The Effect of Multinutrient Fertilization on Understory Vegetation Annual Production

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ABSTRACT: *This study quantified the effects of operational multinutrient fertilization on understory shrub, forb, and grass production in inland Northwest forests. Understory vegetation annual production increased at some sites while other sites showed no change or decreases following fertilizer treatments. The greatest understory response to fertilization occurred in low density, shade-intolerant, overstory-dominated stands. Understory vegetation response was lower under overstories dominated by more shade-tolerant conifers. Multinutrient fertilization produced increases in annual understory production of up to 2,400 lb/ac for combined understory growth forms over the entire growing season. West. J. Appl. For. 17(3):147–153.*

Key Words: Fertilizer, understory vegetation.

Forest fertilization may be an effective treatment to increase or maintain multiple resource outputs on a declining land base. Most forests in the inland Northwest are nutrient deficient, and overstory conifers respond favorably following fertilization (Shaffii et al. 1989, Moore et al. 1991, Garrison et al. 2000). However, information regarding fertilization effects on understory vegetation in the inland Northwest is minimal. Overstory tree density and species effects on subordinate understory vegetation response to fertilization have also not been extensively studied in the region.

Productivity of forest plants is influenced by many factors, such as genetics, climate, nutrition, and soil moisture (Gessel et al. 1960, Riegel et al. 1995, Klinka et al. 1996). Nutrition is one factor that can be feasibly and economically manipulated. Following fertilization, understory growth may increase because existing plants are nutrient-limited, may remain unchanged because optimum nutrient amounts already exist, or may decrease due to increased competition from the tree overstory, toxicity, or nutrient imbalance. Understory response substantially depends on the nutrient requirements of the existing plant community (Chapin et al. 1986).

Several studies have shown that understory plant communities in mature forests respond to nitrogen fertilization (Freyman and van Ryswyk 1969, Abrams and Dickmann 1983, Riegel et al. 1991, Nams et al. 1993, Prescott et al. 1993, Papanastasis et al. 1995). These studies suggest that N fertilization may increase understory vegetation production in conifer stands but that the level of response will likely depend on specific site/treatment interactions. One of these factors is overstory tree density (Jameson 1967, Persson 1981, Alaback and Herman 1988, Riegel et al. 1995, Nabuurs 1996, Klinka et al. 1996, Peitz et al. 1999). Understory vegetation growth response to fertilization may be affected by increased overstory tree growth, as well as by initial stand density. Tree foliar biomass increases following fertilization for many conifer species (Turner and Olson 1976, Turner 1977, Brix 1981, Teskey et al. 1994), and derives from both increases in needle production and retention of older needle age classes (Turner 1979).

Understanding the interaction between overstory density and understory response is important since wildlife species use understory vegetation for cover, nesting, and food (Alaback and Herman 1988, Stubbendieck et al. 1997). Many forest stands are also grazed by livestock (Tisdale 1961, Geist 1976). Thinnings, coupled with fertilization, could increase biodiversity, wildlife habitat, and range productivity. The above literature suggests that fertilization increases the quantity of the understory for browse and forage. Other research has shown that animals prefer fertilized vegetation over unfertilized (Anderson et al. 1974, Geist et al. 1974, Nams et al.1993, Kimball et al. 1998). If annual understory vegetation production increases in fertilized areas, then wildlife habitat and grazing conditions will be generally improved since there will be more vegetative growth available for food and cover.

Accurate quantification of response to different nutrient applications will allow more informed vegetation

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manipulation to best meet management objectives. Thus, the primary objective of this study was to determine if multinutrient fertilization increased understory biomass in inland Northwest conifer stands. We also wanted to see if different overstory densities and/or species composition affected understory response.

Methods

Eight different sites from five general locations, three in Idaho and one each in Oregon and Washington, were included in this study. The study sites were selected to be representative of mid-elevation conifer forests in the inland Northwest with elevations ranging between 670 and 1,245 m. A range of habitat types, tree densities, and overstory species was sampled (Table 1). Overstory tree species composition included natural, second-growth, mixed conifers as well as plantations composed of Douglas-fir (*Pseudotsuga menziesii*) or ponderosa pine (*Pinus ponderosa*). The study sites did not have any sort of overstory tree cutting within the last 10 yr, and they represent a range of site and stand conditions often targeted for operational forest fertilization in the region.

