Comments

Will We Run Out of Wood in the South?

Less and less timber has been cut on federal lands in the last few years due to the current cloudy climate of environmental and political controversy. As a result, forest industries are producing more wood from fewer acres and many non-industrial private forest (NIPF) landowners nationwide are responding to this opportunity by "cashingin" their timber to take advantage of high prices. Currently, in the South, stumpage prices are at an alltime high and reports of over $500 per thousand board feet of pine timber are not uncommon. Can NIPF landowners help meet this demand for timber without compromising good forest management principles and long-term productivity? *Will they have the foresight to make the down payment on the next harvest by following good reforestation practices?*

Fewer and fewer harvested acres in the South are being replanted— acreage figures have been decreasing steadily over the last 6 years. Currently only 50% of the NIPF acres harvested are replanted (source: Southern Group of State Foresters). In some states, only 20 to 30% of these acres are replanted! Current reforestation rates must be increased if a reliable longterm timber supply is to be assured from southern forests. *This is not just a regional issue but one with national and global consequences.* Our industrialized society has a large appetite for wood products. Just as a sharp reduction in timber harvest on federal lands in the West caused a sharp increase in harvests in the South, a reduced supply of southern timber will cause a shift in focus to other regions or to tropical forests, which are already under great pressure.

Although natural regeneration will keep many acres in production, often these areas will never reach their full potential. Natural seeding from residual and adjacent seed trees often results in low-quality trees, whereas planting genetically improved seedlings would result in 10 to 15% more wood per acre per year than allowing natural regeneration to reforest these lands. In areas where there is no natural seed source present, harvested acres left unplanted will quickly revert to "brush fields." Low-quality hardwoods, greenbrier, honeysuckle, and/or kudzu will take over, requiring substantial site preparation work before productive trees can be reestablished. This situation results in delayed production as well as additional cost.

Thus, there are economic, environmental, and silvicultural reasons for aggressively replanting harvested acreage in the South. Avoiding any future "timber shortfalls" will require a well-coordinated effort by the entire forestry community in two areas:

- Educating NIPF landowners
- Fine-tuning the reforestation system

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Cover: Fir and aspen, Grand Mesa National Forest, Colorado (Photograph by R. E. Grossman, USDA Forest Service).

Educating NIPF landowners is a continuing challenge to state service foresters, extension foresters, county agents, forestry consultants, and industrial "landowner assistance program" foresters. Information can be transferred via workshops, shortcourses, field days, demonstration plantings, and publications. One of the most effective methods is a demonstration area where local landowners can see the results of good reforestation work accomplished by one of their neighbors.

"Fine-tuning" the reforestation system requires teamwork and coordination within the organization. Any system is only as effective as its weakest link. Neither the tree improvement workers, nor nursery workers, nor managers work independently. All groups must work together as a team for the most effective results. An estimate of accomplishment such as plantation survival often serves to focus attention on the need for teamwork.

Likewise, there must be continued and intensified cooperation among forestry organizations. Reforestation accomplishments in the South have come about through the spirit of teamwork developed through the federal and state reforestation programs, the industrial landowner assistance programs, and the nursery and tree improvement cooperatives. Technical assistance provided by the state forestry agencies to NIPF landowners is a critical link in the reforestation system. Often the county forester is the only local professional source of information on species, seed source, and reforestation techniques available to the NIPF landowner. Likewise, the seedling storage and delivery system is unique to the state forestry agencies and it is essential for maximum seedling survival and growth. When all of the local forestry agencies work together as a team, everyone will benefit, including the landowners, the logging or site preparation contractors, forest industries, the local economy, and the state forestry agencies-as well as the resource itself. *Let's all work together to help provide a continued supply of high-quality timber in the future!*

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Note: Our concept of this editorial space is that it should be a place to publish opinions and ideas relating to the reforestation profession. We invite you to submit ideas for commentaries. The views expressed here are solely those of the author(s) and do not necessarily reflect those of the *Tree Planters' Notes* editorial staff, the Forest Service, or the U.S. Department of Agriculture.

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Effectiveness of BGR-P and Garlic in Inhibiting Browsing of Western Redcedar by Black-Tailed Deer

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Repellents may offer a feasible approach to alleviating browsing damage by herbivores. We evaluated the effectiveness of Big Game Repellent-Powder® (BGR-P) and garlic in inhibiting browsing by black-tailed deer (Odocoileus hemionus) *on western redcedar* (Thuja plicata *Donn ex D. Don.). Seedlings were examined for browsing damage at 24 and 48 hours after treatment and then at 1week intervals for 10 weeks. Seedlings treated with BGR-P suffered less damage than did seedlings treated with garlic or untreated seedlings for the first 8 weeks of the study. The garlic treatment reduced damage below that incurred by untreated seedlings for only 48 hours. BGR-P provides a feasible approach to inhibiting browsing damage for short time spans. The garlic treatment provided marginal protection in these tests but might be worthwhile for other, less desirable tree species.* Tree Planters' Notes 46(1):46; 1995.

Elk and deer browsing of tree seedlings (figure 1) seriously hinders reforestation efforts in the Pacific Northwest (Rochelle 1992). Browsing suppresses growth and delays regeneration, as well as killing many seedlings that are repeatedly browsed or pulled out of the ground (Evans 1987). Repellents may offer a feasible approach to inhibiting browsing, particularly in areas where the damage is inflicted by migrating herds and the seedlings are only subjected to browsing for a short, clearly defined period.

Figure 1—*Black-tailed deer browsing western redcedar treated with garlic capsules.*

In the present experiment, we evaluated the effectiveness of Big Game Repellent-Powder® (BGR-P) and garlic in inhibiting black-tailed deer *(Odocoileus hemionus)* browsing of western redcedar *(Thuja plicata* Donn ex D. Don.). Although the available data suggested that either product can temporarily deter some ungulates, their effectiveness in protecting western redcedar from browsing deer was largely unknown.

Materials and Methods

Subjects. A resident herd of 8 adult black-tailed deer served as subjects. Deer were group-enclosed in an area (4 ha) that was reflective of natural habitat consisting of Douglas-fir *(Pseudotsuga menziesii* (Mirb.) Franco) and alder *(Alnus* spp.*)* and associated understory vegetation. Although natural forage was readily available, animals were also provided free access to deer pellets and water throughout the study.

Repellents. BGR-P was donated by IntAgra (Minneapolis, MN) and the test garlic product was donated by Plant Pro-Tech, Inc. (Oak Run, CA). Repellents were applied according to the label or directions provided with each product. BGR-P-treated trees were first sprayed with water and then sprinkled with BGR-P. A Plant Pro-Tech (garlic) capsule was affixed to the terminal branch of each seedling as per directions. Control seedlings were sprayed with water.

Procedure. Immediately before the trial (April 4, 1994), 6 blocks of 3 plots each were established in the deer enclosure. Each plot contained 9 redcedar seedlings (mean height of 85 cm) planted in 3 rows of 3 trees at 2-m spacings. Plots within a block were separated by 25 m, and blocks were spaced at a minimum of 75 m apart. One plot within each block was randomly selected for each one of the treatments (BGR-P, garlic, or control) as described above.

Seedlings were examined for browsing damage at 24 and 48 hours after treatment and then at 1-week intervals for 10 weeks. Four weeks after the beginning of the study, the number of blocks assessed for damage was reduced to 4 because deer were excluded from the portion of the enclosure that contained the other 2 blocks. During damage evaluations, each seedling was examined to determine whether the terminal branch had been clipped and to count the number of bites taken from lateral branches. Bite counts were limited to a maximum of 25, because after 25 bites the seedlings were essentially defoliated. Generally, browsing damage consisted of either only a few bites from lateral foliage or complete defoliation. Regardless, the evaluation criteria were consistent among treatments and provided an accurate assessment to evaluate:

- The number of undamaged seedlings
- The number of seedlings with terminal damage
- The mean number of lateral bites taken
- The number of completely defoliated seedlings (25 bites)

Though these evaluation measures are interrelated, we report all 4 criteria because they are indicative of different levels of damage intensity.

Analysis. Chi-square goodness-of-fit tests were used to assess differences among treatments. Observed values were the summation of data across blocks for the respective treatments. A separate analysis was conducted for each evaluation criterion.

Results

A greater number of seedlings treated with BGR-P remained undamaged for the first 8 weeks of the study than did seedlings treated with garlic or control seedlings (figure 2). During the first 48 hours, garlic provided better protection than no treatment. Similar time intervals occurred when damage was assessed by the number of completely defoliated trees for each treatment (figure 3). More terminal branches escaped damage on seedlings treated with BGR-P than did garlic-treated seedlings or control seedlings for 6 weeks (figure 4). Again, seedlings treated with garlic fared better than the untreated seedlings for the first 48 hours of the study. A similar number of lateral bites were counted on seedlings treated with garlic or untreated seedlings throughout the study, but fewer bites were taken from BGRP-treated seedlings until week 7 (figure 5).

