EVALUATING THE COMPETITIVE AND ECOLOGICAL EFFECTS OF UNDERSTORY SPECIES AT VARYING DENSITIES ON THE PRODUCTIVE POTENTIAL OF YOUNG DOUGLAS-FIR PLANTATIONS

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Introduction

Fewer than 4% of the world's forests are planted. Yet, plantations provide one-fifth of the wood we consume. Evidence for sustained high yields from plantations is unassailable (Powers 1999) and there is overwhelming evidence that plantation yields will be far superior to those from forests regenerated naturally from seed. Plantations assure rapid reforestation and compliance with forest practice laws. They afford early stocking control to capture a site's potential quickly and produce a commercially useful product in the shortest possible time. Tree planting also carries the possibility of genetic improvement. While conservation trends here and in other developed nations de-emphasize timber harvests in natural forests, world demand for wood continues to rise. This means that plantations stand as our best hope for meeting projected global shortfalls in supply (Nambiar 1999). Therefore, intensive forest management will center on planted forests.

Vegetation Control. One challenge of plantation forestry is to capture site potential quickly and efficiently. Throughout North America, the most profound factor affecting early plantation performance is competition between trees and other vegetation for light, moisture and nutrients. Findings from the North American Long-Term Soil Productivity study show that effects of weed competition on tree growth easily exceed the deleterious effects of severe soil compaction or site organic matter removal during the early stages of stand development (Table 1). Even on clayey soils, competition from woody shrubs easily masks the detrimental impacts of soil compaction and the more fundamental imacts on productivity are visible only if weeds are removed (Powers 1999). In summer drought regions of the West, hardwoods, shrubs and herbs can take a heavy toll on the early development of conifer plantations (Tappeiner et al. 1992).

Conventional wisdom holds that below-ground competition is primarily for soil moisture. However, moisture availability is linked directly with nutrient availability and moisture cannot be influenced without influencing nutrients, too (Nambiar and Sands 1993). For example, vegetation control increases plant water potential by reducing competition for soil moisture. But it also increased foliar concentrations of nitrogen (N) and phosphorus (P) for several years in ponderosa pine (*Pinus ponderosa)* plantations (Powers and Reynolds 1999). Vegetation control experiments have centered more on ponderosa pine than on Douglas-fir (*Pseudotsuga menziesii*) (Tappeiner et al. 1992). For pine, competitive effects can be severe when shrubs cover as little as 20 percent of the ground (Oliver 1984, Shainsky and Radosevich 1986, White and Newton 1989). Recent findings from two Garden of Eden plantations (Fig. 1) indicate that about half of the competitive reduction in tree growth occurs by a ground cover of 30 percent. The effect is most pronounced on the poorest sites and diminishes as site quality improves. Growth reduction follows a negative exponential trend on poorer sites and a more linear trend on better. Wagner et al. (1989) point out that competitive thresholds for tree growth and for survival are quite different—the latter occurring at much higher weed densities than the former. Vegetation control is expensive and complete vegetation control is not usually an aim of management. Therefore, a critical question is to what degree is vegetation control needed to accomplish successful growth rates.

Are All Weeds "Equal?" A question remains as to whether all vegetation is equally competitive. Most competitive vegetation studies have centered on woody shrubs and hardwoods. However, eliminating only shrubs and hardwoods may capture a fraction of a site's early potential growth unless herbaceous vegetation also is controlled. Wagner and Radosevich (1998) found that shrubs and herbaceous vegetation had similar influence on the development of Coast Range Douglas-fir plantations in the first 5 years. In his review of weed competition, Wagner (2000) recognized timing differences. He concluded that herbaceous vegetation has a stronger influence on plantation development prior to crown closure, while woody vegetation has a much stronger bearing on long-term stand development.

