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Effect of redistributing windrowed topsoil on growth and development of ponderosa pine plantations

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This paper is dedicated to the memory of an esteemed colleague, Dr. Robert F. Powers, who designed and oversaw the installation and early data collection of this experiment.

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ABSTRACT

Windrowing site preparation often displaces significant amounts of topsoil including nutrients and carbon into the strip-piles. Although short-term growth may increase due to the early control of competing vegetation, this practice can reduce long-term plantation productivity. Here, we report an experiment established in 1989 in a 28-year-old ponderosa pine (*Pinus ponderosa*) plantation to determine if redistributing topsoil, along with several shrub control measures, have influenced soil fertility and tree growth. Five treatments from a partial factorial design with three levels of shrub treatment and two levels of soil manipulation were applied in each of five blocks and consisted of: Control (C, do nothing); understory hydroaxed (masticated) to chips and left in the plot (H); windrows redistributed over brush (S); understory hydroaxed and windrows redistributed over chips (SH); and understory manually removed off-site and windrows redistributed (SM). Over the next 21 year period total windrowed topsoil volume and mass were determined, soil nutrient concentrations in and between windrows including soil mineralizable N, total N and C were determined, understory biomass measured, tree diameter, basal area, and volume measured in 1989, 1994, 2005 and 2010, and nitrogen concentration of tree foliage was measured in 1989, 1991 and 1994. Results showed that about 18 cm of topsoil had been displaced into windrows, including 1.98 (±0.13) Mg N ha^{-1} and 41.04 (±2.46) Mg carbon ha^{-1}. In general, redistributing windrowed topsoil (S, SH, and SM) yielded a consistently positive effect on quadratic mean diameter, basal area (BA), and volume compared to C and H. No difference in growth was found between SH and SM. These results were supported by higher soil nitrogen and mineralizable nitrogen contents in the three topsoil redistribution treatments. Higher foliage nitrogen concentrations in the redistribution treatments further supported these higher tree growth rates. The positive effects of shrub removal were evidenced only on the treatments without topsoil redistribution (C versus H); the difference in BA and volume between C and H was only significant in 1994. Redistributing topsoil reduced woody plant biomass but significantly enhanced herbaceous biomass six years after treatment. This shows that windrowing site preparation reduces plantation growth and stand development through displacement of topsoil and its nutrients. These negative effects can be mitigated by carefully redistributing windrowed topsoil, even in an established plantation.

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1. Introduction

Windrowing is a site preparation operation, usually performed by machine, which piles debris and shrub slash in linear rows immediately prior to planting (Helms, 1998). The primary objectives are to increase survival and growth of planted trees by improving the seedling microsite and controlling competing vegetation. Increased access, lower fire risk, and reduced pests are secondary objectives (Atzet et al., 1989). This practice, however, directly impacts surface soil, or topsoil, where organic matter and labile nutrients are disproportionally concentrated in the soil profile (Powers, 1990; Powers et al., 1990). Tew et al. (1986) estimated that displacement of surface materials into windrows removed two to three times more N and P than does whole-tree harvesting. Because temperate and boreal forests can store as much as three times more nutrients in the forest floor than in the standing forest (McColl and Powers, 1984), windrowing has a significant impact on nutrient displacement and subsequently site

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productivity (Morris et al., 1983; Dyck and Beets, 1987; Powers et al., 1988; Fox et al., 1989).

During the 1950s and 1960s, many plantations were established using windrowing methods in the United States and across the world (Fig. 1). The direct impact of such practices on early plantation productivity often was confounded by reduced weed competition (Powers et al., 1990). For example, volume growth for a *Pinus taeda* plantation grown on windrowed sites as compared to those with intact topsoil significantly increased at age 3 in Alabama, which was mainly due to plant competition reduction (Tuttle et al., 1985). However, volume was similar at age 12 in Louisiana (Haywood and Burton, 1989). Because topsoil displacement also reduced weed competition, fertility losses were confounded with reduced competition.

In New Zealand's pumice region, displacing logging debris and a thin layer of topsoil into windrows during site preparation produced nutrient deficiency and led to a 30% loss in volume growth in a 17-year-old *Pinus radiata* plantation (Dyck and Beets, 1987). In the North Carolina Piedmont, windrowing on a Typic Hapludult soil led to a 23% volume growth reduction at 25 years (Fox et al., 1989). Powers et al. (1988) compared nutritional characteristics of 22 established plantations of ponderosa pine (*Pinus ponderosa*) in California and Oregon that had or had not been windrowed during site preparation. Although results were confounded somewhat by differing soil types, windrowed plantations averaged one-third less mineralizable soil N, one-tenth less foliar N, and one-third lower site indices than non-windrowed plantations. Nitrogen fertilization produced four times the relative volume growth response in windrowed plantations versus non-windrowed ones.