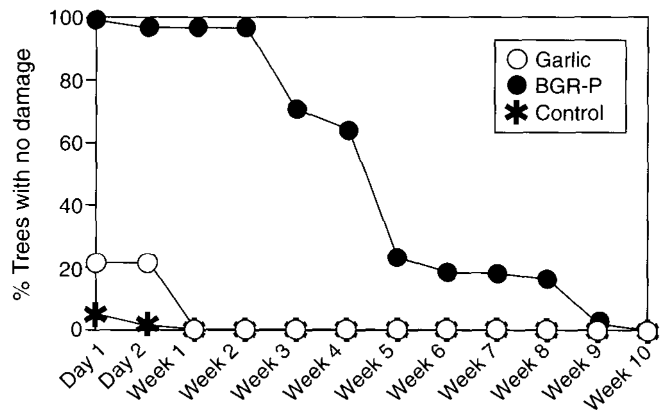

Figure 2—Percentage of seedlings treated with garlic or BGR-P or untreated that remained undamaged for each evaluation period.

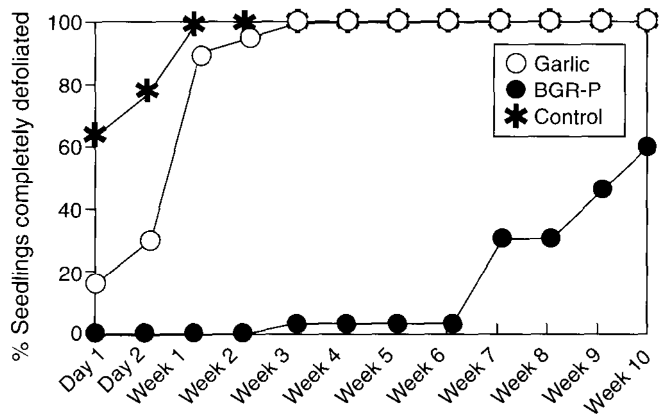

Figure 3—Percentage of seedlings treated with garlic or BGR-P or untreated that were completely defoliated (≥ 25 bites) for each evaluation period.

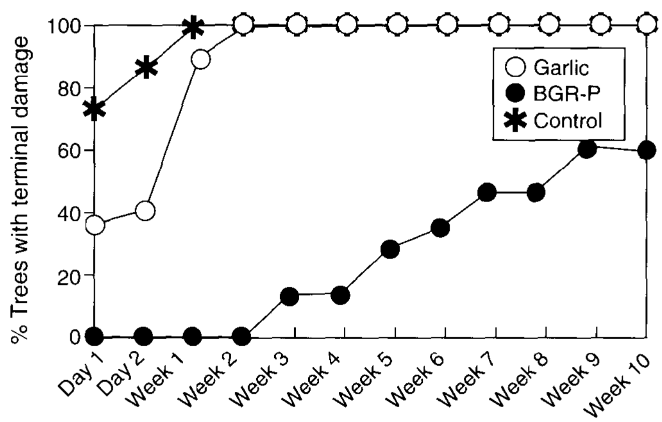

Figure 4—Percentage of seedlings treated with garlic or BGR-P or untreated that sustained damage to their terminal branch for each evaluation period.

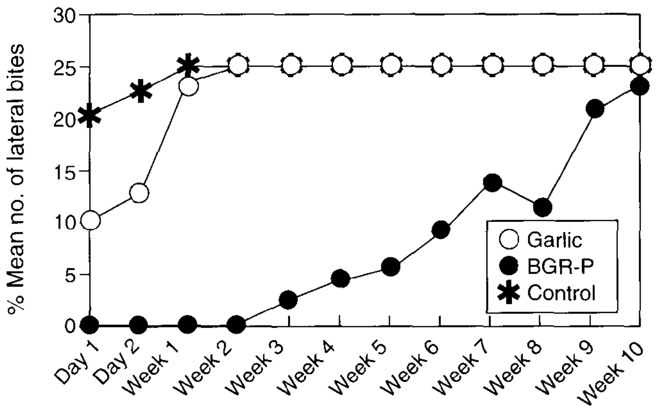

Figure 5—Mean number of bites taken from the lateral branches of seedlings treated with garlic or BGR-P or untreated for each evaluation period.

Discussion

Forage selection is relative and depends on the available options. An animal may select one food over another either because it is attracted to the first or because it is avoiding the alternative (Galef 1985). Thus, the efficacy of a repellent depends on the desirability of the plant to be protected as well as the availability and palatability of the surrounding forage. A preferred plant in a barren environment is far more difficult to protect than an unpalatable shrub amongst lush forage.

Experimental conditions of this study provided the deer with a variety of alternative choices. Browse was readily available along with *ad libitum* access to deer pellets. Though the deer were not food-deprived, the test food–western redcedar— is a preferred forage. These conditions are similar to many field situations where repellents may be applicable, for example, reforestation sites where palatable tree seedlings are vulnerable to browsing herbivores that have alternative foraging opportunities.

BGR-P virtually eliminated damage for 2 weeks after treatment, and the deer inflicted substantially less damage to BGR-P-treated trees than to control trees during the first 8 weeks of the study. These results compare favorably with those found in other studies (Conover 1984, Harris and others 1993, Palmer and others 1983, Andelt and others 1991 and 1992). However, avoidance of garlic-treated seedlings was brief. Other studies indicate that garlic deters foraging herbivores only as long as other options are readily available (Nolte and others 1992). An operational application of garlic capsules to ponderosa pine *(Pinus ponderosa* Dougl. ex Laws.) also failed to produce favorable results. None of the 2,000 ponderosa pines treated with garlic escaped damage from winter browsing by elk (Sigrist, personal communication). Trees are long-lived, and browsing damage is difficult to prevent completely. No repellent is likely to provide total protection. Nevertheless, repellents can reduce damage during periods when trees are most vulnerable. Use of BGR-P is a feasible approach to protecting seedlings when they are first outplanted or during seasons when damage is most likely to occur only briefly, at known times. Garlic was only marginally effective under our test conditions, but it may be more successful in protecting less preferred plant species.

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Germinant Sowing in South Africa

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Germinant sowing is operational for tree nurseries in South Africa. The technique reduces seed costs for eucalypts and pines. Filled cell percentage is usually near 98%. Seed efficiency at many North American container nurseries can be improved by adopting either germinant sowing or singlesowing technology. Tree Planters' Notes 46(1):7-10; 1995.

Managers at most container nurseries attempt to produce one tree per container cell. This makes efficient use of containers, bench space, and potting media. Three different approaches are used to minimize the number of empty cells. A traditional approach in North America is to sow multiple seeds per cell and to thin cells that have more than one seedling (Schwartz 1993, Wenny 1993). A second method was developed in Sweden and involves removing dead and unfilled seeds prior to sowing (Simak 1984, Donald 1986). This method involves three steps (incubation, drying, and separation, or IDS. Because the germination percentage can be increased to over 93%, the IDS treatment promotes the sowing of one nongerminated seed per cell. A third method involves germinating seeds prior to sowing and sowing only germinated seed. Although the concept of fluid drilling (sowing germinants in a viscous gel) was introduced into the Southern United States in early 1980's (Barnett 1983 & 1985), mechanical sowing of germinants is not common in tree nurseries in North America. However, in tree nurseries in South Africa, mechanical sowing of germinants has been operational since 1986. The South African method suspends the germinated seed in water instead of mixing germinants in with a viscous gel. This paper reviews some of the advantages of germinant sowing and suggests that managers of container nurseries in North America consider adopting this technology.

Seed Efficiency

Seed efficiency is defined as the percentage of plantable seedlings produced by pure live seed (South 1990). Achieving high seed efficiency is important when using valuable genetically improved seed or when seed cost is high. For example, in the southern United States, seed efficiencies were often low (for example, 33%) when nursery stock was not genetically improved. However, today, most pines are genetically improved and seed efficiencies in bareroot nurseries often exceed 80%. When seed are valued at 0.3 cent (that is, 3/10th of 1 cent) or more, there is a strong economic incentive for improving seed efficiency (South 1990).

In North America, seed efficiency in container nurseries can be low if multiple seed are sown in each cell. For example, in British Columbia, seed efficiency from container nurseries is expected to range from 28 to 40% for woods-collected seed (table 1). At some operational container nurseries, seed efficiency can be less than 35% (Eremko and others 1989). In some cases, seed efficiency can be higher at bareroot nurseries (table 2). In general, container nurseries will have high seed efficiency when single-sowing (that is, one seed per cell) is used. Many managers will single-sow when germination percentage is more than 90%. However, some recommend sowing two or more seeds when the germination percentage is less than 95% (Wenny 1993). Four or more seeds are sometimes recommended if germination is less than 70%.

When seed costs and thinning costs are considered, the logic for multiple-sowing is less attractive (Space and Balmer 1977). Table 3 compares the cost of production when using seed that costs 0.3 cent per pure live seed. In this example, seeding plus thinning costs were 34% greater for double-sowing than for single-sowing. Although seed and thinning costs make single-sowing more attractive, many nurseries in North America continue to multiple-sow and thin. In North America, a typical nursery worker can thin about 40 trees per minute.