Some common competitors fix atmospheric N. Biological N fixation generally is considered an important mechanism for soil N accretion in forests, particularly such actinorhizal plants. Annual fixation rates of 130 kg N ha^{-1} yr^{-1} have been reported for *Alnus rubra* (Binkley 1981). But high rates (20-200 kg N ha^{-1}) also have been reported for actinorhizal shrubs common to the western Cascades, most notably snowbrush (*Ceanothus velutinus*) (Binkley et al. 1982, McNabb and Cromack 1983, Youngberg and Wollum 1976, Zavitkovski and Newton 1968). However, N fixation estimates are somewhat questionable because of the variety of methods used, experimental artifacts, and the assumptions made (Busse 2000). Busse et al. (1996) and Johnson (1995) found that N and organic carbon was more concentrated in soil beneath snowbrush and other N-fixing plants than beneath non-N-fixing species.

The possible beneficial influence of snowbrush on plantation performance has led some environmental groups to challenge the value of chemical control where snowbrush is growing densely with young trees (Californians for Alternatives to Toxics, et al. v. Michael Dombeck, et al. 2001). Snowbrush is seen by some to serve as a nurse crop for young trees such as Douglas-fir, and saplings growing in proximity to snowbrush plants may be as tall as those growing under more open conditions (Horowitz 1982). In contrast, snowbrush clearly depletes soil moisture and leads to physiological stress and reduced growth in young Douglas-fir stands (Petersen et al. 1988). While early growth is invariably sacrificed by shrub competition, survival may be adequate and Douglas-fir usually persists on most sites. Given enough time, the argument goes, trees will overtop *Ceanothus* and benefit from the added N. However, such arguments are speculative and have not been put to the test of rigorous science. Given the nature of legal appeals, such issues should be addressed squarely.

Fertilization. Fertilization sometimes is considered both in combination with, or as an alternative to, vegetation control to enhance early plantation performance. It is one of the few cultural means of boosting site quality. For ponderosa pine, fertilizing with soluble salts at planting reduced survival on droughty, gravelly sites (Powers and Ferrell 1996). For average sites and poorer, repeated fertilization through year 6 had little influence on stand volumes unless vegetation was controlled. But on a site with higher precipitation and better soil water storage capacity, fertilization produced 10-year standing volumes equivalent to those from vegetation control, alone (Powers and Reynolds 1999).

Controlled-release fertilizers seem more promising than soluble salts for fertilization at planting because they reduce the risk of lethal levels of burning or osmotica. Rose and Ketchum (2002b) found that Douglas-fir responded positively and significantly to multi-nutrient briquettes on one site and that survival was relatively unaffected. However, the greatest growth response was to vegetation control. Fertilization growth response was less pronounced on a second site and first-year mortality was greater on fertilized plots. The best growth responses were associated with higher precipitation sites. Regardless, fertilization at planting is meant to give seedlings a jump on competitive vegetation and is not a panacea for fundamental site improvement.

Findings throughout the Pacific Northwest suggest that positive fertilizer responses occur only when soil moisture is not a strong limiting factor (Rose and Ketchum 2002b). On droughty sites, this can only be achieved with aggressive weed control. Optimal nutrition studies on Vancouver Island (Weetman et al. 1997) and in California (Powers and Reynolds 1999) suggest that repetitive fertilization once stands have established can lead to growth response well-beyond those predicted from yield tables and possibly raise the site's growth potential to a lasting level. Largely, the effect seems due to N, but other nutrients may become important once N is raised to a sufficiency level.

Critical questions

- How are Douglas-fir plantations affected by understory competition on non-coastal sites where soil drought is more likely?
- Is the density of the understory important?
- Is there a competitive difference between herbaceous species vs. woody shrubs?
- Is there a difference between N-fixing and non N-fixing shrubs?
- How does fertilization interact with shrub control?
- Do effects vary by site?

Methods

The study will center on forest industry lands of average and better site quality in the western Cascades of Oregon and California within the natural range of Douglas-fir. Such lands must have an understory history of both *Arctostaphylos* and *Ceanothus*. Soil at each selected installation will be characterized physically and chemically from at least three pits according to the national standards of the Natural Resource Conservation Service.

