Tree Planter's Notes, Vol. 46, No. 1 (1995)

Legume Seeding Trials in a Forested Area of North-Central Washington

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Seeding nitrogen-fixing species is a proven silvicultural practice to increase site nutrient capital, but species' responses are site specific. Alsike clover (Trifolium hybridum *L.) , white clover (T.* repens *L.), black medic* (Medicago lupulina *I.), cicer milkvetch* (Astragalus cicer *L.), two varieties of birdsfoot trefoil* (Lotus corniculatus *I.), and Hederma pine lupine* (Lupinus albieaulis *Dougl.) were planted at several elevations on the Wenatchee National Forest in Washington state. After 2 years, alsike clover and Hederma pine lupine were the most successful species on highelevation (>1,219-m or 4,000-ft) sites, and black medic and Hederma pine lupine were the best performers* on *low-elevation sites. Average total nitrogen inputs from top growth of planted species during the 1991 growing season were between 20 and 115 kg/ha (18 and 103 lb/acre). Nitrogen delivered by atmospheric fixation was between 6 and 40 kg/ha (5 and 36 lb/acre). Legumes can successfully establish in eastern Washington, ameliorating losses in nutrients after logging and residue treatment. Legumes increased total nitrogen on these sites and enhanced nutrient cycling in planted areas.* Tree Planters' Notes 46(1):19-27; 1995.

Soil nitrogen capital is often deficient in forested settings of the interior Northwest. Additionally, timber harvesting and residue treatment practices are utilizing increasing amounts of forest biomass, thus increasing the likelihood of offsite transport of nutrients (Grier 1975, Clayton 1981). Woodmansee and Wallach (1981) and Tamm (1991) reported that nitrogen-fixing organisms may be required for adequate and consistent nitrogen supplies in forest settings. Ideally, site nutrient capital should be restored to preharvest levels prior to the next harvest to maintain long-term site productivity (Everett and others 1990). Nitrogen-fixing plant species have been promoted as alternatives to inorganic fertilizers because of their long-duration N enrichment, reduced leaching losses, increased soil organic matter and microflora, and increased availability of other nutrients (Granhall 1981, Khanna 1981, Klock 1982, Tarrant 1983). The use of leguminous species to restore degraded soils has been an agronomic practice worldwide for centuries (Fred and others 1932), and legumes have been used for decades as nurse crops for conifers in New Zealand (Mikola and others 1983).

Practicing foresters need information about legume species that can establish and enrich soil N on disturbed forest lands of the interior Pacific Northwest. Prior seeding trials with non-inoculated legumes in the 900 to 2,100 m (2,950 to 6,900 ft) elevational zone of north-central Washington showed little or no establishment success (Klock and others 1975). Increased legume establishment success and soil nitrogen accumulation were expected with the addition of inoculum.

This experiment was conducted to select promising species for establishment in forest stands of north-central Washington. We tested selected legumes for establishment as pioneer species on recently burned disturbed sites (figure 1). Long-term evaluation of these plots will provide information on the interaction of legume and indigenous species succession, and impacts on reforestation efforts.

Methods

Seven commercially grown herbaceous legume species (table 1) were selected for these seed trials. Non-native species were chosen because collection of native species seeds and rhizobium were cost-prohibitive for widespread applications. Legume species with known positive responses to harsh, dry climates were chosen where possible (Trowbridge and Holl 1989).

Seven trial sites (figure 2) were established on the east slopes of the Cascades. Two replications in a small shrub understory were established at lower elevations and five replications in a grass or grasslike understory were established at higher elevations. Sites had been broadcast burned during the fall of the previous year and burning had consumed all slash so that the planting surface consisted of ash and mineral soil. No other seedbed preparation was applied to planted areas. Sites were located over a range of elevations and plant associations to sample climatic differences on the north end of the Wenatchee Na-