Study Design

The study areas were designed to be fertilizer trials within much larger operational fertilization areas. Size of experimental areas ranged from 10 to 120 ha, and the physical arrangement of the various study sites differed resulting in six to ten transects per site. The fertilizer and control treatments were randomly assigned to study stands within a site to the extent possible, given operational constraints. Aerial photographs were used to help determine the exact locations of the fertilized units, and boundaries were marked for each treatment location. Fertilizers were applied aerially by helicopter, and containers were placed throughout each treatment area to collect fertilizer. Collected fertilizer was then weighed to monitor and ensure even distribution throughout the study site. The fertilizer blends and treatment dates for each stand are provided in Table 1. We assume that the small differences in the micronutrient component of the fertilizer blends had no significant effect on understory response.

One-hundred-meter transects were established in both control and fertilized areas, with 13 m^2 subplots located every 10 m along a transect for a total of 11 subplots. Transects were placed in each stand to minimize variability within a transect as well as to capture variation across the treatment unit. A transect is the sample unit in this study for both understory vegetation and overstory basal area measurements. Overstory tree measurements were made on variable radius plots located at each vegetation subplot just prior to treatment.

Vegetation Measurements

Three growth forms were sampled: shrubs, forbs, and grasses, using the 13 m^2 subplots following protocols described in Moeur (1985). Sampling occurred in midsummer and late summer of 1997 and 1998. The exact sampling date differed by site to make plant phenological development stage similar among sites. We wanted to sample during the period of maximum understory production and again at the end of the growing season. Vegetation sampling plots were marked with a PVC pipe in the center. Variable-radius overstory tree plots were centered on the vegetation plots to

Table 1. Selected site, stand, and treatment characteristics at the experimental locations.

Site	Dominant overstory species	Age	Initial trees/ha	Initial basal area* (m^2/ha)	Crown competition factor* (%)	Habitat type series†	SI†† (m)	Treatment date	Multi-nutrient fertilizer blend (kg/ha)
Bovill, ID	Mixed conifer	47	1,272	30	286	Red cedar	28	Fall 1997	N 220, K 110, S 88, Cu 11, B 5.5
Goldendale, WA	Douglas-fir & ponderosa pine	85	309	15	118	Douglas-fir	17	Spring 1997	N 220, K 220, S 88, Cu 11, Zn 11, B 5.5, Mo 1
New Meadows, ID	Ponderosa pine	68	422	20	106	Douglas-fir	19	Fall 1996	N 220, K 220, S 88, B 11, Cu 11, Zn 11, Mo 1
Potlatch, ID	Red cedar & grand fir	95	1,157	57	353	Red cedar	25	Fall 1997	N 220, K 110, S 88, Cu 11, B 5.5
	Douglas-fir	15	981	5	16	Red cedar	26	Fall 1997	N 220, K 110, S 88, Cu 11, B 5.5
	Ponderosa pine	15	945	11	14	Red cedar	26	Fall 1997	N 220, K 110, S 88, Cu 11, B 5.5
Wallowa, OR	Mixed conifer	30	748	16	103	Grand fir	20	Fall 1995	N 220, K 220, P 110, S 99, B 11, Cu 11, Zn 11, Mo 1
	Ponderosa pine	14	420	10	60	Grand fir	21	Fall 1995	N 220, K 220, P 110, S 99, B 11, Cu 11, Zn 11, Mo 1

* Includes all tree species.

† After Steele et al. 1981 and Johnson and Clausnitzer et al. 1992.

†† Douglas-fir site index from Monserud 1984.

measure overstory tree density and species composition. Each measured tree was marked at diameter breast height (dbh) to assist in future remeasurements. Average basal area/ha and crown competition factor (CCF) (Krajieck et al 1961) were calculated as the average of the transects for each treatment (Table 1).

The need to quickly and accurately estimate the amount of herbage in a pasture or forest is recognized by most researchers (Haydock and Shaw 1975). Measuring plant yield directly by clipping is accurate; however, only a limited number of samples are feasible, and the method is destructive (Haydock and Shaw 1975, Tucker 1980, Erixson 1993). Many samples of lower precision are better than a few samples of high precision to account for vegetation variability across a site (Haydock and Shaw 1975). Tucker (1980) analyzed five different methods to obtain yield and found that the comparative yield method was the most reliable. This method allows for greater numbers of sample plots compared to using the clipping-only method, although there is a loss of individual quadrat precision. However, due to larger sample size, the precision of the overall site estimate of annual production may increase (Haydock and Shaw 1975).