IDS System

In Sweden, batches of tree seeds are routinely sorted to remove dead and unfilled seeds. Fully imbibed seeds are incubated (kept in warm, moist conditions) for a few days and then are placed under controlled drying conditions. During the drying process, dead

Table 1-*Recommended seeding rates, oversowing factor (that is, extra cells sown to ensure meeting production targets), and expected seed efficiency from container nurseries using 1994 BC Ministry of Forests sowing rules*

	Woods-collected seed			Seed orchard seed		
Germination percentage	No. seed/ cell	Oversow factor (%)	Seed efficiency (%)	No. seed/ cell	Oversow factor (%)	Seed efficiency (%)
100	2	25	40	1	40	71
95	3	30	40	1	45	72
85	3	35	30	2	30	45
75	3	40	32	3	40	32
65	4	50	26	4	50	26
55	4	60	28	4	60	28

Table 2 -*Seed efficiency from container and bareroot nurseries in British Columbia during the 1980's and seed costs from a seed dealer*

	Seed efficiency (%)		Cost of pure
Species	Container	Bareroot	live seed (¢/seed)
Coastal Douglas-fir ***Pseudotsuga menziesii*** (Mirb.) Franco)	23	32	0.21
Western hemlock *(Tsuga heterophylla* (Raf.) Sarg.)	27	25	0.09
Western larch (*Larix occidentalis* Nutt.)	28	28	0.22
Lodgepole pine (*Pinus contorta* Dougl. ex Loud.)	30	41	0.08
Ponderosa pine (*P. ponderosa* Dougl. ex Laws.)	22	38	0.80
Western white pine (*P. monticola* Dougl. ex D.Don)	53	66	0.54
Sitka spruce *(Picea sitchensis* (Bong.) Carr.)	35	43	0.20
Grand fir *(Abies grandis* Dougl. ex D.Don) Lindl.)	22	24	0.42
Pacific silver fir *(A. amabilis* Dougl. ex Forbes)	59	23	0.59

Note. seed efficiency data from Eremko and others (1989).

seeds loose water at a greater rate than live seeds. After drying, seeds can be separated by density separation (dead seeds float and live seeds sink). The IDS procedure is used on Scots pine *(Pinus sylvestris* L.) and Norway spruce *(Picea abies* (L.) Karst.) to produce non-germinated seed with a high germination rate (98%). Researchers in North America have not developed the technique to an operational level. However, this method has promise for several North American species (Donald 1986, Edwards 1989, Malek 1992, McRae and others 1995) and could be used to eliminate the need for multiple sowing.

Table 3- *Estimated sowing and thinning costs associated when producing 10 million seedlings*

	Two seeds/ cell	One seed/ cell	One germinant/ cell
Cells needed	10,666,666	13,333,333	10,204,082
Germination %	75	75	75
Seeds required	21,333,332	13,333,333	13,333,333
Blanks expected	666,666	3,333,333	204,082
Excess trees	6,000,000	0	0
Seed cost ($)	64,000	40,000	40,000
Sowing cost ($)	5,333	6,666	5,102
Thinning cost ($)	24,000	0	0
Cost of carrying empty cells ($)	5,333	26,666	1,633
Total costs ($)	98,666	73,332	46,735

Germinant Sowing

In South Africa, filled cell percentages of 98 to 99% are consistently achievable with the use of germinant sowing. Originally developed in the United Kingdom, the concept was refined and simplified in South Africa. Much of the initial work was conducted in Natal by Bryan's Machinery in cooperation with Sappi Forests. The equipment is now available in North America from a distributor in Ontario. With the old system, seed were germinated in a tray, "pricked out" by hand, and transplanted into containers. With this method, about 150,000 *Eucalyptus grandis* W. Hill ex Maid. seedlings could be produced from 1 kg of seeds. With germinant sowing, the number of seedlings increased to 600,000/kg. With a value of $2,000/kg for genetically improved seeds, the germinant sowing system reduced seed costs by $10/thousand seedlings.

In addition to improving seed efficiency, labor costs were reduced at the Sappi Nursery. With the old system (manual transplanting into cells), the labor for 1 million plants was 175 person-days. With germinant sowing, labor was reduced to 51 days. These are savings in the sowing operation. In addition, there are subsequent large savings in not having to thin the crop after emergence. At the Sappi Nursery, one machine can produce 10 million plants/year. An added benefit is that seedling crops are very uniform because all the seeds are sown at the same stage of germination.

The key to success with this technique is sorting dead from live seeds. The seed sample must be clean and well graded (of the same size and mass). This factor is imperative in order to successfully separate germinated from nongerminated seeds. For both pine and eucalypts, the germination fluid is water. If seeds are well graded, germinants will imbibe water and will change in size but not mass. Therefore, germinants have a lower specific gravity than nongerminants. The imbibed (swollen) seeds are separated by using a sugar solution (Taylor and Kenny 1985). Seeds are placed in a small amount of water and a concentrated sugar solution is added slowly until imbibed seeds float to the top. These are then removed from the solution with a tea strainer. If seeds are germinated for too long, the radicals become elongated, and tangling can result in multiple sowing. Ideally, the seed coat should be broken, with the radical about to emerge.

After separation, germinated seeds are placed in a water trough just below the vacuum head. Special needles on the vacuum head are dipped in the water and when removed, several germinants may adhere to each needle. A water rinse is used to remove excess germinants while a single germinant remains attached due to the vacuum. Needle size (hole size) varies from 0.1 to 0.9 mm. Correct needle selection is important (too small = misses; too large = doubles). Vacuum setting is also important (too low = misses; too high = doubles). Cycle time will vary with seed size. Large pine seeds require that the nozzles remain for a longer period in the fluid trough in order for the seed to become properly attached. For pine, almost no doubles occur but with the smaller eucalypt seeds, about 10% of the cavities will have doubles.

Bryans' Miniseeder will sow 60 to 225 trays/hour (128 cavities/tray). The system can sow one row at a time or up to one quarter of a tray at a time. At the Sappi Nursery, four machines are used for sowing. Germinant sowing is used for all eucalypts and for pine when the germination percentage is less than 90%. Dry single-sowing of pine is still practiced when germination is greater than 89%.

Two models of precision drilling machines are available in North America. Both are currently sold by INNO-TEC I.T.U., Inc., Thunder Bay, Ontario. The Miniseeder costs $25,000 and a full-size Precision Fluid Drilling System (figure 1) about $48,000. The full-size machine can sow full trays and production is about 66% faster than the Miniseeder. Currently, two fullsize machines are in use in Canada and one in Mexico.

If the purchase of a germinant sowing machine (at $48,000) would eliminate double-sowing, the potential savings in reduced seed costs and thinning costs could pay for the machine after only 10 million seedlings. For example, the estimated difference in cost between

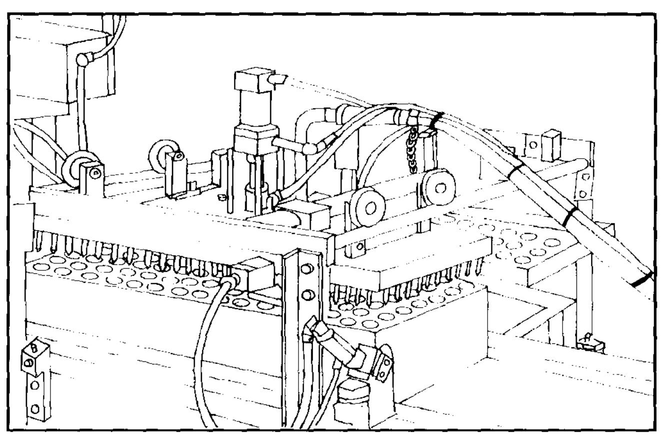

Figure 1—*The ITU Precision drilling system (from a photograph courtesy of Jim Reed, Thunder Bay, Ontario).*

double-sowing and germinant-sowing could amount to $5,100 per million seedlings (table 3). This savings results when each pure live seed is worth 0.3 cent and thinning costs amount to $4/thousand thinned plants. Where seeds are provided to nurseries free of charge (for example, Canada), savings in thinning costs could pay for the machine after sowing 20 million seedlings. However, in situations where both seeds and labor are free or inexpensive, it may be difficult to justify investing in germinant sowing.

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A New Greenhouse Photoperiod Lighting System for Prevention of Seedling Dormancy

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An oscillating light fixture consisting of a 400-watt highpressure sodium arc lamp and an oscillating parabolic mirror was designed and tested on blue spruce (Picea pungens *Engelm.). It successfully prevented apical bud dormancy at distances up to 13 m (43 ft) and light intensities as low as 0.5 µE/m²/sec (4 foot-candles) in a greenhouse.* Tree Planters' Notes 46(1):11-14; 1995.