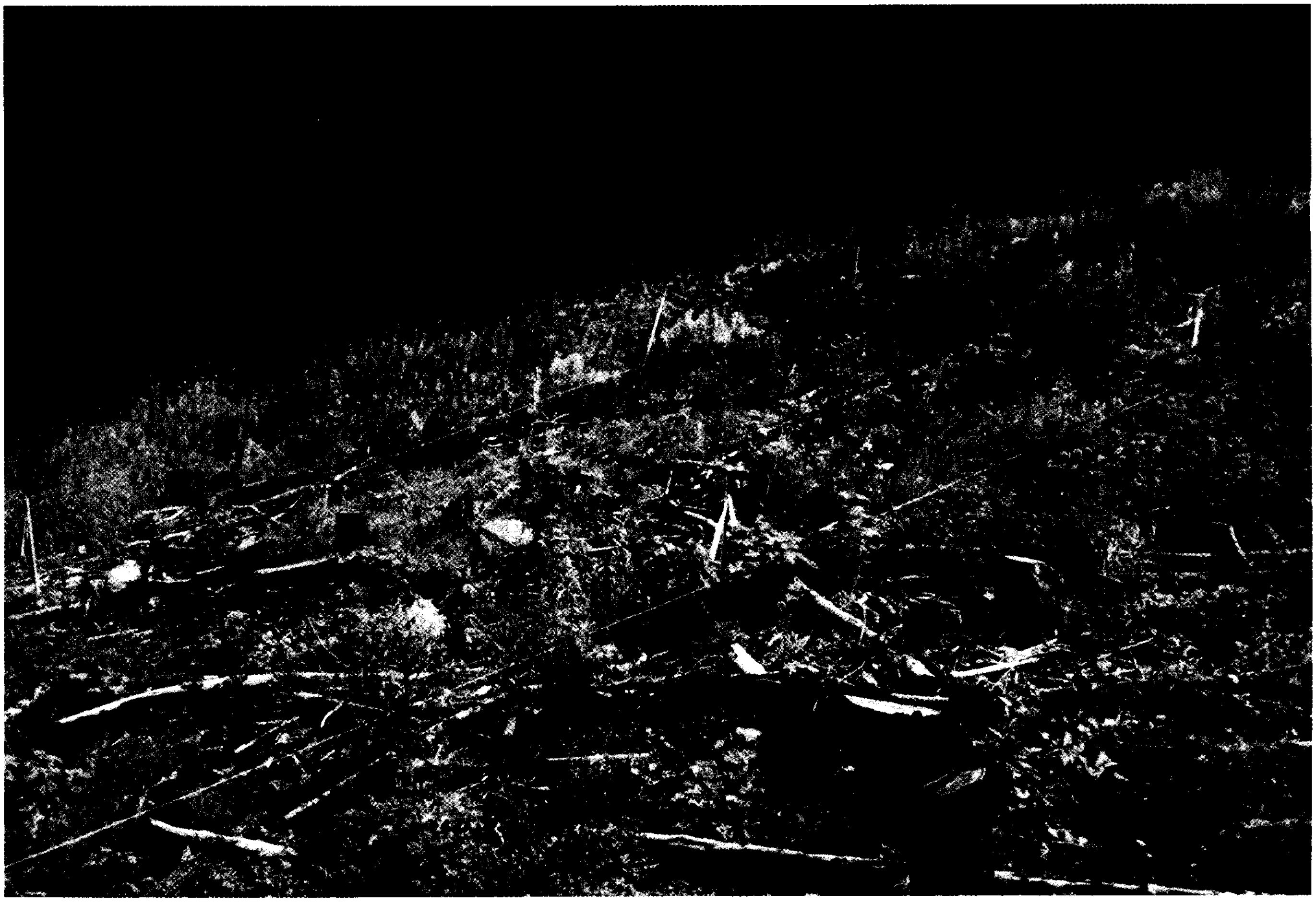

Figure 1— One of the test sites.

tional Forest (table 2). Complete plant association descriptions including climate, soil, associated vegetation, and productivity have been made by Williams and Smith (1990). Sowing occurred as soon in 1990 as sites could be accessed by road (table 2) because leguminous species have been shown to establish more successfully when planted in the spring rather than in the fall (Anderson and Elliott 1957, Brooke and Holl 1988). Eight plots, including a control, measuring 7 m^2 (24 by 24 ft) were established once at each site. Individual legume species were sown on each plot with the control plots left unsown.

Considerable loss of seed prior to plant establishment is normal in forest settings (Krugman and others 1974, Walton 1983, Thompson 1984). Normal seeding rates for stabilizing harvested or burned forest sites are 430 to 1,076 seeds/m^2 (40 to 100 seeds/ft^2) or 5.6 to 8.9 kg/ha (5 to 8 lb/acre) (McLean and Bawtree 1971, Klock and others 1975). For this study, Hederma pine lupine was sown at 86 seeds/m^2 (8 seeds/ft^2) and the smaller-seeded species were sown at 516 seeds/m^2 (48 seeds/ft^2). Seed lots showing test results of greater than 5% hard seed were scarified with sand. Species-specific rhizobium was applied to inoculate the seed with N-fixing bacterium immediately before hand broadcasting and a small amount of milk was added for stickiness and moisture (Hannaway and McGuire 1981). Sand was added prior to sowing to increase the evenness of seed dispersal.

After sowing, three 250-cm^2 (20- by 20-in) subplots were randomly located in each species plot to serve as subplots in tracking plant response over time. First-year legume density counts were taken (number of plants/250 cm^2, converted to number of plants/m^2) during the fall of 1990. A site was considered unsuccessfully planted and dropped from the study if all seven legume species produced less than a minimum density of 10 leguminous plants/m^2 (1 plant/1.1 ft^2) or covered less than one-tenth of treated plots. We found sown areas not meeting one of these criteria continued

Table 1-*Legume species selected* for *seeding* trials

Species/"variety"	Scientific name	References
Alsike clover	*Trifolium hybridum* L.	Anderson and Elliott 1957, Haines and DeBell 1980, Walton 1983, Brooke and Holl 1988, O'Dell 1992, Trowbridge and Holl [in press]
White clover New Zealand "Grasslands"	*Trifolium repens* L.	Hafenrichter and others. 1968, Dobson and Beaty 1977, Haines and DeBell 1980, Walton 1983
Black medic "George"	*Medicago lupulina* L.	Klock and others 1975, Haines and DeBell 1980, Smith and Baltensperger 1983, Baltensperger and Smith 1984, O'Dell 1992
Cicer milkvetch "Monarch"	*Astragalus cicer* L.	Hafenrichter and others 1968, USDA 1969, Leffel 1973, Klock and others 1975, Holecheck and others 1982, Walton 1983
Birdsfoot trefoil	*Lotus corniculatus* L.	McKee 1961, Hafenrichter and others 1968, USDA 1969, Klock and others 1975, Holecheck and others 1982, Jorgensen and Craig 1983, Walton 1983
Birdsfoot trefoil dwarf English "Kalo"	*Lotus corniculatus* var. *arvensis* L.	USDA 1978, and above
Pine lupine "Hederma"	*Lupinus albicaulis* Dougl.	Haines and DeBell 1980, USDA 1980, Johnson and Rumbaugh 1981, USDA 1982, Kenny and Cuany 1990, O'Dell 1992