The experiment will center on freshly prepared sites within the natural range of Douglas-fir in southern Oregon and Northern California. Treatment plots will encompass 5.7 ha (14 acres) and must be surrounded by an additional cleared area at least 30 m (100 feet) wide. Existing vegetation will be removed and sites will be subsoiled in two directions before planting to minimize any legacy of skid trails or landings. Sites will be planted at a 3.65 m (12-ft) spacing with superior quality Douglas-fir and a second species, such as--but not limited to--ponderosa pine, depending on the industry cooperator's preference. Each site will be stratified into four blocks based on land form or soil properties. Plot corners will be monumented and referenced by GPS. Six main effect treatments will be assigned randomly within blocks and applied on 0.1 ha (0.27 acre) plots as follows:

- No vegetation control
- Complete vegetation control using appropriate herbicides
- Herbaceous competition, only, using appropriate methods
- Woody shrubs, only (non N-fixing)
- Woody N-fixing shrubs, only
- Fertilization with a complete mix of nutrients at lower levels of vegetation competition

Brush seedlings (*Arcostaphylos patula* and *Ceanothus*) from sources adapted to each site will be produced in a commercial nursery and planted amongst the planted trees to achieve, by 5 years, ground covers of 5, 15, 30, and 50 percent. The "No Vegetation Control" treatment will provide an upper boundary of 100 percent cover, or greater. I anticipate that these cover densities will be sufficient to define the hypothetical response curve of vegetative cover effects on plantation volume growth (Fig. 2). Planting densities will be based on assumed rates of mortality and estimated diameters of shrub crowns at 5 years. Natural recruits (quite likely following site preparation) will help supplement any planted seedling mortality. Each ground cover density will be maintained by spot treating individual plants either mechanically or with appropriate herbicides (Rose and Ketchum 2000a) when a ground coverage treatment has increased to one-third of the target level of the next highest cover class.

Treatments with a target ground cover of 15 percent will be fertilized with mixtures of macro and micro nutrients at three intervals: (1) at planting, using controlled-release briquettes placed in the vicinity of seedling roots (Rose and Ketchum 2002b); (2) at 3 to 5 years when trees are well established; (3) when tree crowns have reached about two-thirds ground cover (the rapid stage of crown building and nutrient demand). Fertilizers at intervals (2) and (3) will be applied as dry salts of 9 nutrients at rates used for the Garden of Eden experiment in years 4 and 6 (Powers and Ferrell 1996). This results in a cumulative load (kg ha^{-1}) of approximately 1,000 N, 500 P and potassium, and lesser amounts of other nutrients. Rates are predicated on uptake requirements of a rapidly growing stand so as to avoid nutrient stress from deficiency or toxicity. Targeting only the 15 percent coverage treatment for fertilization will be the means of assessing the potential for fertilization to fundamentally change site quality.

Measurement plots will be established within each treatment plot from the third row of trees inward, producing a measurement area of 0.03 ha (0.08 acres) of 25 trees bordered by a 2-tree buffer. Vegetative measurements will be recorded at years 1, 3, 5, and 10 (more frequent and detailed measurements may be taken as funds permit). Survival, height, stem diameter, along with crown length and diameter will be recorded for all trees in each measurement plot, providing input needed for current growth simulators. Vegetative ground cover and height by species will be measured using the 10 m line intercept method (Powers and Ferrell 1996). Foliar samples will be taken from current and 1-year foliage for nutrient analysis at each measurement interval. Samples also will be analyzed for cumulative water stress as measured by ^{13}C and ^{12}C isotopic ratios. Soil samples will be analyzed for microbial abundance and diversity (functional and numerical) and well as for standard nutrient measures. Meteorological data will be recorded continuously using data loggers.