Many woody plants— especially those native to high latitude, high elevation, or continental climates-are sensitive to photoperiod (Tinus 1976, D'Aoust 1978, Arnott 1979, Tinus 1981, Arnott and Macey 1985, Arnott and Simmons 1985). They tend to have long critical day-lengths (or required light periods) and set bud and become dormant under short days. However, they may be kept growing in height by long days. In greenhouses, provision of light at night (or dark period) is an important tool for maintaining height growth for as long as necessary for the seedlings to reach the desired height (Struve and Blazich 1980, Arnott and Simmons 1985, Landis and others 1992, Lascoux and others 1993).

In the United States, more forest tree nurseries use incandescent lights operated intermittently than use any other lighting system (Eriksson 1978, Terbun 1980, Landis and others 1992), although a variety of other systems have been tried and used successfully (Cathey and Campbell 1975, Johnstone and Brown 1976, Young and Hanover 1977, Wheeler 1979, Cathey and Campbell 1980, Klueter and others 1980, Kraus 1980, Falk 1985, Bartok 1988, Arnott 1989). In spite of their effectiveness and widespread use, incandescent lights are not very efficient for maintaining shoot growth because their spectrum contains substantial farred light (735 nm), which partially reverses the dormancy– preventing effect of red light (660 nm). However, they can be operated intermittently, which saves power, cost, and labor of changing lamps, and have been proven effective (Hassig and Clausen 1977, Tinus and McDonald 1979).

Other lamps in use include high-pressure sodium arc lights. These are highly efficient lamps for lengthening the photoperiod, because their conversion of electricity into light is efficient, the spectrum is concentrated close to the band of maximum effectiveness for dormancy prevention, and they produce little far-red light (Thimjian and Heins 1983, Bartok 1988). They have been found effective at light intensities much lower than those recommended for incandescent lights (Arnott and Macey 1985). However, arc lights cannot be operated intermittently on short cycles because they contain ballasts that require several minutes to warm up when lighted and must cool after being turned off before they can be relighted. Furthermore, turning them on and off repeatedly greatly shortens their lifetime. Intermittent lighting can be achieved by mounting lamps on a moving boom, usually the same one that provides irrigation. This considerably reduces the number of fixtures needed, but there are questions of reliability, because the unit would normally be operating at night unattended.

The objective of this study was to design, construct, and test a device that would make best use of the capabilities of high-pressure sodium arc lamps and provide reliable intermittent lighting.

Materials and Methods

A 400-watt high-pressure sodium arc lamp (General Electric Lucolux) was rigidly mounted on a yoke so that the ceramic cylinder in the center of the bulb, where the arc is produced, was located at the focal plane of a parabolic mirror. A gear motor and drive train oscillated the mirror in a sinusoidal fashion to flick a collimated (that is, with light rays in parallel) beam from one end of the greenhouse to the other and back repeatedly with a cycle time of 1 minute (figure 1). In a large commercial greenhouse, the lamp and mirror assembly would be mounted as high as practical in the middle of the house. In this experiment, only a small 6- x 15-m (20- x 48-ft) research greenhouse was available, so the lamp was mounted at one end of the greenhouse to permit measurement of its effect as far away from the lamp as possible. The lamp operated throughout the dark period each night. Light intensity at various locations in the greenhouse was measured

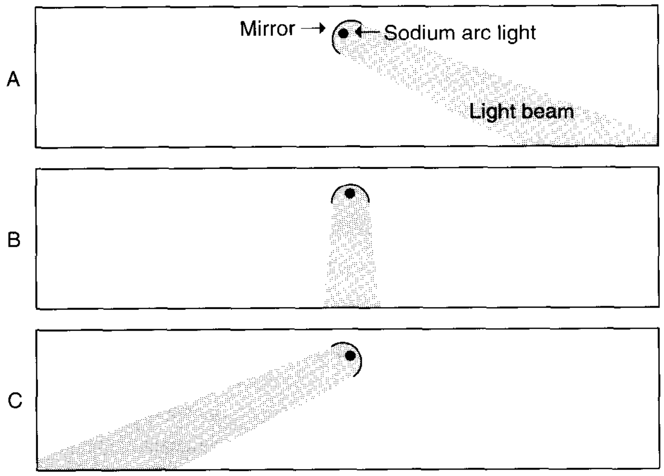

Figure 1—*Longitudinal cross section of a greenhouse. Sodium arc lamp is rigidly mounted high in the center, and the mirror oscillates in orientation from A to B to C to B to A in a 1-minute cycle, flicking the light beam from one end of the greenhouse to the other.*

with a hand-held lux meter and the readings converted to microEinsteins per square meter per second (µE/ m^2/sec) according to Thimjian and Heins (1983).

Blue spruce *(Picea pungens* Englm.) was chosen as a test species because it is highly sensitive to photoperiod and easily goes dormant unless it receives adequate light at night to maintain height growth (Tinus and McDonald 1979). If growth of blue spruce can be maintained by this lighting system, then maintaining growth of other species should not be difficult. McCreary and others (1978) have shown that 22-hour day-lengths were actually optimal for growth of seedlings. Their study, however, used continuous light periods. In this experiment, 24-hour daylengths were used, but plants received intermittent light at 1min cycles throughout the dark period (figure 1).

A crop was seeded May 15, 1990 in 400-ml (25-in^3) Spencer-LeMaire Rootrainers filled with a peatvermiculite mix. There were 20 cavities to a tray. Twenty-one trays were arranged in rows of 3 trays each at regular intervals from one end of the greenhouse, directly under the sodium arc lamp, to the other end as far from the lamp as they could be placed. Within rows the 3 trays were placed on the floor at the center of the greenhouse, the outer side wall, and halfway in between. Each night the trays were covered with polyethylene bags that were removed in the morning. Within each row, two of the bags were clear (transparent) and the third was black (opaque), and their location was randomized. This provided the seedlings with a nighttime environment that was uniform in temperature and humidity but either exposed the seedlings to the light or completely shielded them from it.

The trees were grown under day (light period) temperatures of 20 to 22 °C (68 to 72 °F) and night (dark period) temperatures of 11 to 13 °C (52 to 56 °F). Suboptimal night temperatures (Tinus and McDonald 1979) were chosen to further increase the sensitivity of the trees to inadequate light at night. Greenhouse humidity and irrigation and fertilization of the seedlings were appropriate for maintenance of the rapid growth phase of blue spruce (Tinus and McDonald 1979). Total height was measured and terminal budset noted in mid-September, October, and November 1990, and January 1991.

Results and Discussion

Light intensity was greatest directly under the lamp and least at the far end of the greenhouse (figure 2). However, the duration of illumination was shortest directly under the lamp and longest at the far end of the greenhouse. (This was observed but not measured.) The reciprocal relation of light intensity and illumination time was expected to help produce a more uniform plant response throughout the house.

Trees shielded from the light had stopped growing in height by the time of the first measurements in September (figure 3) and were setting buds (figure 4). At this time the proportion of trees setting bud gener-

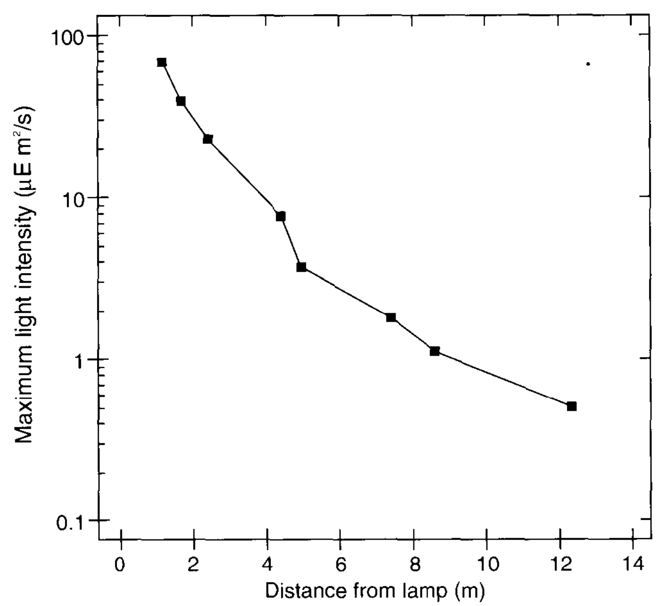

Figure 2—*Maximum light intensity versus distance from the lamp. First data point at the left is directly beneath the lamp, and the last is at the far end of the greenhouse.*