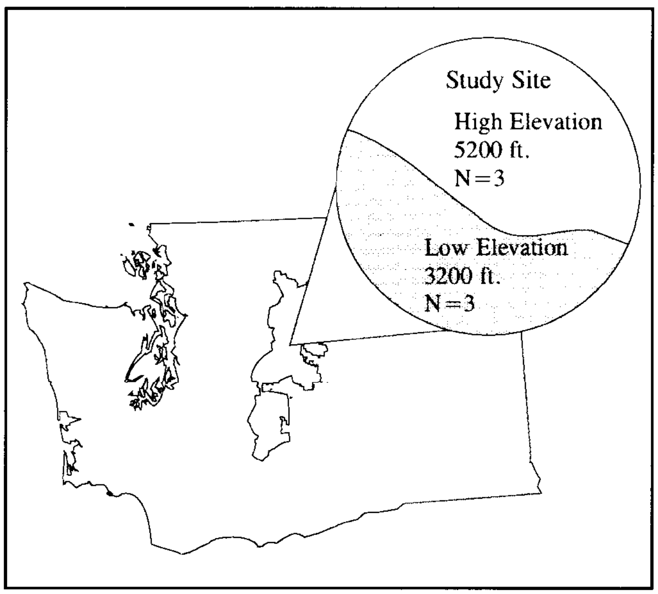

Figure 2*—Location of the test sites in the Wenatchee National Forest, Washington.*

to decline in seeded legume cover over time. Two sites located in the subalpine fir/broadleaf arnica/elk sedge (ABLA2/ARLA/CAGE) plant association failed using either of the above criteria and were not used in the statistical analysis of this study. Possible reasons for failure are outlined in the discussion section of this paper. Legume plant densities, legume and indigenous cover values (estimation method where decimeters per square meter = percentage cover), and biomass (dry weight in kilograms per hectare) samples for the remaining sites were taken again in 1991. Subplots were clipped at peak biomass to determine herbage production. Legume and indigenous species were separated and woody material older than present-year spring wood was removed from indigenous plants. Dry weights were recorded to obtain biomass.

First- and second-year plant densities, second-year cover values and second-year biomass were compared for the five successfully planted sites. Because significant differences in cover values and biomass could not be detected between plant associations, cover and biomass data were combined by plant association, providing two replications for low-elevation sites (ABGR/ACCI-CHUM) and three replications for highelevation sites (ABGR/CARU and ABLA2/CARU). Further analysis compared individual species using multifactor analysis of variance at the P = 0.05 significance level (Mead and others 1993).

Table *2-Plant associations, site descriptions, and sowing dates of areas selected for 1990 planting on the Wenatchee National Forest*

Site	Plant association	Elevation m	Elevation ft	Aspect	Sowing date
Lower Beaver	ABGR/ACCI-CHUM	853	2,800	ENE	June 12
Upper Beaver	ABGR/ACCI-CHUM	975	3,200	N	May 14
Dorthy's Plots	ABGR/CARU	1,219	4,000	NNW	May 18
Mill Canyon	ABGR/CARU	1,372	4,500	N	May 17
Billy #9 (failed)	ABLA2/ARLA/CAGE pumice	1,402	4,600	Flat	June 14
Longview	ABLA2/CARU	1,615	5,300	NNE	May 24
Billy #12 (failed)	ABLA2/ARLA/CAGE pumice	1,676	5,500	Flat	June 13

Note: ABGRACCI-CHUM = Grand fir/vine maple/western prince's pine; moist habitat with well-drained soil, tephra, glacial or landslide deposits with leaves covering the soil surface; ABGR/CARU = Grand fir/pinegrass; relatively warm, well-drained shallow soils, colluvium most often derived from basalt or andesite rock types; ABLA2/ARLA/CAGE= subalpine fir/broadleaf arnica/ elk sedge, formed in ash or pumice; opportunity for freezing year round, ash or pumice over basalt, andesite and metamorphic rocks, highly susceptible to compaction. ABLA2/CARU =subalpine fir/pinegrass; relatively cool and dry, extremes in environmental conditions, droughty soils.

Three to five individual alsike clover, Hederma pine lupine, and black medic plants were randomly chosen and harvested at 853 m (2,800 ft), 975 m (3,200 ft) and 1,372 m (4,500 ft) sites and shoots were dried for at least 48 hours at 70ºC. Total nitrogen in aboveground plant tissue was analyzed according to the micro-Kjeldahl technique (Nelson and Sommers 1972) and reported as percentage of total N. Nitrogen inputs due to fixation were measured by determining the abundance of natural ^{15}N (Shearer and Kohl 1986).