Understory biomass was estimated using the comparative yield method of Haydock and Shaw (1975) to reduce the amount of vegetation destruction and sampling time. At each permanent understory sample plot, two separate components were involved in estimating annual production based on the comparative yield method: destructive (clipping and weighing) and nondestructive (ocular estimates) plots. General methodology was as follows: first, five 1 m^2 reference quadrats were selected that constituted the yield scale against which the yields of the sample 13 m^2 subplots were rated for each site. Two 1 m^2 quadrats (standards 1 and 5) were established on low and high yielding areas to define a range that included most dry matter yield samples within each site. Then a 1 m^2 location within the site was selected that approximated dry matter yield midway between those for 1 and 5. Subsequently, 1 m^2 quadrats (standards 2 and 4) were selected that approximated yields midway between 1 and 3, and 3 and 5, respectively. Next, the 13 m^2 subplots along the transect lines were ocularly estimated using the previously established yield rating. Each 13 m^2 subplot was divided into quarters, and a 1 m^2 quadrat was placed in the middle of each quarter and rated according to one of the five scale categories. All four ratings were then averaged to obtain a rating for the 13 m^2 subplot. After all subplots were rated, the five intensive sampling quadrats were harvested at each study site. Forbs and grasses were clipped at ground level, and shrub production was estimated using the reference unit method proposed by Erixson (1993). This method consisted of using a clipped twig from a plot perimeter representing between 30 and 100% of the average aboveground annual production for shrubs. The selected twig became the reference unit to which all other twigs were compared. Live annual production for each shrub was ocularly estimated to the nearest 1% of its weight relative to the reference unit (i.e., the selected twig); estimates for each shrub were then summed to obtain plot totals. The reference unit method was used in our study to efficiently obtain green and dry weights for shrubs in the clipped square meter plots. Several researchers have found that this method is nearly as accurate as clipping and weighing all shrubs (Andrew et al. 1979, Kirmse and Norton 1985, Erixson 1993).

All harvested material was stored in plastic bags, placed in a cooler, transported back to the laboratory, and then oven-dried at 70°C for 48 hr (Erixson 1993). A site-sampling period-treatment-year specific regression equation was developed relating dry weight yield from the clipped plots to the ocular scale rating from the same clipped plots. Yield for any 13 m^2 subplot was then obtained by substituting its ocular rating into the regression equation. Grazing was excluded from the study sites, except for a light amount at the New Meadows location.

Statistical Analysis

Understory vegetation annual production (AP) was the dependent variable in our analysis. Understory vegetation AP was computed and analyzed separately for shrubs, forbs, and grasses, as well as collectively for all three growth forms. The 13 m^2 subplots were averaged by transect; the transect estimates were then averaged within each site and treatment and the averages used in the subsequent statistical analyses. Individual growth form AP was estimated by multiplying average site and treatment combination percent covers (based on Daubenmire 1959) by the average site and treatment combination AP (Payne 1974, Olson and Martin 1981). This experiment was designed for using Analysis of Variance (ANOVA), and statistical comparisons among fertilizer treatments were conducted using PROC GLM of the Statistical Analysis System (SAS Institute Inc. 1989). The significance level chosen for statistical tests was 0.10.

Results

Shrub, forb, grass, and combined growth form AP differed by study site. Treatment produced a significant main effect for all growth forms. Forb and combined growth form AP varied significantly by sampling period. A significant treatment by sampling period interaction was evident only for combined growth forms. Analyses of all four growth forms showed significant treatment by site interactions. The site by sampling period interaction was significant for forbs, grasses, and combined growth forms.

Site-specific least square mean estimates of AP by treatment and sampling period for each understory plant growth form are provided in Table 2. Multinutrient fertilization produced significant increases in AP during 1998 for most growth forms at the New Meadows ponderosa pine, Potlatch western redcedar (*Thuja plicata*)/grand fir (*Abies grandis*), Potlatch ponderosa pine plantation, and the Wallowa ponderosa pine plantation sites for both sampling periods (Table 2). Exceptions were shrubs and grasses for both sampling periods at the New Meadows ponderosa pine site, grasses at the Potlatch western redcedar/grand fir site for both sampling periods, and shrubs in late summer and forbs during midsummer at the Wallowa ponderosa pine plantation. Understory vegetation AP following fertilization did not significantly increase at the

Table 2. Understory vegetation annual production mean values by treatment, plant growth form, and sampling period during the 1998 growing season for eight study locations in the inland Northwest.