Statistical Analyses

Preliminary findings for ponderosa pine from the Garden of Eden experiment (Powers, unpublished) indicate that 4 replications are sufficient to detect competition-induced growth declines of 15 percent or greater with an α of 0.05. The primary analysis of the competitive responses of independent types of vegetation will be through nonlinear fits of regression models. Differences between cover classes will be analyzed through randomized block ANOVA and trends over time will be adjusted by repeated measures procedures. The untreated and full vegetation control treatments will serve as standards for comparing the effectiveness of all other treatments.

Costs and Timetable

Installation and establishment costs are estimated to be about $69 thousand per plantation (Table 2). Given the fixed level of Agenda 2020 funding, this permits the establishment of the experiment on two sites of average to better quality. Supplemental funding will be sought through competitive grants for further research but further installations are beyond the purview of this grant. However, smaller scale "satellite studies" may be established on other sites of the Sierra Cascade Intensive Forest Management Research Cooperative. The annual nature of Agenda 2020 funds mean that the two sites will be staggered in time. Sites have been proposed by members of the Sierra Cascade Intensive Forest Management Research Cooperative. Candidates are on lands of Boise east of Medford, OR; Roseburg Resources near Big Bend, CA; and Sierra Pacific Industries near McCloud, CA, and perhaps one or two others. Prospective sites will be visited in spring 2003 and a final selection will be made. Sites will be prepared in summer-fall of 2003 and 2004 for planting the following springs. Nursery operations will commence to produce conifer, *Arctostaphylos*, and *Ceanothus* seedlings (tentatively, Cal Forests Nursery). Field and nursery operations will be overseen by the Sierra Cascade Intensive Forest Management Research Cooperative.

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Table 1. Conclusions from ANOVA OF 5-year growth response for LTSP installations at 8 geographic regions of North America (Powers, unpublished). Not assessed = na.

Location	**No. sites**	**Tree species**	**OM removal**	**Soil compaction**	**Vegetation control**
California	9	*Abies, Pinus, Pseudotsuga, Sequoiadendron*	+	+/-	+
British Columbia	4	*Picea, Pinus*	**0**	**0**	**na**
Gulf States	7	*Pinus*	**0**	**0**	+
Idaho	4	*Pinus, Pseudotsuga*	+	**0/+**	+
Lake States	10	*Populus*	+/-	**0/-**	**na**
Missouri	3	*Pinus, Quercus*	**0/-**	+	+
North Carolina	3	*Pinus*	**0**	**0**	+
Ontario	5	*Picea, Pinus*	**-**	**0**	**na**

Table 2. Costs per installation through the 3-year life of the grant

Activity	**Year 1**	**Year 2**	**Year 3**
Site identification and preparation (20 acres)	2,000		
Slash abatement	1,300		
Tree seedlings	3,000		
Brush seedlings	12,000		
Plot layout	1,700		
Meteorological station		6,000	
Plant trees		2,000	
Plant brush		4,500	
Herbicide treatment		2,500	
Tree and brush measurements		4,000	
Brush density adjustments			2,500
Chemical analyses			10,000
Soil sampling			4,500
Microbial analysis			7,000
Data analysis			6,000
Total by year	**20,000**	**19,000**	**30,000**