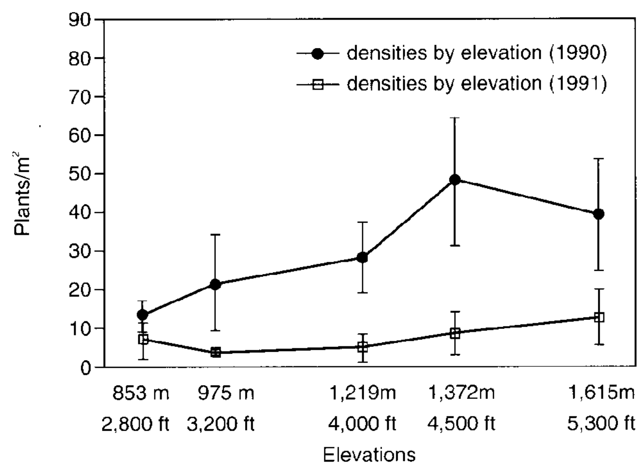

Figure 3*—Density counts of legume species combined and compared across elevations during 1990 and 1991 (P = 0.05).*

Results

Legume densities. When legume species were combined, densities tended to increase as elevation increased (figure 3) and there were more plants in 1990 than in 1991. When comparing individual legume species in 1991 (figure 4), white clover and black medic had the highest plant densities on the lowest elevation site. White clover densities were also highest on the 1,615-m (5,300-ft) site. Cicer milkvetch expressed its highest densities at 1,372 m (4,500 ft). Birdsfoot trefoil, and to some extent Kalo dwarf English trefoil, had increasing numbers of plants establish as elevation increased. Birdsfoot trefoil expressed its greatest densities on the highest elevation plot. Hederma pine lupine exhibited various plant densities at all elevations, with an average high of 10 plants/m^2 at 975 m (3,200 ft). Alsike clover had relatively even densities at all elevations, with a tendency toward decreasing densities at the lower elevations.

Low-elevation (ABGR/ACCI-CHUM) legume and indigenous cover and biomass. All legume species except cicer milkvetch produced 20% or greater cover on low-elevation plots (figure 5). Black medic and Hederma pine lupine provided the greatest amounts of cover, each averaging more than 50%. All legumes except cicer milkvetch and white clover suppressed native cover when compared to control plots. Black medic and Hederma pine lupine tended to produce more biomass at low-elevation sites than other legume or indigenous species (figure 6). All legume species except white clover suppressed indigenous biomass compared to control plots.

High-elevation (ABGR/CARU and ABLA2/CARU) legume and indigenous cover and biomass. At high elevations, only alsike clover exhibited greater than 20% cover, which was considerably more than all other legume species (figure 5). When indigenous cover in seeded plots was compared to indigenous cover in control plots, no seeded species suppressed indigenous cover except cicer milkvetch. Alsike clover tended to produce more biomass than all other legume species (figure 6). Hederma pine lupine provided greater biomass than black medic, cicer milkvetch, and both trefoil species. Only alsike clover suppressed indigenous biomass when compared to controls.