		Combined		Shrubs		Forbs		Grasses	
Site	Treatment	Mid	Late	Mid	Late	Mid	Late	Mid	Late
		(lb/ac)							
Bovill, ID	Control	1,608	2,125	878	1,156	656	898	74	72
	Fertilized	1,774	2,326	958	1,235	732	1,008	84	83
Goldendale, WA	Control	464	835	153	303	201	354	110	178
	Fertilized	1,220	1,732	263	438	515	682	442	612 ↑
New Meadows, ID	Control	790	415	258	145	215	56	318	214
	Fertilized	1,362 ↑	886 ↑	350	222	552 ↑	325 ↑	459	338
Potlatch, ID									
Red cedar/grand fir	Control	–136	–89	–35	–13	–23	28	–1	–6
	Fertilized	–41 ↑	–31 ↑	14 ↑	13 ↑	19 ↑	42 ↑	0	–1
Douglas-fir	Control	4,565	2,487	663	1,538	1,608	142	1,583	1,385
	Fertilized	5,166	2,605	–1,084	1,487	1,765	–188	2,067	1,703
Ponderosa pine	Control	1,632	1,440	413	435	676	577	543	428
	Fertilized	4,016 ↑	2,919 ↑	1,337 ↑	1,041 ↑	1,378 ↑	793 ↑	1,300 ↑	1,085 ↑
Wallowa, OR									
Mixed conifer	Control	2,096	1,999	1,059	1,162	866	689	170	149
	Fertilized	2,517	1,515	1,283	785	938	550	296	179
Ponderosa pine	Control	904	1,025	213	329	532	365	158	331
	Fertilized	2,028 ↑	1,987 ↑	602 ↑	693	806	727 ↑	619 ↑	567 ↑

↓↑Arrows indicate a significant increase or decrease following treatment ($P < 0.10$).

Bovill mixed-conifer, Potlatch Douglas-fir plantation, and the Wallowa mixed-conifer sites for both sampling periods of 1998 (Table 2). The only significant increase in AP at the Goldendale mixed-conifer site was for grasses in late summer.

Discussion

Combined Growth Forms

Total understory vegetation AP is useful to measure changes in the entire plant community following multinutrient fertilization. Site, treatment, and their interaction were statistically significant for all growth forms. All significant treatment effects were positive; no treated areas showed significantly lower AP than the controls (Table 2). The dominant understory species at the significantly responding New Meadows ponderosa pine site were the shrubs common snowberry (*Symphoricarpos albus*), western serviceberry (*Amelanchier alnifolia*), the forbs western yarrow (*Achillea millefolium*), and strawberry (*Vesca* spp.), and the grasses elk sedge (*Carex geyeri*) and pinegrass (*Calamagrostis rubescens*). The dominant understory species at the Potlatch western redcedar/grand fir stand were common snowberry, and the forbs Menzie's silene (*Silene menziesii*) and western starflower (*Trientalis latifolia*). The statistically significant response was not visually apparent at this site partly because understory vegetation amounts were so low, even in the treated area. This low absolute amount of increased production should have little effect on animal-carrying capacity. It is surprising that a response occurred at this site at all since the understory species are late-seral and thus adapted to low light and tightly cycled nutrients (Tilman 1985) and usually show lower response to increased nutrients (Grime 1977). No individual species substantially changed in percent cover following fertilization at this site.

A significant increase in understory AP was also produced at the Potlatch ponderosa pine plantation. The greatest response (approximately 2,400 lb/ac) occurred in midsummer (Table 2). The shrubs common snowberry, western serviceberry, the forbs speedwell (*Veronica* spp.) and western yarrow, and the grasses Kentucky bluegrass (*Poa pratensis*) and pinegrass dominated the understory. Large increases in percent cover following fertilization were seen for common snowberry, strawberry, western yarrow, bluegrass, and pinegrass. Speedwell percent cover substantially decreased in the fertilized unit. Overstory basal area was relatively low in this plantation.

Significant understory biomass increases were seen at the Wallowa ponderosa pine plantation, and response peaked in midsummer at about 1,100 lb/ac (Table 2). The dominant understory species were the shrubs common snowberry and thimbleberry (*Rubus parvifolia*), the forbs strawberry and montana thermopsis (*Thermopsis montana*), and the grasses Kentucky bluegrass and slender hairgrass (*Deschampsia elongata*). Substantial increases in percent cover occurred for thimbleberry and slender hairgrass, while no individual species substantially decreased in percent cover.