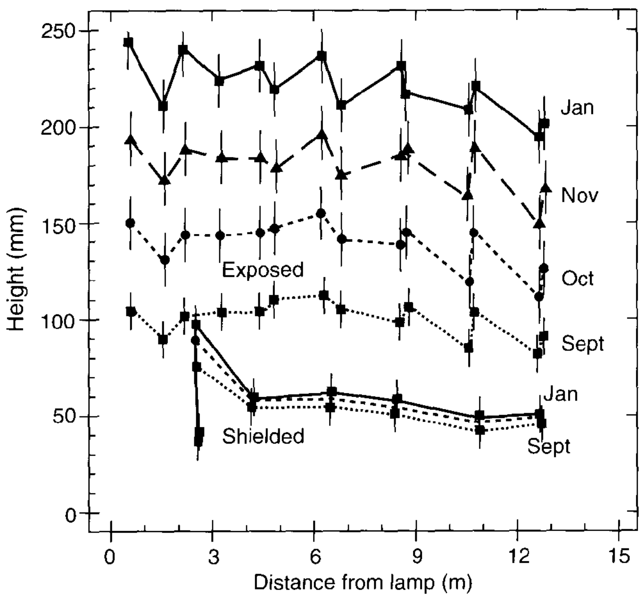

Figure 3—*Blue spruce height as a function of age and distance from the sodium arc lamp. Data points in the same vertical column are the same seedlings measured on successive dates. For each date, points are connected to show the effect of distance from the lamp on height. Seedlings exposed to the light continued height growth, while those shielded from it had stopped height growth by September. Error bars are the 95% interval, and where they do not overlap, the data points are deemed significantly different.*

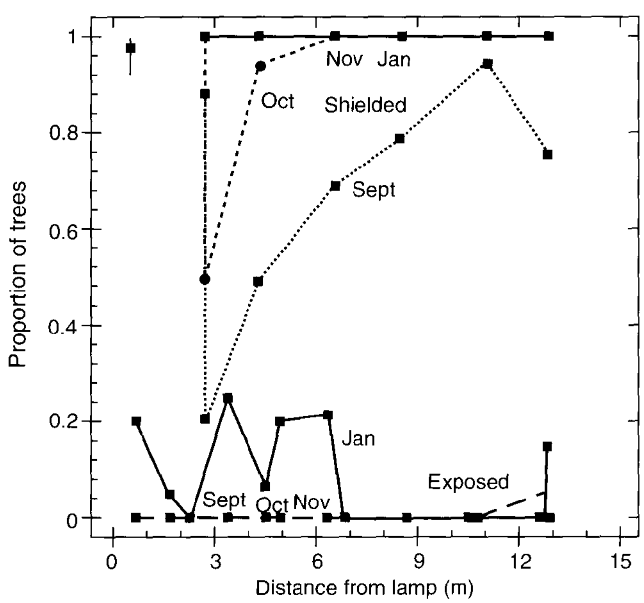

Figure 4—*Proportion of blue spruce that had set a dormant bud at successive dates, either exposed to or shielded from the light.*

ally increased with distance from the lamp, suggesting that the black bags were not entirely opaque. Budset was complete by November.

In contrast, the trees exposed to the light continued to grow in height through January (figure 3). At the far end of the greenhouse, seedlings may have been slightly shorter compared to seedlings close to the lamp, but one-way ANOVA's at each measurement date failed to show enough pairwise differences to consider the shortening significant. Budset was just beginning in January and was not significantly related to distance from the light (figure 4). The beginning of budset in spite of adequate light at night may have been caused by the seedlings becoming too large for the container volume and spacing, thus restricting growth.

Omi and Eggelston (1993) compared the effects of a 400-watt sodium arc lamp with oscillating mirror with conventional intermittent incandescent lighting on seven conifer species (with both determinate and indeterminate growth patterns) in 9- x 30-m (30- x 100-ft) greenhouses at the USDA Forest Service Coeur d'Alene Nursery. Although there were species differences, growth and morphology were generally adequate to meet regional standards under both types of light and at sodium arc light intensities as low as 1 µE/ m^2/sec (8 foot-candles).

Conclusions

A single 400-watt high-pressure sodium arc lamp with an oscillating parabolic mirror providing intermittent light proved effective in preventing bud dormancy in blue spruce. Light intensities up to 13 m (43 ft) from the lamp, measuring 0.5 µE/m^2/ sec (4 foot-candles) were able to prevent budset. This light level is considerably lower than currently recommended for intermittent incandescent lights (Arnott and Macey 1985, Landis and others 1992). Not only can the sodium arc lamps replace large banks of incandescent lights, but they are easy to install— you can "hang them up and plug them in"— and inexpensive to operate.

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Nitrogen Fertilization Requirements of Douglas-fir Container Seedlings Vary by Seed Source

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Growth of container Douglas fir (Pseudotsuga menzesii *(Mirb.) Franco) from different seed sources from western Washington to western Montana was evaluated following application of 100, 150, or 200 ppm nitrogen (N) during the rapid growth phase. The optimal level of N varied between seed sources for height, caliper, and bud growth, as well as for shoot-to-root ratio. Target seedling specifications were met adequately for the westernmost sources at 100 and 150 ppm N, whereas eastern sources required 150 or 200 ppm. Nitrogen levels should thus be tailored to individual Douglas fir seed sources to maximize the number of shippable seedlings per lot.* Tree Planters' Notes 46(1): 15-18; 1995.

Nitrogen is the mineral nutrient that most affects seedling growth rate, and controlling N fertilization levels is an important cultural tool in container nurseries. Prescribed N levels in the published literature have varied tremendously over the years, ranging from as low as 50 ppm to as high as 300 ppm, with recent guidelines of 150 ppm for container tree seedlings (Landis and others 1989). However, nitrogen fertilizer rates need to be determined for individual species at each nursery prior to starting a fertilization program.

We know that seedlings from different seed sources often exhibit variable growth rates because of their individual response to the nursery environment. Applying one nitrogen fertilization rate for all seed sources of a particular species in a nursery may prevent individual seed sources from realizing their full growth potential or result in growth imbalances. Tailoring nitrogen regimes to the needs and potentials of individual seed sources can allow the grower to produce a more desirable seedling. Conversely, if the nutritional needs of different sources are quite similar, it may make better operational sense to apply one nitrogen rate to all sources and accept slightly less than optimal growth in some lots.

The objective of this study was to compare the growth response of Douglas-fir seedlings from six seed sources to three nitrogen regimes and determine the optimal regime for each source. Sources ranged in longitude on an west-to-east gradient and in elevation, from 914 m (3,000 ft) of elevation on the west side of the Cascade Range (Enumclaw, Washington) to 1,645 m (5,400 ft) of elevation in the Rocky Mountains (Seely Lake, Montana) (figure 1).

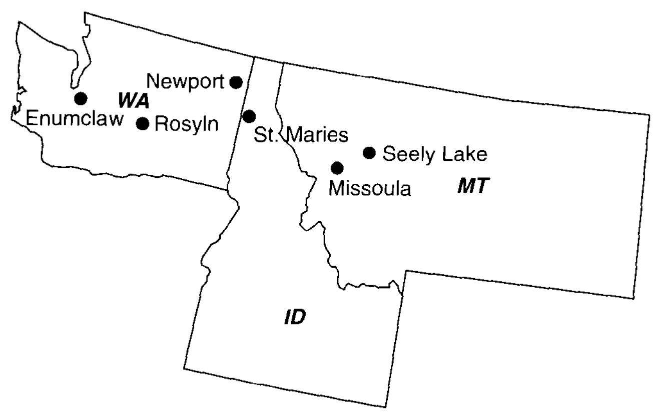

Figure 1—*Location of seed sources in the Pacific Northwest.*

Methods

Six lots of Douglas-fir from seed sources in Washington, Idaho, and Montana were grown at the Plum Creek container nursery at Pablo, Montana, under three different regimes of nitrogen supplementation: 100 ppm, 150 ppm, and 200 ppm. In total, the six seedlots and the three nitrogen rates resulted in 18 different treatments, one block each (160 seedlings/ block).

Three "Styro-4" Styrofoam® block containers (approximately 65.5 cm^3, or 4 in^3 in volume) were sown for each seed source, and one block container of each seed lot was grown under each of the three N rates. All six seed-source test blocks were placed together on the same bench in three different greenhouses and were grown with an operational crop of seedlings under one of the three N rates. The test blocks were placed in the interior of the greenhouse benches to minimize environmental effects. In this nursery it was common practice to use different N rates for different species: western larch (*Larix occidentalis* Nutt.) was grown at 100 ppm N, Englemann spruce *(Picea engelmannii* Parry ex Engelm.) at 150 ppm, and western white pine (*Pinus monticola* Dougl. ex D. Don) at 200 ppm N.

Seed was sown on March 29, 1989, in W.R. Grace Forestry Mix C media. All seedlings were provided a complete liquid fertilizer regime that had been custom-formulated to supply all 13 essential mineral nutrients. The fertilization regime consisted of 3 phases. During the establishment phase, the seedlings were given three applications of **starter feed** at the same N rate (80 ppm N) beginning about 2 weeks after sowing. The three different N levels began with the **growth feed** applications (table 1) approximately 3 to 4 weeks after sowing and continued for about 14 to 15 weeks until the target shoot height was reached. To initiate the hardening phase, all seedlings were leached twice with a **fresh water rinse** for 2 hours and then given a lowN **hardening-off feed** applied to all treatments with the next irrigation and continued through the end of the growing season in December.

Twenty-five seedlings randomly chosen from each treatment group were removed towards the end of the growing season and sent to International Paper Company's Seedling Testing Service in Lebanon, Oregon, for morphological measurements: shoot height, stem caliper, bud height, and shoot and root weights (table 2). Statistical significance between treatments for these attributes was determined using analysis of variance, Duncan's multiple range test, and t-tests.

