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Advancing Forest Cover Development on a High-Elevation Sierra Nevada Mine Site with Nutritional Amendments

Roger F. Walker[1,2]

Abstract

Selected nutrient amendments were evaluated for their capacity to enhance growth and nutrition of established but stunted Jeffrey pine (*Pinus jeffreyi* Grev. & Balf.) saplings on an acidic Sierra Nevada surface mine. The amendments were applied by topdressing at three rates each and consisted of Forestcote 22-4-6 + Minors, a controlled-release formulation; Free Flow 29-3-4 and Hydro Agri 21-7-14, two conventional fertilizers, with the former featuring urea as the predominant N source, whereas that for the latter was exclusively ammoniacal and nitrate forms; and Milorganite 6-2-0 + Iron, an organic amendment based on municipal biosolids. All formulations reinvigorated sapling growth, generally more so as the amounts supplied increased, with the Free Flow and Hydro Agri amendments marginally more stimulative than Forestcote and Milorganite. Foliar analysis revealed that fertilized saplings had more N, with concentrations that generally rose with amounts supplied, and P but less Mn and Al than the control. Enhanced N nutrition in particular but also that of P probably accounted for most of the growth stimulation by the amendments, as availability of both in the soil was limiting. Of the two metallic elements, reduced Mn was likely most critical because concentrations encountered here were exceedingly elevated overall, including that in the soil, although soil Al was also high. These results suggest that a variety of nutritional amendments can be employed in forest restoration on surface mine sites and those similarly degraded, including sites for which dry climates greatly influence the selection of remedial practices.

Key words: forest fertilization, forest nutrition, forest restoration, phytotoxicity, *Pinus jeffreyi*, mine reclamation, reforestation.

Introduction

Drastic disturbances of natural landscapes, such as those from surface mining, often result in complete loss of native soil and vegetation. If the disturbance is sufficiently severe, natural recovery processes cannot resume without substantial delay, if they resume at all. Consequently, well-conceived reclamation initiatives to restore on-site productivity and minimize off-site environmental perturbations are frequently needed. Barriers to be overcome in such efforts include substrate characteristics that can inhibit or preclude vegetation establishment. These substrates may be droughty due to lack of organic matter or toxic because of immoderate acidity influences on metallic element availability, but almost all of them are infertile (Mays & Bengtson 1978; Smith & Sobek 1978; Butterfield & Tueller 1980; Heinsdorf 1996; Katzur & Haubold-Rosar 1996; Fisher & Binkley 2000). Therefore, nutrient amendments are a near-universal requirement for the successful reestablishment of vegetative covers. If these revegetation efforts include trees, however, concerns about effects on seedling survival of applying nutritional supplements at planting, especially conventional water-soluble amendments, have sometimes rendered this practice inadvisable (Czapowskyj 1973; Vogel 1981; Walker et al. 1989), although controlled-release nutrients have proven less detrimental in this regard if formulations and application rates are judiciously chosen (Berry 1979, 1983; Marx & Artman 1979; Walker 1999*b*, 2002*a*, 2003; Clemente et al. 2004). Nevertheless, some risk to survival is inherent in fertilization at planting, especially on harsh sites that predispose seedling stress, from potential damage of excessive salts to young root systems.

A solution for possible mortality from fertilization at planting is to delay application of nutrient amendments until stands are well established. The sapling stage of development is attractive in this regard because any mortality is likely to have already occurred, thus preventing waste associated with applying amendments to seedlings that do not survive, and the sapling stage is a period of rapid biomass accrual that can also be marked by stunting if mineral nutrient supply is inadequate to support such growth, a common occurrence on surface-mined sites (Singh et al. 2000). Tailoring fertilization to the sapling stage, however, again involves decisions beyond

[1] Department of Natural Resources and Environmental Science, University of Nevada, Reno, NV 89512, U.S.A.
[2] Address correspondence to R. F. Walker, email walker@cabnr.unr.edu

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