Many of the species occurring on our sites that showed significant understory fertilization response, such as common snowberry, western yarrow, thimbleberry, western starflower, elk sedge, pinegrass, bluegrass (*Poa canbyi*), and tufted hairgrass (*Deschampsia caespitosa*), have been demonstrated to respond to fertilization in other studies (Freyman and van Ryswyk 1969, Bowns 1971, Riegel et al. 1991, Prescott et al. 1993, Nams et al. 1993). Decomposition rates should increase as a result of increased production at responding sites (Flanagan and Van Cleve 1983) and should produce a future increase in nutrient availability for the overstory trees (Flanagan and Van Cleve 1983, Chapin et al. 1986).

Overall understory AP is important, but individual growth form AP changes more precisely determine wildlife habitat and animal use differences (Holechek et al. 1995). Changes in grasses and forbs will have more impact on grazing animals (i.e., cattle and elk), and changes in shrubs should have more effect on animals that are browsers (i.e., white-tailed deer) (Holechek et al. 1995). Therefore, we analyzed shrub, forb, and grass AP separately.

Shrubs

Shrub AP increased for most sites and sampling periods coincident with overall annual production increases (Table 2) except for the New Meadows ponderosa pine site for both sampling periods and the Wallowa ponderosa pine plantation in late summer. Common snowberry was a dominant shrub and was responsive at all three sites where overall AP increased. This species is known to be responsive to fertilization (Riegel et al. 1991, Prescott et al. 1993). However, snowberry cover decreased at the Wallowa mixed-conifer site and the Potlatch Douglas-fir plantation. Other shrubs that showed cover increases for at least one site were thimbleberry at the Wallowa ponderosa pine plantation; Utah honeysuckle (*Lonicera utahensis*) at the Wallowa mixed-conifer site; Rocky mountain maple (*Acer glabrum*) at the Potlatch Douglas-fir plantation; squaw carpet (*Ceanothus prostratus*) at the Goldendale mixed-conifer site; and blueberry (*Vaccinium* spp.) at the Bovill mixed-conifer site. Abrams and Dickmann (1983) found that another species of *Vaccinium* was responsive to fertilization. Pinemat manzanita (*Arctostaphylos nevadensis*) did not respond to fertilization, showing decreased cover in fertilized areas at the Goldendale mixed-conifer site. Nams et al. (1993) found that kinnikinnik (*Arctostaphylos uva-ursi*) also did not respond to fertilization. Rose (*Rosa* spp.) also decreased in cover at the Wallowa mixed-conifer site inconsistent with the findings of Prescott et al. (1993), and shiny-leaf spirea (*Spirea betulifolia*) cover decreased at the Potlatch Douglas-fir plantation.

Forbs

Forbs showed significant AP increases at the New Meadows ponderosa pine, Potlatch western redcedar/grand fir, and the Potlatch ponderosa pine plantation sites for both sampling periods. A significant increase was also observed at the Wallowa ponderosa pine plantation in late summer. Western yarrow showed large cover increases at the New Meadows ponderosa pine site, the Potlatch ponderosa pine plantation, and the Goldendale mixed-conifer site consistent with the results of Nams et al. (1993). Strawberry also substantially increased in cover at the Potlatch ponderosa pine plantation, and hawkweed (*Hieracium* spp.) was highly responsive at the Goldendale mixed-conifer site. Speedwell cover greatly decreased at the Potlatch ponderosa pine plantation site, and Montana thermopsis decreased at the two Wallowa sites.

Grasses

Grasses responded less frequently to multinutrient fertilization than did shrubs and forbs. Significant grass AP increases were observed for both sampling periods at the Potlatch and Wallowa ponderosa pine plantations. Grasses at the Goldendale mixed-conifer site also increased for late summer. Large increases were observed for pinegrass cover at the Potlatch ponderosa pine plantation. This species has been shown to be highly responsive to fertilization (Freyman and van Ryswyk 1969, Riegel et al. 1991), but no increase was observed at the New Meadows ponderosa pine site. Bluegrass, which has been shown to be highly responsive to fertilization (Bowns 1971), and Columbia brome (*Bromus vulgaris*) cover increased at the Potlatch ponderosa pine and Douglas-fir plantations. Cover also increased for slender hairgrass at the Wallowa ponderosa pine plantation. Bowns (1971) found that another species of *Deschampsia* responded to fertilization. Western fescue (*Festuca occidentalis*) at the Goldendale mixed-conifer site also responded strongly. Nams et al. (1993) reported that another species of *Festuca* responded to fertilization. Elk sedge decreased in cover at the New Meadows ponderosa pine site inconsistent with the findings of Riegel et al. (1991).