Results and Discussion

Towards the end of the growing season, size differences between the seed sources became evident, and this was verified by the morphological analyses.

Shoot height. Seedling shoot height varied between the 6 seed sources and 3 N treatments (figure 2). For all seed sources, height increased with increasing N rates, although seedlings grown from seed from the westernmost source (Enumclaw, Washington) were consistently the tallest at all fertilization rates. Height response was more variable in the sources from eastern Washington, Idaho, and Montana. With respect to the target height specification, the best N fertilization level varied between the western and eastern sources. For example, 100 ppm N was adequate for Enumclaw, WA, Roslyn, WA, and St. Maries, ID, but 150 ppm was better for the 3 easternmost seed sources. For all seed sources, the 200-ppm N rate was excessive because it caused seedlings to grow too tall, creating problems with seedling balance and survival after outplanting.

Table 1—*Custom fertilizer recipes for growth feed at the three nitrogen test rates**

Medium (150-ppm) nitrogen rate (150:40:150)†
Add water to following ingredients to each tank to make 55 gallons:

Tank A		
Calcium nitrate	40	lb
Potassium nitrate	35	lb
Ammonium nitrate	12.5	lb
Iron chelate	2	lb
Manganese chelate	1	lb
Tank B		
Magnesium sulfate	20	lb
Micronutrient conc.	1	gal
Phosphoric acid	4	liters
Sulfuric acid	500	ml

High (200-ppm) nitrogen rate (200:40:150)

Tank A—Increase ammonium nitrate to 25 lbs
Tank B—Same as above

Low (100-ppm) nitrogen rate (100:40:150)

Tank A—Omit ammonium nitrate entirely
Tank B —Same as above

* = *For use with 1:200 injector (1 part concentrate to 200 parts water).*
† = *ratio of* $N:P_2O_5:K_2O$.

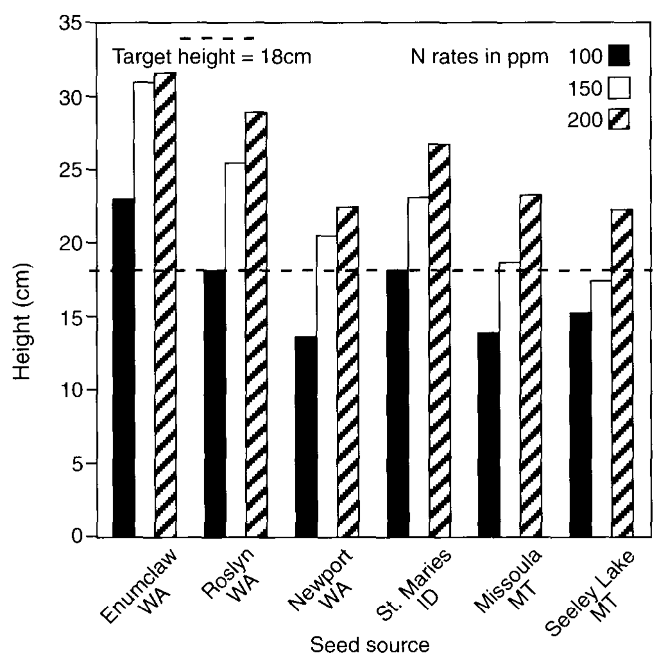

Figure 2—*Height growth of Douglas-fir container seedlings from various seed sources in response to three levels of N fertilization.*

Table 2-*Morphological quality indices of 6 Douglas-fir seed sources at 3 different nitrogen fertilizer rates*

Seed source/ N rate (ppm)	Shoot height (cm)	Stem caliper (mm)	Bud height (mm)	Ovendry weights Shoots (g)	Ovendry weights Roots (g)	Shoot:root ratio
Enumclaw, WA						
100	23.1 a	3.2 a	5.3 a	1.36	0.87	1.56
150	31.2 b	3.5 b	5.8 b	1.96	0.95	2.06
200	31.8 b	3.9 c	5.5 ab	2.57	1.19	2.16
Roslyn, WA						
100	18.1 a	2.9 a	5.6 a	1.00	0.86	1.16
150	25.5 b	3.1 b	6.5 a	1.08	0.86	1.26
200	28.9 c	3.6 c	5.5 a	2.38	1.15	2.07
Newport, WA						
100	13.7 a	2.7 a	5.4 a	0.62	0.64	0.97
150	20.5 b	3.2 b	5.6 a	1.10	0.89	1.24
200	22.5 b	3.4 b	4.9 b	1.41	0.94	1.50
St. Maries, ID						
100	18.0 a	2.7 a	5.5 a	0.90	0.79	1.14
150	23.1 b	3.5 b	5.7 a	1.48	1.22	1.21
200	26.6 b	3.6 b	4.7 b	1.70	1.11	1.53
Missoula, MT						
100	13.8 a	2.9 a	5.3 a	0.69	0.76	0.91
150	18.7b	3.3b	5.7 a	1.13	0.99	1.14
200	23.2 c	3.5	4.5 b	1.43	0.96	1.49
Seely Lake MT						
100	15.1 a	2.8 a	5.4 a	0.80	0.73	1.10
150	17.3 b	3.2 b	5.6 a	1.00	0.92	1.09
200	22.1 c	3.6 c	5.2 a	1.62	1.02	1.59

Note: values for shoot height, stem caliper, and bud height in columns for each site followed by different letters differ significantly according to t-tests.

Stem caliper. The nitrogen fertilization treatments did not have as dramatic an effect on stem caliper. For each source, the stem caliper increased with increasing N fertilizer and even the lowest 100-ppm N rate produced seedlings that met the 2.5-mm target specification for all seed sources (figure 3). Growing seedlings with too much caliper is not a problem, because it is widely accepted that the larger the seedling caliper the better survival and growth (Mexal and Landis 1990). Nitrogen does affect stem caliper indirectly, however, because excessive N fertilization produces seedlings that are too tall in proportion to the size of the stems and root systems.

Shoot-to-root ratio and bud size. The ratio of the size of the seedling shoot to the size of the root system is important to seedling survival, especially on dry outplanting sites. In this trial, all treatments produced a good shoot-to-root (S:R) ratio of 2:1 or less, although

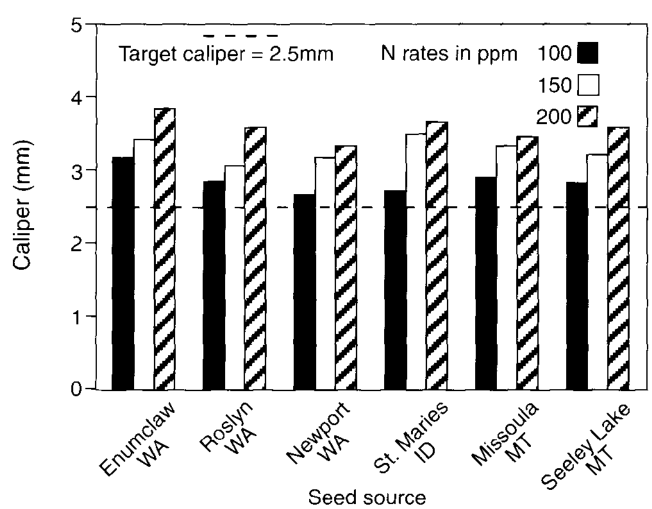

Figure 3—*Caliper growth of Douglas-fir container seedlings from various seed sources in response to three levels of N fertilization.*

on the drier sites in Montana a shorter, stockier seedling with a S:R ratio closer to 1:1 may survive and grow better. The height of the dormant terminal bud is another index of seedling quality, and the larger the bud the better (Thompson 1984). Bud height was greatest at the 150 ppm N rate and, for five of the six seed sources, lowest at 200 ppm.

Percentage of shippable seedlings. The effect of each nitrogen regime was also evaluated by the percentage of seedlings in each treatment that exceeded cull standards, which are the minimum acceptable size for shipping. The number of shippable seedlings is an quality index of seedling morphology, including height, caliper, root size and bud development. At Plum Creek Nursery, the goal was to produce 93% shippable seedlings. The Washington and Idaho seed sources achieved this goal at either 100 or 150 ppm N. The Montana sources exhibited considerable variation in shoot height however, and so the desired percentage of shippable seedlings was achieved only at the 200-ppm N rate.

Summary

Not surprisingly, seed sources of container Douglas-fir seedlings responded differently to different rates of nitrogen fertilization. The best N level for seedlings from western Washington sources (west of the Cascade Range) was 100 ppm because seedlings grew too tall at the higher fertilizer rates. For seed sources in eastern Washington and Idaho, the best N fertilization rate was 150 ppm. For the more variable Montana sources, the highest fertilization rate of 200 ppm N was used operationally at Plum Creek Nursery. This preliminary study indicates that container nurseries should consider seed source differences in N requirements when developing their growing schedules, and customize the rates to meet the demands of different species and seed sources. Each nursery may want to test its own species and seed sources to determine operational N levels.