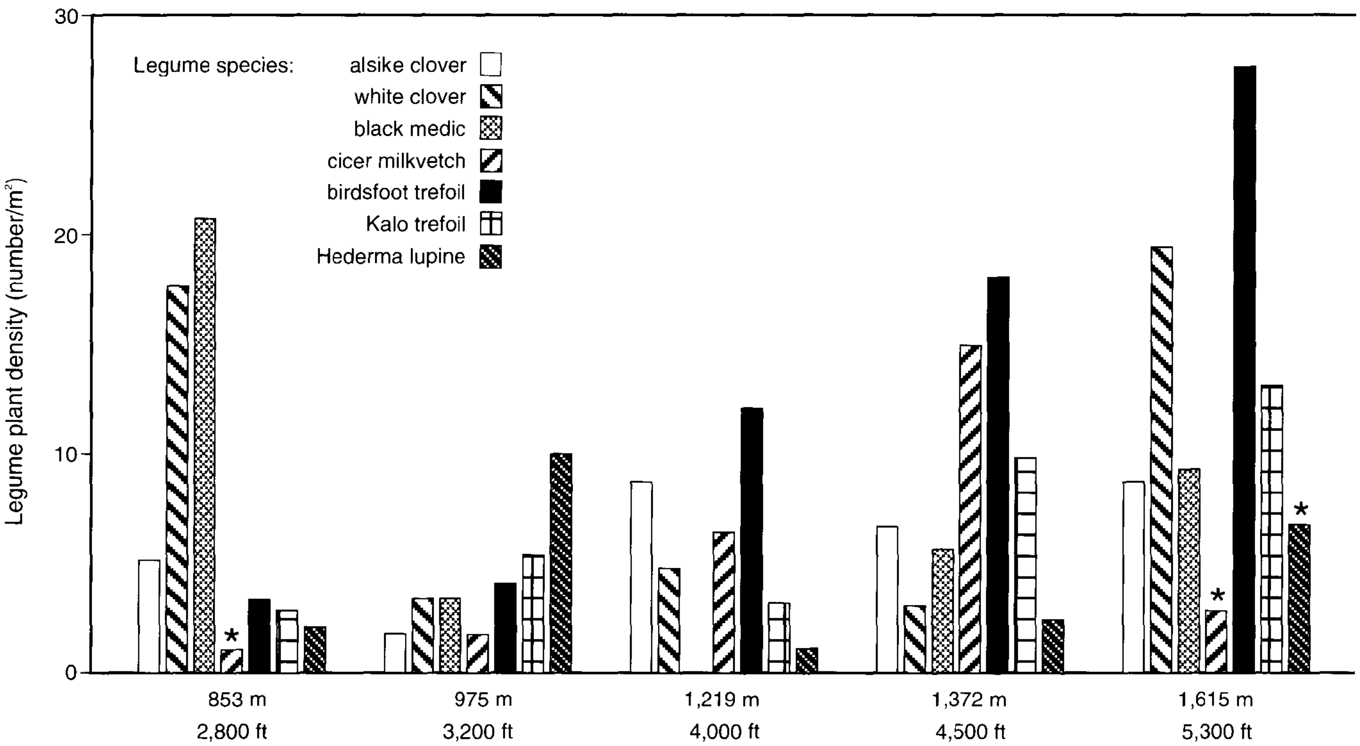

Figure 4—Legume densities for each species at each site in 1991. Bars marked with an asterisk (*) showed significantly (P = 0.05) fewer plant numbers than most successful species at each site.

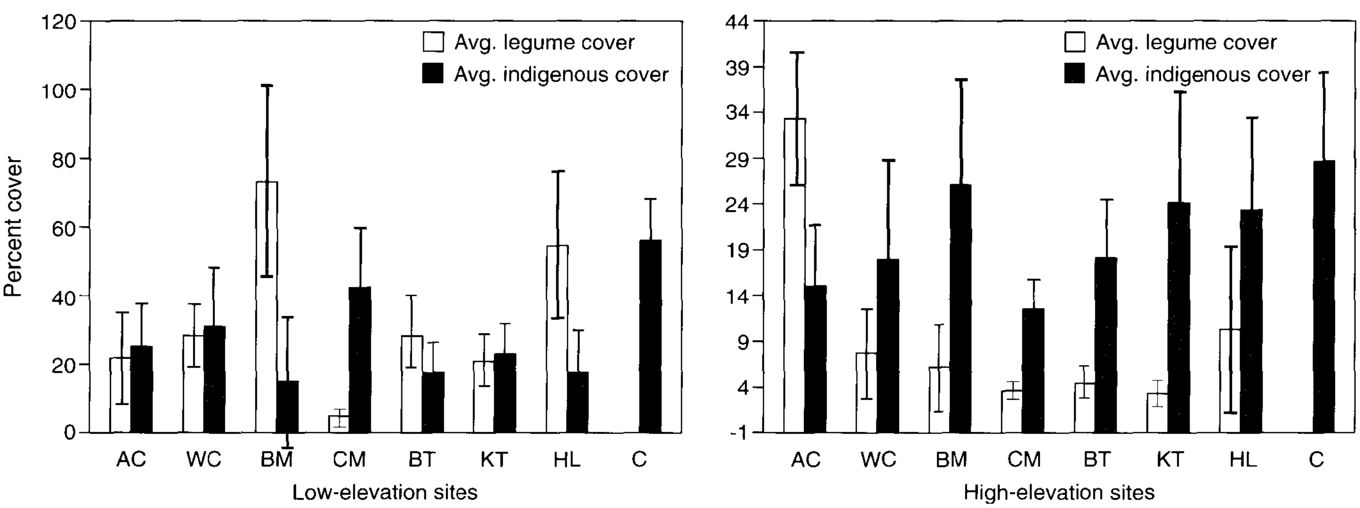

Figure 5—Legume and indigenous cover compared to unplanted controls at low and high elevations (P = 0.05) in 1991. Species: AC = alsike clover, WC = white clover, BM = black medic, CM = cicer milkvetch, BT = birdsfoot trefoil, KT = Kalo trefoil, HL = Hederma lupine, C = control.

Nitrogen content. We estimated the total potential N input from aboveground biomass during the first 18 months after sowing to be 20 to 115 kg/ha (18 to 103 lb/acre) for the three tested legumes (table 3). Of that total, 6 to 40 kg/ha (5 to 36 lb/acre) was fixed by rhizobia (table 4). Although species differed somewhat in amounts of nitrogen obtained by fixation, there were appreciable differences in amounts of total N because of the variations in biomass production.

Discussion

Reforestation efforts can be improved by an aggressive program to restore harvested sites using legumes.