Mitigating the impacts of windrowing on these maturing plantations can be difficult. As far as we are aware, no studies have been reported showing before and after results from redistributing topsoil. Moreover, few studies have aimed to test if windrowing affects long-term stand productivity and overall ecosystem health. Here, we report results from a well-designed experiment initiated by the late Dr. Robert Powers in 1989 to determine if and how topsoil redistribution and shrub control affects soil productivity and tree growth in an established plantation.

2. Materials and methods

2.1. Study site

The study is located in Northeastern California on the Doublehead Ranger District, Modoc National Forest (Lat. 41.33N; Long. 121.27W). Elevation is about 1650 m. Site index is 22 m at 50 years. Slopes average about 15% gradient with an easterly aspect. Soils are of volcanic origin where pumice, ash and cinders were deposited on the lower side slopes of Medicine Lake volcano. The USDA soil series is Tionesta, classified as a pumiceous or ashy-pumiceous over medial-skeletal, mixed, frigid, Typic Haploxerand; the textural class and modifier of the topsoil is very gravelly loamy coarse sand. From the spline climate surfaces at the site for 1950–2004 (Rehfeldt, 2006), average annual precipitation is about 520 mm at the site. Mean annual temperature is 6.7 °C. Maximum temperature in the warmest month is 27.8 °C and minimum temperature in the coolest month is −8.9 °C. Growing degree-days (>5 °C) is about 1560.

The site was windrowed by bulldozer in 1960 and planted with ponderosa pine seeds in the fall of 1961. The plantation grew up with a dense understory mainly of greenleaf manzanita (*Arctostaphylos patula*), snowbrush (*Ceanothus velutinus*), bush chinquapin (*Chrysolepis sempervirens*) and a few other minor species. The plantation was thinned from below in 1987 by removing trees from lower crown classes to favor those in the upper crown classes. The residual trees averaged dbh 18.3 cm and height of 7.3 m.

2.2. Treatment design and application

The experiment was established in the fall of 1989 and consisted of five treatments which were randomly assigned to each of five blocks (Fig. 1). They are: control (C, do nothing); understory hydroaxed to chips which were left in the plot (H); windrows redistributed by bulldozer over brush (S); understory hydroaxed and windrows redistributed over chips (SH); understory removed manually and windrows redistributed (SM). Hydroaxe (Blount, Inc., Zebulon, NC, USA) is one type of mechanical rotary shredder to masticate brush into chips, commonly used at the time. Treatment plot size is 0.12 ha and the measurement plot is the inner 0.06 ha. The blocks were arranged generally along the contour between the windrows. Treatment characteristics for trees are shown in Table 1.

2.3. Tree measurements

In 1989 all trees in the measurement plots were individually tagged and measured for height and diameter at 1.37 m (dbh) immediately after the treatments were applied. Marked staffs were used for precise dbh height. Trees within one meter distance from and on the windrow, or where the windrow had been prior to treatment, were separated for future comparison. Tree height and dbh were re-measured in 1994, 2005, and 2010. In the first three measurement periods, three trees representing small, average, and large size from each plot were selected, and total stem volume inside bark was determined using a Barr-Stroud FP15 optical dendrometer and application of a regional bark thickness equation

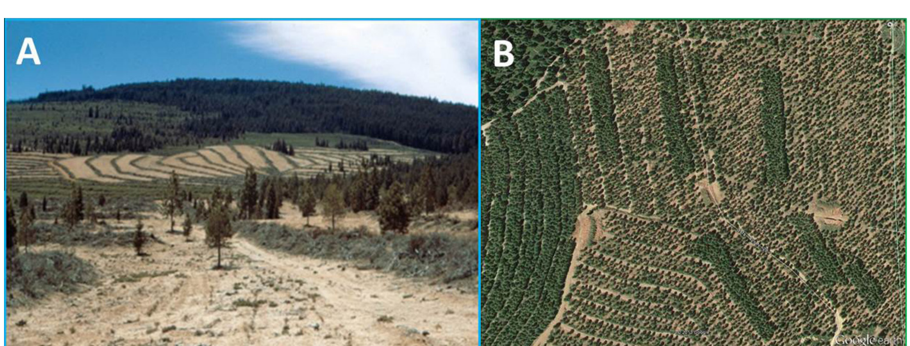

Fig. 1. Windrowing site preparation (A) and 54-year-old plantation (B) in which a 2012 thinning for fuels reduction was conducted around the research blocks (5 rectangular strips). Picture B is adapted from Google Earth.