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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-

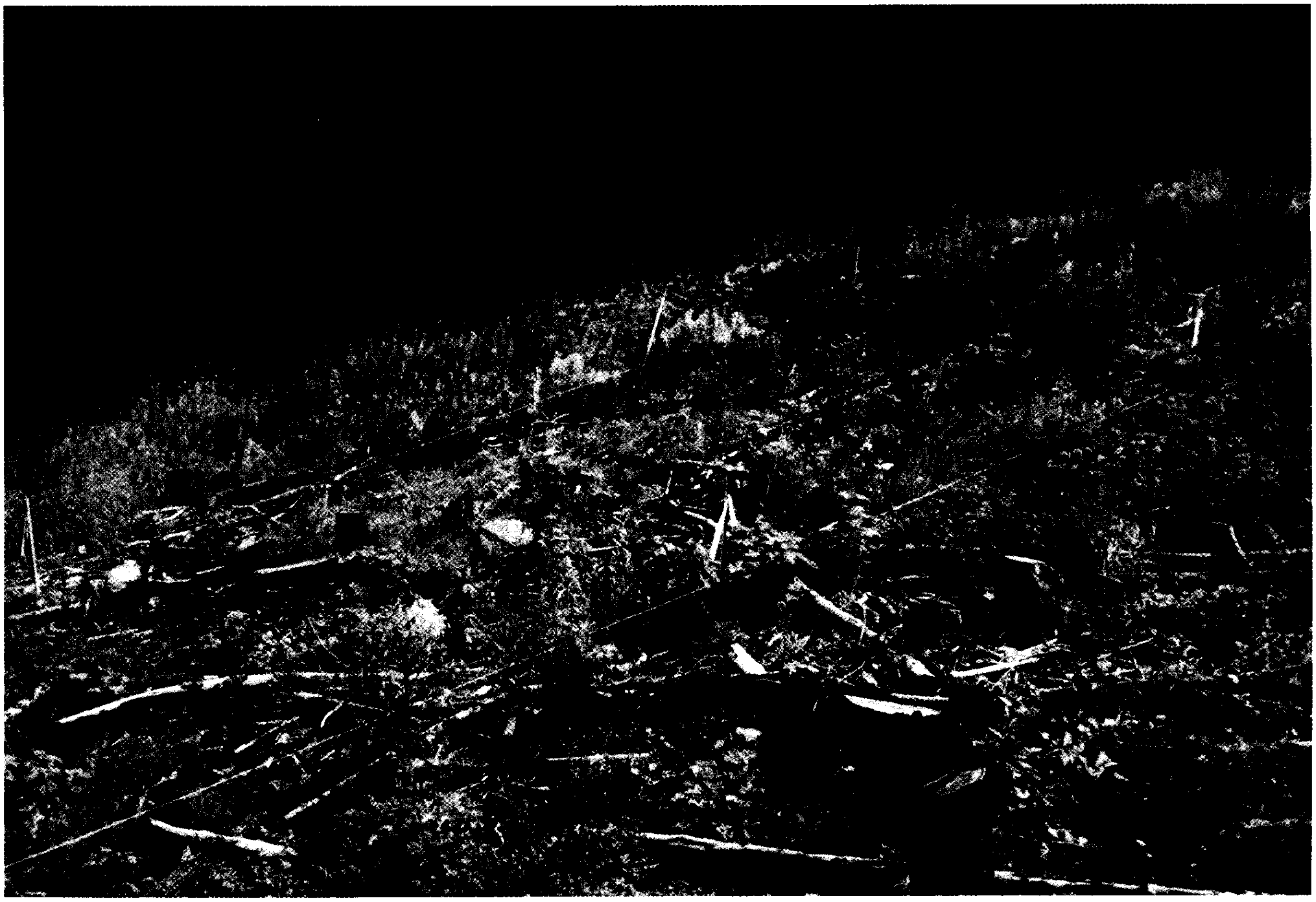

Figure 1— One of the test sites.

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

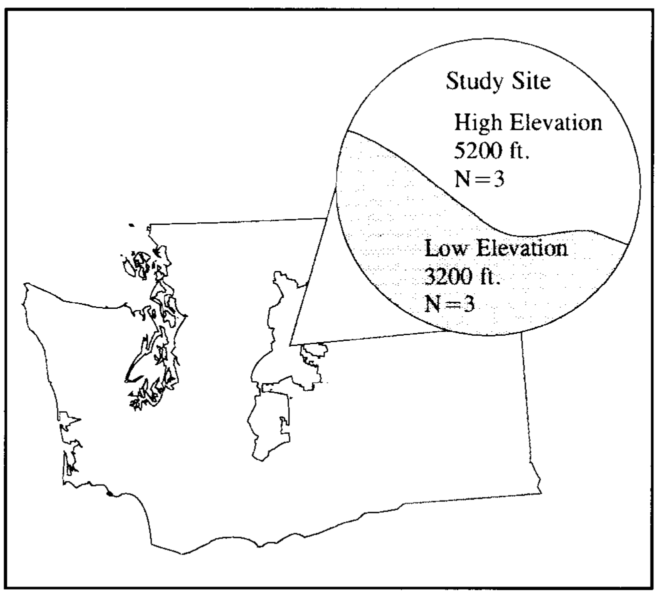

Figure 2—*Location of the test sites in the Wenatchee National Forest, Washington.*

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).

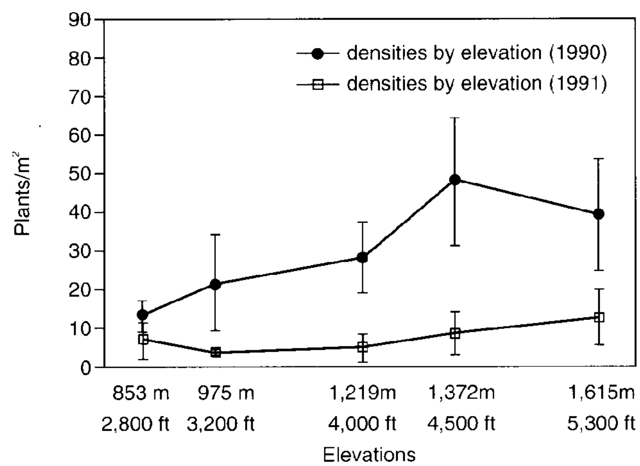

Figure 3—Density counts of legume species combined and compared across elevations during 1990 and 1991 (P = 0.05).

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.

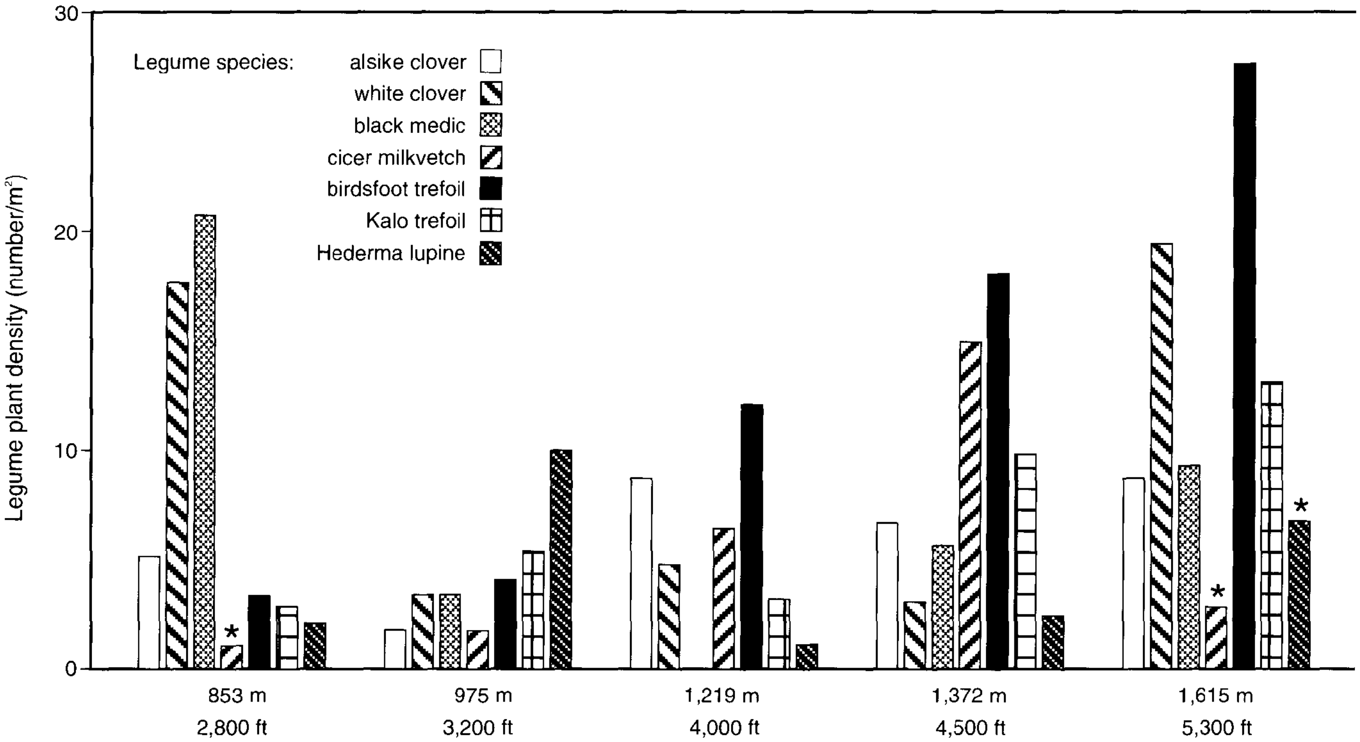

Figure 4—*Legume densities for each species at each site in 1991. Bars marked with an asterisk (*) showed significantly (P = 0.05) fewer plant numbers than most successful species at each site.*

