2005; Page-Dumroese et al., 2006).