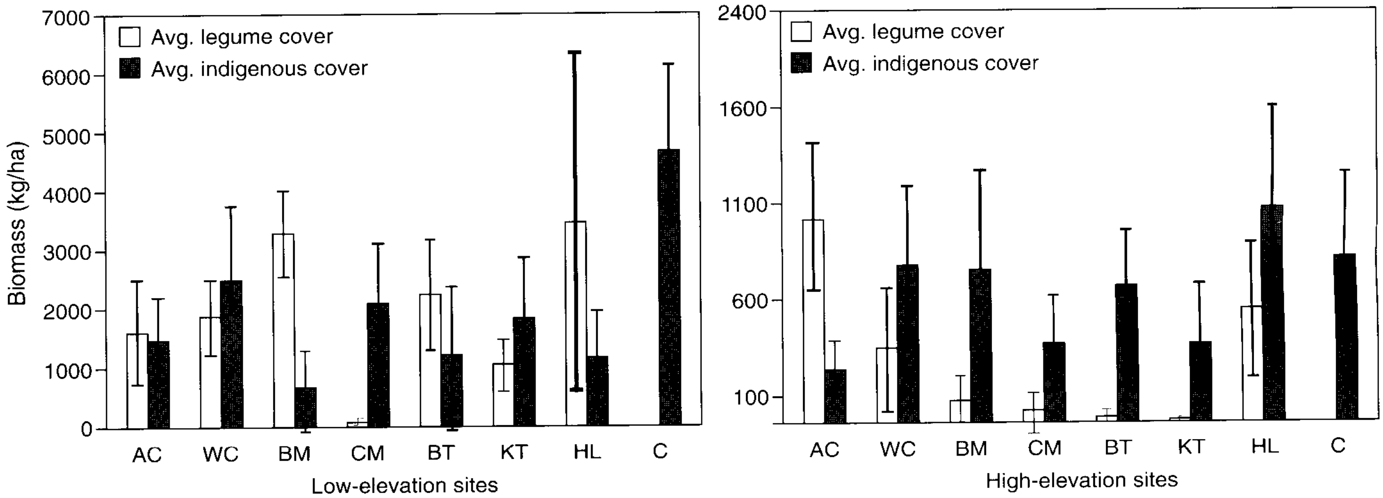

Figure 6—*Legume and indigenous biomass compared to unplanted controls at low and high elevations (P = 0.05) in 1991. Species: AC = alsike clover, WC = white clover, BM = black medic, CM = cicer milkvetch, BT = birdsfoot trefoil, KT = Kalo trefoil, HL = Hederma lupine, C = control.*

Table 3-*Average total nitrogen inputs for aboveground tissue of selected species across three sites*

	Species/elevation			Topgrowth biomass		Total nitrogen†	
	m	ft	Topgrowth nitrogen* (%)	kg/ha	lb/acre	kg/ha	lb/acre
Alsike clover	>1,219	4,000	2.36	1,059	944	25	22
	<1,219	4,000	2.83	1,558	1,390	44	39
Pine lupine	>1,219	4,000	3.29	593	529	20	18
	<1,219	4,000	3.33	3,457	3,084	115	103
Black medic	>1,219	4,000	—	125	112	—	—
	<1,219	4,000	2.70	3,273	2,920	88	78

* Data from O'Dell (1992).

†Second column x third column.

Table 4 -*Nitrogen (kg/ha) derived from fixation by rhizobia for selected species*

Site	Alsike clover	Black medic	Pine lupine	Average/site
Lower Beaver	6.150	31.240	26.295	21.228
Upper Beaver	25.245	39.968	12.151	25.788
Mills Canyon	25.093	6.462	25.476	19.010
Average/species	18.829	25.890	21.307	22.009

Erosion control is an immediate benefit. Long-term benefits are the restoration of site nutrient capital to preharvest levels and the maintenance of long-term site productivity. The use of leguminous species is warranted where nitrogen deficiency is a concern and timber harvest and residue practices have had a negative impact on physical soil conditions and nutrient cycling. We found that certain legume species can be successfully established in north-central Washington forests after timber harvest. Determining relevant site factors such as soil type, elevation, plant associations, and early spring accessibility prior to selection of specific legumes will increase success. Competition among legumes, planted trees, and native vegetation can also be minimized by selection of appropriate legume species.

Nitrogen concentrations in the tissues of alsike clover, Hederma pine lupine, and black medic (table 3) were within acceptable ranges for legumes in the arid Northwest (LaRue and Patterson 1981). This amount of nitrogen is lower than that obtained in some studies of field crops but considerably more than the estimated

1.9 kg/ha from broadleaf lupine *(Lupinus latifolius* Agardh var. *subalpinus* (Piper & Robbins.) Smith) in a logged lodgepole pine *(Pinus contorta* Dougl. ex Loud.) stand (Hendrickson and Burgess 1989). Nitrogen was fixed somewhat more efficiently on low-elevation sites than on high-elevation sites, probably because of better overall site quality. Inoculating these legumes did increase legume establishment success, as evidenced by the lack of establishment of non-inoculated legume seeds in a study conducted in this area by Klock and others (1975).

Overall, first-year legume densities tended to be greater at high-elevation sites but those differences were nonexistent after the first winter. Greater first-year legume densities on high-elevation plots were likely a function of increased moisture availability at the soil surface. This could also explain the lack of establishment success on the highly drained pumice soils of the ABLA2/ARLA/CAGE plant association. The failure of two sites in the same plant association suggests that alternate seeding techniques should be developed and/or different species selected if legumes are to establish in similar areas. Neither of these sites could be accessed by road before June. Perhaps aerial application at an earlier date could have increased spring planting success. The decline in plant numbers on all sites between 1990 and 1991 is normal and further justification for high seeding rates. Some plant establishment failure is expected when moving seed from the area in which it was originally grown to more extreme conditions.

Cover and biomass, both indicators of site quality, usually decrease as elevation increases. The suppression of native cover and biomass expressed on our low-elevation plots could be beneficial to outplanted trees where native vegetation causes intense competition and if the planted legumes do not overtop young trees or compete with them for water. The tradeoffs to be considered are increased ground cover, which reduces erosion and excludes unwanted vegetation, versus the short-term competition with planted conifers.