Operational fertilization in our study produced variable understory vegetation responses in inland Northwest conifer stands. However, response was generally predictable. The Bovill mixed-conifer (dominated by grand fir, Douglas-fir, and western redcedar), Potlatch Douglas-fir plantation, and the Wallowa mixed-conifer (dominated by grand fir, Douglas-fir, and Engelmann spruce [*Picea engelmannii*]) sites showed no significant changes in AP for combined or individual growth forms (Table 2). The Goldendale mixed-conifer site (dominated by Douglas-fir and ponderosa pine) showed significant biomass increase for only one growth form. These four sites contained some of the same understory species that responded to fertilization at other sites. Greater understory biomass response was evident in stands dominated by shade-intolerant overstory species (ponderosa pine) than those with moderately shade-tolerant (Douglas-fir) and shade-tolerant overstory (western redcedar, grand fir, Engelmann spruce) species.

Stands with lower overstory density showed more understory production in our control treatments, consistent with work conducted by Jameson 1967, Alaback and Herman 1988, Uresk and Severson 1989, and Klinka et al. 1996. Low-density stands also produced larger understory response to fertilization in our study. The western redcedar/grand fir site at Potlatch showed statistically significant production increases following multinutrient fertilization; however, the magnitude of annual production response was small compared to the ponderosa pine plantations and the New Meadows ponderosa pine site. This result is as expected, since understory vegetation is under severe competition for light, water, and nutrients in stands with high overstory density (Jameson 1967, Persson 1981, Riegel et al. 1995, Nabuurs 1996).

Understory plant species exhibit large differences in their nutrient requirements (Grime 1977, Chapin et al. 1986, Meerts 1997). Our results show that some understory species in inland Northwest conifer stands increase in cover following multinutrient fertilization while others do not or may even decrease in cover. The shrubs (blueberry, common snowberry, Rocky mountain maple, rose, thimbleberry, and Utah honeysuckle) the forbs (hawkweed, strawberry, and western yarrow), and the grasses (blue wildrye, Columbia brome, Kentucky bluegrass, pinegrass, and western fescue) increased in cover following fertilization at one or more sites. Decreases in cover following fertilization occurred at one or more sites for the shrubs blueberry, common snowberry, rose, shiny-leaf spirea, and western serviceberry, for the forbs Montana thermopsis, self-heal (*Prunella vulgaris*), speedwell, and for pinegrass.

The largest increases in understory production were seen in stands dominated by shade-intolerant overstory species that have low overstory densities. However, overstory tree total volume response to fertilization in the inland Northwest is greatest over a basal area range of about 125 to 175 ft^2/ac. (Moore et al. 1998). Our study shows that understory response would be low in stands with high priority for overstory fertilization.

An important issue for resource managers in the inland Northwest is the presence of noxious weeds. Fertilization has the potential to increase not only desirable but also undesirable understory species. In our study hawkweed generally increased in cover. The species of hawkweed we encountered were *Hieracium albiflorum* and *H. albertinum* rather than the exotic, noxious members of this genus.

Conclusions

Our study suggests that little change in understory vegetation AP will occur following multinutrient fertilization in stands with higher overstory tree density. Therefore, stands in midelevation forests in the inland Northwest normally targeted for operational fertilization to increase overstory growth may not produce large increases in understory vegetation AP following treatments. The largest responses in understory vegetation AP following multinutrient fertilization should be in low density overstory stands, dominated by shade-intolerant tree species. The following individual species can be characterized as responsive to multinutrient fertilization: the shrubs, common snowberry and thimbleberry; the forbs, hawkweed, strawberry, and western yarrow; and the grasses, Kentucky bluegrass, slender hairgrass, and western fescue. We do not intend to imply that only the plants listed above are responsive to fertilization, merely that these plants showed increased growth following treatment in our study.

Literature Cited

Abrams, M.D., and D.I. Dickmann. 1983. Response of understory vegetation to fertilization on mature and clearcut Jack pine sites in northern lower Michigan. Am. Midl. Natur., 110:194–200.

Alaback, P.B., and F.R. Herman. 1988. Long-term response of understory vegetation to stand density in *Picea-Tsuga* forests. Can. J. For. Res. 18:1522–1530.

Anderson, B.L., R.D. Pieper, and V.W. Howard. 1974. Growth response and deer utilization of fertilized browse. J. Wildl. Manage. 38:525–530.

Andrew, M.H., I.R. Noble, and R.T. Lange. 1979. A non-destructive method for estimating the weights of forage shrubs. Aust. Range. J. 1:225–231.