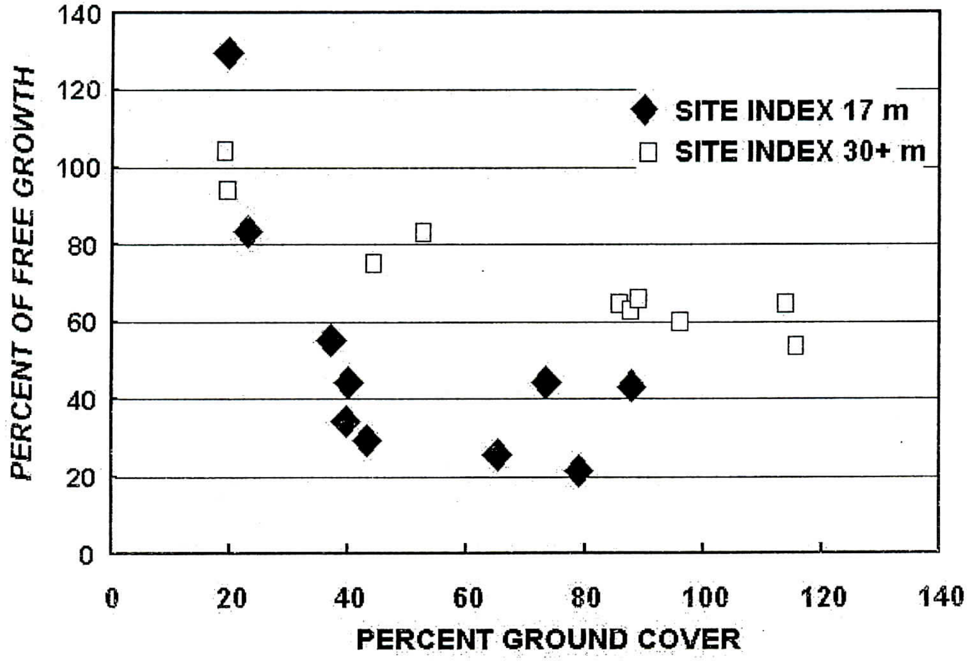

Figure 1. Effect of percentage ground cover on potential volume of planted ponderosa pine on two Garden of Eden sites. As ground cover increases, volume growth decreases. Effect is stronger on poorer sites (site index 17 m at 50 years) than on better (site index 30+ m at 50 years).

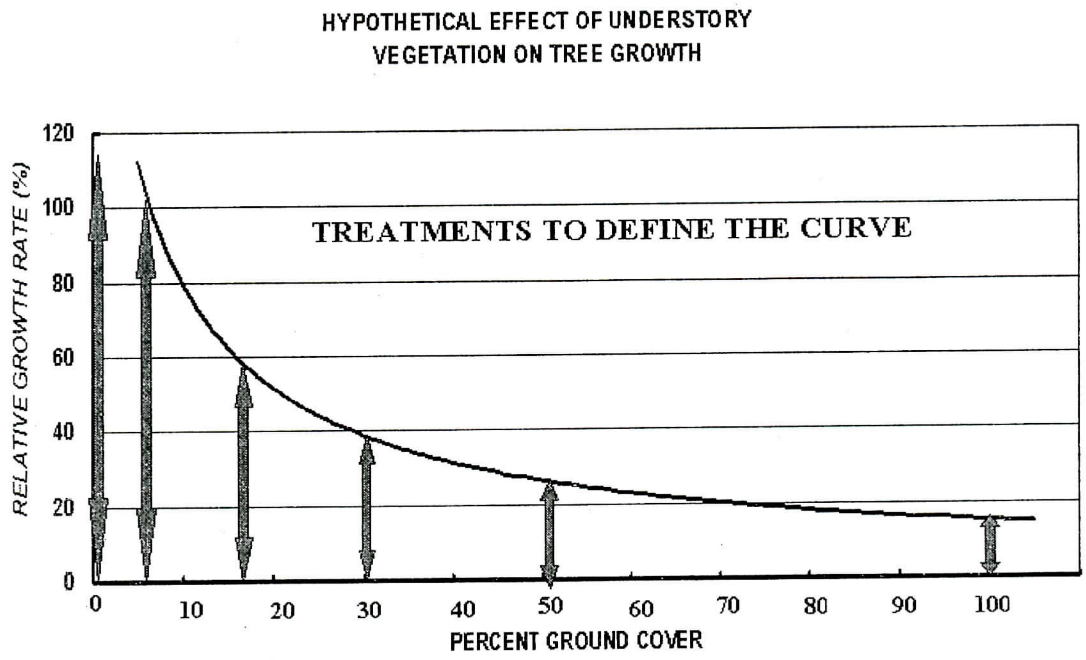

Figure 2. Planned levels of shrub ground cover achieved at 5 years and beyond.