Low-elevation sites had acceptable establishment of all tested species except cicer milkvetch. Black medic and Hederma pine lupine were the most successful species at lower elevations. Alsike clover, Hederma pine lupine, and to some extent, Grasslands white clover would be acceptable choices for early establishment on high-elevation sites. Although birdsfoot trefoil had low cover values, it did show large numbers of established plants and acceptable amounts of biomass on most sites. Birdsfoot trefoil may have a longer establishment period (Jorgenson and Craig 1983) than the other species tested. Both trefoils should be considered where intense competition from indigenous species is not expected in the first couple of years. Although black medic, and to some extent birdsfoot trefoil, are considered weedy species in maritime climates, they have no opportunity to become weedy over large areas east of the Cascades because of extremes in climatic conditions. This study has shown that black medic does not thrive at high elevations in the north-central Washington area and birdsfoot trefoil may have similar limitations.

The high degree of variability in data results suggests the need for increased replication on individual sites and more intensive testing within plant associations. Further study is also needed on the long-term success of the seeded species, their effects on biodiversity, and their usefulness for increasing site productivity through future rotations. Indigenous nitrogen-fixing plant species are better choices where environmental issues are the only concern but present establishment costs generally make such an alternative prohibitive. The tested legumes could impact native plant biodiversity as well as displace noxious weeds and for those reasons should be monitored as to amount and rate of spread. If they are found to pose no threat to native plant populations, further analyses should include impacts to soil, water, flora, and fauna as well as to the financial economy of the local community.

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Acknowledgments

We would like to thank Larry Shaw on the Entiat Ranger District and Ron Simon of Longview Fiber Company for assistance in finding and using forest lands at various elevations in north-central Washington; George Scherer of the Wenatchee Forestry Sciences Laboratory for his work on the initial layout and data collection; and Robin Rose at Oregon State University, Corvallis, Oregon, and C.F. Thompson of the Ministry of Forests, Nelson, British Columbia for their thorough reviews of the first drafts.

Literature Cited

Anderson CH, Elliott CR. 1957. Studies on the establishment of cultivated grasses and legumes on burned-over land in northern Canada. Canadian journal of Plant Science 37:97-101.

Baltensperger AA, Smith MA. 1984. Nitrogen fixation estimates for some native and introduced legumes, forbs and shrubs. Journal of Range Management 37(1):77-78.

Brooke BM, Holl FB. 1988. Establishment of winter versus spring aerial seedings of domestic grasses and legumes on logged sites. Journal of Range Management 41(1):53-57.

Clayton JL. 1981. Soil disturbance caused by clearcutting and helicopter yarding in the Idaho Batholith. Res. Note INT-305. Ogden, UT: USDA Forest Service, Intermountain Forest and Range Experiment Station. 7 p.

Dobson JW, Beaty ER. 1977. Forage yields of five perennial grass with and without white clover at four nitrogen rates. Journal of Range Management 30(6):461-465.

Everett RL, Zabowski D, McColley P. 1990. Vegetative restoration of western-montane forest soils. In: Symposium, Management and productivity of western-montane forest soils. 1990 April 1012; Boise, ID. Gen. Tech. Rep. INT-280. Ogden, UT: USDA Forest Service, Intermountain Forest and Range Experiment Station. 161-165.

Fred EB, Baldwin IL, McCoy E. 1932. Root nodule bacteria and leguminous plants. University of Wisconsin Studies in Science, No. 5. [Reprinted by University Microfilms International, Ann Arbor, MI. 1979.] 343 p.

Granhall U. 1981. Biological nitrogen fixation in relation to environmental factors and functioning of natural ecosystems. In: Clark FE, Rosswall T, eds. Terrestrial nitrogen cycles. Ecological Bulletin 33:131-144.

Grier C. 1975. Wildfire effects on nutrient distribution and leaching in a coniferous ecosystem. Canadian Journal of Forest Research 5:599-607.

Hafenrichter AL, Schwendiman JL, Harris HL, MacLauchlan RS, Miller HW. 1968. Grasses and legumes for soil conservation in the Pacific Northwest and Great Basin states. Agric. Handbk. 339. Washington, DC: USDA Soil Conservation Service. 69 p.

Haines SG, DeBell DS. 1980. Use of nitrogen fixing plants to improve and maintain productivity of forest soils. In: Impact of intensive harvesting on forest nutrient cycling: Symposium of the State University of New York, College of Environmental Science and Forestry; 1979 August 13-16; Syracuse, NY. Radnor, PA:USDA Forest Service, Northeast Forest Experiment Station. p 277303.

Hannaway DB, McGuire WS. 1981. Inoculating alfalfa and clover seed. EC-1055. Corvallis, OR: Oregon State University Extension Service. p 75-77.

Hendrickson OQ, Burgess D. 1989. Nitrogen-fixating plants in a cutover lodgepole pine stand of southern British Columbia. Canadian Journal of Forest Research 19:936-939.

Holecheck JL, DePuit EL, Coenenberg JG, Valdez R. 1982. Legume establishment on strip mined lands in southeastern Montana. Journal of Range Management 35(3):298-300.

Johnson DA, Rumbaugh M.D. 1981. Nodulation and acetylene reduction by certain rangeland legume species under field conditions. Journal of Range Management 34(3):178-181.

Jorgenson JR, Craig JR. 1983. Legumes in forestry: results of adaptability trials in the southeast. Res. Pap. 237. Asheville, NC: USDA Southeastern Forest Experiment Station. 11 p.

Kenny ST, Cuany RL. 1990. Nitrogen accumulation and acetylene reduction activity of native lupines on disturbed mountain sites in Colorado. Journal of Range Management 43(1):49-51.