Baskerville, G.L. 1972. Use of logarithmic regression in the estimation of plant biomass. Can. J. For. Res. 2:49–53.

Bowns, J.E. 1971. Low level nitrogen and phosphorus fertilization on high elevation ranges. J. Range. Manage. 273–276.

Brix, H. 1981. Effects of thinning and nitrogen fertilization on branch and foliage production in Douglas-fir. Can. J. For. Res. 11:502–511.

Chapin, F.S., III., P.M. Vitousek, and K. Van Cleve. 1986. The nature of nutrient limitation in plant communities. Am. Natur. 127:48–58.

Cooper, D.R. 1987. Assessment of forage production for cattle and wildlife on dry grazing. M.S. thesis, Univ. of Idaho, Moscow. 58 p.

Daubenmire, R. 1959. A canopy-coverage method of vegetational analysis. Northwest Sci. 33:43–64.

Erixson, J.A. 1993. Estimating shrub production and utilization in northern Idaho. M.S. thesis, Univ. of Idaho, Moscow. 63 p.

Flanagan, P.W., and K. Van Cleve. 1983. Nutrient cycling in relation to decomposition and organic-matter quality in taiga ecosystems. Can. J. For. Res. 13:795–817.

Freyman, S., and A.L. van Ryswyk. 1969. Effect of fertilization on pinegrass in southern British Columbia. J. Range. Manage. 22:390–395.

Garrison, M.T., J.A. Moore, T.M. Shaw, and P.G. Mika. 2000. Foliar nutrient and growth response of mixed-conifer stands on the Okanogan and Umatilla National Forests to three fertilization treatments. For. Ecol. Manage. 132:183–198.

Geist, J.M. 1976. Forested range fertilization in Eastern Oregon and Washington. Rangemans J. 3:116–118.

Geist, J.M., P.J. Edgerton, and G.S. Strickler. 1974. Yukky to Yummy-with fertilizers. Rangemans J. 1: 39–41.

Gessel, S.P., K.J. Turnbull, and F.T. Tremblay. 1960. How to fertilize trees and measure response. National Plant Food Institute, Washington, DC. 67 p.

Grime, J.P. 1977. Evidence for the existence of three primary strategies in plants and its relevance to ecological and evolutionary theory. Am. Natur. 111:1169–1194.

Haydock, K.P., and N.H. Shaw. 1975. The comparative yield method for estimating dry matter yield of pasture. Aust. J. Exp. Agric. Animal Husband. 15: 663–670.

Holechek, J.L., R.D. Pieper, and C.H. Herbel. 1995. Range management. Prentice–Hall, Upper Saddle River, NJ. 542 p.

Jameson, D.A. 1967. The relationship of tree overstory and herbaceous understory vegetation. J. Range. Manage. 20:247–249.

Johnson, C.G., and R.R. Clausnitzer. 1992. Plant associations of the Blue and Ochoco mountains. USDA For. Serv. Publ. R6-ERW-TP-036-92. 162 p.

Kimball, B.A., E.C. Turnblom, D.L. Nolte, D.L. Griffin, and R.M. Engeman. 1998. Effects of thinning and nitrogen fertilization on sugars and terpenes in Douglas-fir vascular tissues: Implications for black bear foraging. For. Sci. 44:599–602.

Klinka, K., H.Y.H. Chen, Q. Wang, and L. de Montigny. 1996. Forest canopies and their influence on understory vegetation in early-seral stands on West Vancouver Island. Northwest Sci. 70 (3):193–200.

Kirmse, R.D., and B.E. Norton. 1985. Comparison of the reference unit method and dimensional analysis methods for two large shrubby species in the Caatinga Woodlands. J. Range. Manage. 38:425–428.

Krajieck, J., K. Brinkman, and S. Gingrich. 1961. Crown competition, a measure of density. For. Sci. 7(1):35–42.

Meerts, P. 1997. Foliar macronutrient concentrations of forest understorey species in relation to Ellenberg's indices and potential relative growth rate. Plant Soil 189:257–265.

Moeur, M. 1985. Cover: A user's guide to the CANOPY and SHRUBS extension of the Stand Prognosis Model. USDA For. Serv. Gen. Tech. Rep. INT-190. 49 p.

Moore, J.A., D.P. Hanley, H.N. Chappell, J. Shumway, S.B. Webster, and J.M. Mandzak. 1998. Fertilizing Eastern Washington coniferous forests. Ext. Bull. EB1874, Wash. State Univ., Pullman. 18 p.