Khanna PK. 1981. Leaching of nitrogen from terrestrial ecosystems-patterns, mechanisms and ecosystem responses. In: Clark FE, Rosswall T, eds. Terrestrial nitrogen cycles. Ecological Bulletin 33:343-352.

Klock GO. 1982. Stabilizing ash-covered timberlands with erosion control seeding and fertilization. In: Proceedings, Mt. St. Helens: effects on water resources; 1981 October 7-8; Jantzen Beach, OR. Pullman, WA: Washington State University Press. 164-190.

Klock GO, Tiedemann AR, Lopushinsky W. 1975. Seeding recommendations for disturbed mountain slopes in north-central Washington. Res. Note PNW-244. Portland, OR: USDA Forest Service, Pacific Northwest Forest and Range Experiment Station. 8 p.

Krugman SL, Stein WI, Schmitt DM. 1974. Seed biology. In: Schopmeyer CS, tech. coord. Seeds of woody plants in the United States. Agric. Handbk. 450. Washington, DC: USDA Forest Service: 103-167.

LaRue TA, Patterson TG. 1981. How much nitrogen do legumes fix? Advances in Agronomy 34:15-38.

Leffel RC. 1973. Other legumes. In: Heath ME, Metcalfe DS, Barnes RR, eds. Forages-the science of grassland agriculture, 3rd ed. Ames, IA: Iowa State University Press. 208-220.

McKee GW. 1961. Some effects of liming, fertilization, and soil moisture on seedling growth and nodulation in birdsfoot trefoil. Agronomy Journal 53:237240.

McLean A, Bawtree AH. 1971. Seeding forest rangelands in British Columbia. Pub. 1463. Ottawa, ON: Canada Department of Agriculture. 14 p.

Mead R, Curnow RN, Hasted AM. 1993. Statistical methods in agriculture and experimental biology. London: Chapman and Hall. 415 p.

Mikola P, Uomala P, Malkonen E. 1983. Application of biological nitrogen fixation in European silviculture. In: Gordon J, Wheeler C, eds. Biological nitrogen fixation in forest ecosystems: foundations and applications. The Hague: Martinus Nijhoff/Dr W. Junk Publishers. p 279-294.

Nelson DW, Sommers LE. 1972. A simple digestion procedure for estimation of total N in soils and sediments. Journal of Environmental Quality 1:423-425.

O'Dell TE. 1992. Mycorrhizal and other root endophytic fungi of lupines in the Pacific Northwest. PhD. Thesis. Corvallis, OR: Oregon State University.

Shearer G, Kohl DH. 1986. N2-fixation in field settings: estimations based on natural 15N abundance. Australian Journal of Plant Physiology 13:699-756.

Smith MA, Baltensperger AA. 1983. Agronomic and acetylene reduction evaluation of three annual medics. Journal of Range Management 36(1):5557.

Tamm CO. 1991. Nitrogen-limited and nitrogen depleted terrestrial ecosystems: ecological characteristics. In: Nitrogen in terrestrial ecosystems: questions of productivity, vegetational changes, and ecosystem stability. New York: Springer-Verlag. p 35-49.

Tarrant, R. 1983. Nitrogen fixation in North American forestry: research and application. In: Gordon JC, Wheeler CT, eds. Biological nitrogen fixation in forest ecosystems: foundations and applications. The Hague: Martinus Nijhoff/Dr W. Junk Publishers. p 269-277.

Thompson BE. 1984. Establishing a vigorous nursery crop: bed preparation, seed sowing, and early seedling growth. In: Duryea ML, Landis TD, eds. Forest nursery manual: production of bareroot seedlings. The Hague: Martinus Nijhoff/Dr W. Junk Publishers. p 41-49.

Trowbridge R, Holl FB. 1989. Legumes in reforestation: field screening trials. Internal reports RR 88003-PR. Victoria, BC: Ministry of Forests, Research Program. 24 p.

Trowbridge R, Holl FB [in press]. Early growth of lodgepole pine after establishment of alsike clover-rhizobium nitrogen-fixing symbiosis.

U.S. Department of Agriculture. 1969. Culture and uses of birdsfoot trefoil in the state of Washington. Plant Science Handbook, Plant Materials Section. Soil Conservation Service, State of Washington, 2 p.

U.S. Department of Agriculture. 1978. Culture and uses of "Kalo" dwarf English trefoil in the state of Oregon. Plant Materials Tech Note 52. Portland, OR: Soil Conservation Service. 4 p.

U.S. Department of Agriculture. 1980. Culture and uses of Sicklekeeled lupine in the state of Oregon. Plant Materials Tech Note 59. Portland, OR: Soil Conservation Service. 2 p.

U.S. Department of Agriculture. 1982. Hederma sickle-keeled lupine. Corvallis, OR: Agricultural Experiment Station, Oregon State University and Soil Conservation Service, Corvallis Plant Materials Center. 2 p.

Walton PW. 1983. Production and management of cultivated forages. Reston, VA: Reston Publishing Company, Inc. 336 p.

Williams CK, Smith BG. 1990. Draft: forested plant associations of the Wenatchee National Forest. Portland, OR: USDA Forest Service, Pacific Northwest Region.

Woodmansee RG, Wallach LS. 1981. Effects of fire regimes on biochemical cycles. In: Clark FE, Rosswall T, eds. Terrestrial nitrogen cycles. Ecological Bulletin 33:649-669.