Moore, J.A., P.G. Mika, and J.L.Vander Ploeg. 1991. Nitrogen fertilizer response of Rocky Mountain Douglas-fir by geographic area across the inland Northwest. West. J. Appl. For. 6:94–98.

Nabuurs, G.J. 1996. Quantification of herb layer dynamics under tree canopy. For. Ecol. Manage. 88:143–148.

Nams, V.O., N.F.G. Folkard, and J.N.M. Smith. 1993. Effects of nitrogen fertilization on several woody and nonwoody boreal forest species. Can. J. Bot. 71:93–97.

Olson, C.M, and R.E. Martin. 1981. Estimating biomass of shrubs and forbs in central Washington Douglas-fir stands. USDA For. Serv. Res. Note PNW-380. 6 p.

Papanastasis, V., Z. Koukoura, D. Alifragis, and I. Makedos. 1995. Effects of thinning, fertilization and sheep grazing on the understory vegetation of *Pinus pinaster* plantations. For. Ecol. Manage. 77:181–189.

Payne, G.F. 1974. Cover-weight relationships. J. Range. Manage. 27(5):403-404.

Persson, H. 1981. The effect of fertilization and irrigation on the vegetation dynamics of a pine-heath ecosystem. Vegetatio. 46:181–192.

Pietz, D., P.A. Tappe, M.G. Shelton, and M.G. Sams. 1999. Deer browse response to pine-hardwood thinning regimes in southeastern Arkansas. South. J. Appl. For. 23:16–20.

Prescott, C.E., L.P. Coward, G.F. Weetman, and S.P. Gessel. 1993. Effects of repeated nitrogen fertilization on the ericaceous shrub, salal (*Gaultheria shallon*), in two coastal Douglas-fir forests. For. Ecol. Manage. 61:45–60.

Riegel, G.M., R.F. Miller, and W.C. Krueger. 1995. The effects of aboveground and belowground competition on understory species composition in a *Pinus ponderosa* forest. For. Sci. 41:(4) 864–889.

Riegel, G.M., R.F. Miller, and W.C. Krueger. 1991. Understory vegetation response to Increasing water and nitrogen levels in a *Pinus ponderosa* forest in Northeastern Oregon. Northwest Sci. 65:10–15.

SAS Institute, Inc. 1989. SAS/STAT User's Guide. Version 6. (4th ed.) Vol. 2. SAS Institute Inc., Cary, NC. 846 p.

Shaffii, B., J.A. Moore, and J.R. Olson. 1989. Effects of nitrogen fertilization on growth of grand fir and Douglas-fir stands in northern Idaho. West. J. Appl. For. 4:54–57.

Steele, R., R.D. Pfister, R.A. Ryker, and J.A. Kittams. 1981. Forest habitat types of Central Idaho. USDA For. Serv. Gen. Tech. Rep. INT-114. 78 p.

Stubbendieck, J., S.L. Hatch, and C.H. Butterfield. 1997. North American range plants. Univ. of Nebraska Press, Lincoln. 501 p.

Teskey, R.O., H.L. Gholz, and W.P. Cropper, Jr. 1994. Influence of climate and fertilization on net photosynthesis of mature slash pine. Tree Physiol. 14:1215–1227.

Tilman, D. 1985. The resource-ratio hypothesis of plant succession. Am. Natur. 125:827–852.

Tisdale, E.W. 1961. Grazing of forest lands in northern Idaho and adjacent areas. P. 150–153. *in* Proc. Soc. Am. For. Annu. Meet., Soc. Am. For., Bethesda, MD. 526 p.

Tucker, C. 1980. A critical review of remote sensing and other methods for non-destructive estimation of standing crop biomass. Grass Forage Sci. 35:177–182.

Turner, J. 1977. Effect of nitrogen availability on nitrogen cycling in a Douglas-fir stand. For. Sci. 23:307–316.

Turner, J. 1979. Effects of fertilization on understory vegetation. P. 168–173 *in* Forest fertilization conf., Gessel, S.P., et al. (eds.). Inst. of For. Resour., Coll. of For. Res., Univ. of Washington, Seattle.

Turner, J., and P.R. Olson. 1976. Nitrogen relations in a Douglas-fir plantation. Annals Bot. 42:1045–1055.

Uresk, D.W., and K.E. Severson. 1989. Understory-overstory relationships in ponderosa pine forests, Black Hills, South Dakota. J. Range. Manage. 42:(3) 203–208.

Wolters, G.L., and R.C. Schimdtling. 1975. Browse and herbage in intensively managed pine plantations. J. Wildl. Manage. 39:557–562.