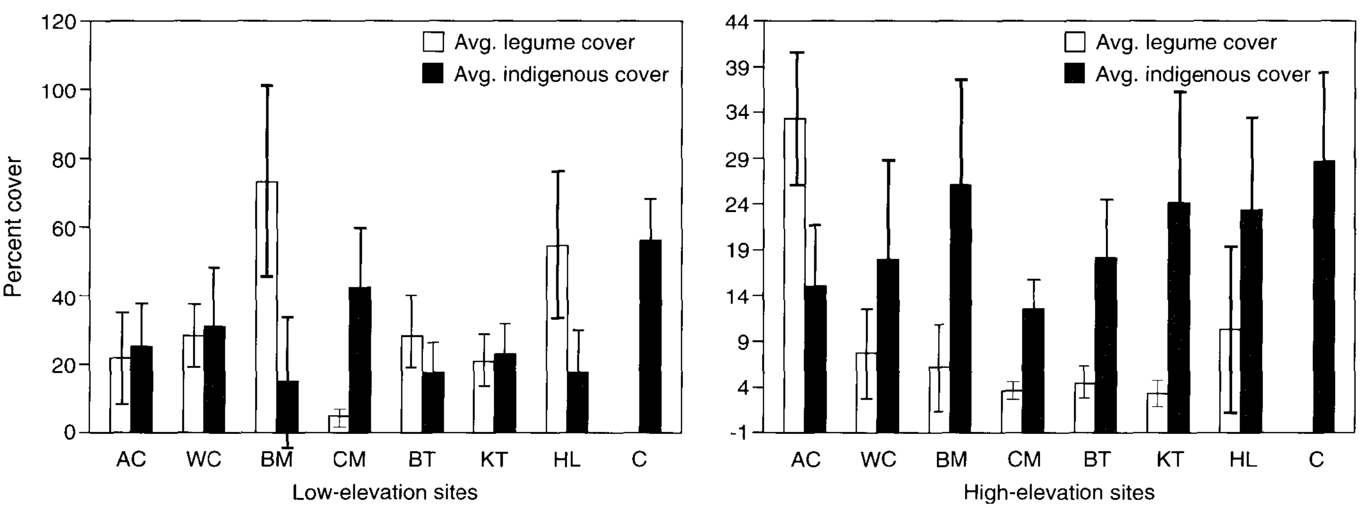

Figure 5—*Legume and indigenous cover compared to unplanted controls at low and high elevations (P = 0.05) in 1991. Species: AC = alsike clover, WC = white clover, BM = black medic, CM = cicer milkvetch, BT = birdsfoot trefoil, KT = Kalo trefoil, HL = Hederma lupine, C = control.*

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.

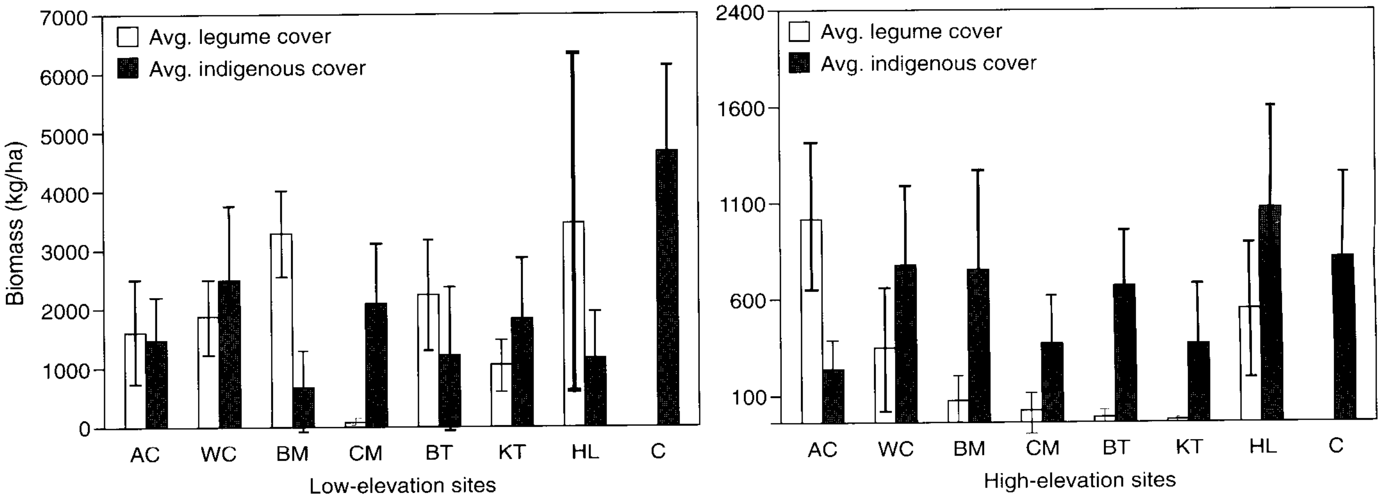

***Figure 6**—Legume and indigenous biomass compared to unplanted controls at low and high elevations (P = 0.05) in 1991. Species: AC = alsike clover, WC = white clover, BM = black medic, CM = cicer milkvetch, BT = birdsfoot trefoil, KT = Kalo trefoil, HL = Hederma lupine, C = control.*

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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Survival and Growth of Planted Loblolly Pine Seedlings on a Severely Rutted Site

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Survival and growth of planted loblolly pine (Pinus taeda *L.) seedlings on a severely rutted site were evaluated over a 3-year period. The soil rutting caused by wet weather logging of the previous stand was divided into three categories of severity (severe, moderate, and light). Four plots, each containing 15 planted seedlings, were monitored for each of the severity categories. Seedling survival was actually greater in the severely rutted plots, probably because competition was reduced by the logging disturbance. However, during the second growing season, height and diameter growth of seedlings in the severely rutted areas was 26 and 21%, respectively, less than that of seedlings in the other two categories. By the end of the third growing season, cumulative height growth was 17% less on the severely rutted plots than on the other two categories.* Tree Planters' Notes 46(1):28-31; 1995.

Wet weather logging with ground equipment usually causes more soil disturbance than similar activities during dry periods (Hatchell and others 1970, Moehring and Rawls 1970, Reisinger and others 1988). Soil compaction and rutting displacement are frequent consequences of operating heavy equipment on wet soils that have reduced strength. Deep rutting displacement occurs when loads applied by wheeled equipment exceed the ability of the soil to support the resulting stress. The situation is further aggravated when four-wheel-drive articulated-frame tractors (typical of wheeled logging skidders) are used, and the rear wheels track in the same path made by the front wheels. The resulting ruts can last for many years, forming potential barriers that interfere with shallow root development. Because most fine tree roots occupy the near-surface soil layers, deep ruts may reduce forest productivity (Moehring and Rawls 1970). Seedlings growing some distance from the ruts may be affected, so that the effect may be greater than the area covered by ruts might indicate. Seedlings that are partially submerged for extended periods in surface water in the ruts also may show reduced growth. In this study, we evaluated the effects of deep rutting on survival and growth of planted loblolly pine *(Pinus taeda* L.) seedlings.

Methods

Study site. The study area was located in a recently logged site in northern Louisiana. Soils of the study area were classified as fine-loamy, siliceous, thermic Typic Paleudults (Soil Survey 1975). The soils are well drained, moderately permeable, strongly acid, low in natural fertility, and moderate in available water capacity. The A and E horizons have sandy loam textures, and the B_t1 is clay loam.

A loblolly pine stand was conventionally harvested on the site using chainsaws for felling and rubber-tired skidders for primary transport. The logging activity occurred during an unusually wet period in late June 1990. Precipitation for the month totaled 13.8 cm (5.4 in), 53% above the 30-year mean for that month. The soils were at or near saturation at the time of the logging activity, and the wheeled skidders created deep ruts on the primary skidtrails and lesser ruts on secondary skidtrails. No attempts were made to restore the rutted areas after the logging activity ceased. Site preparation consisted of herbicide application followed by burning to control competing hardwood vegetation. The site was replanted by hand with 1+0 bareroot loblolly pine seedlings during January 1991 at a 2.5- x 2.5-m (8- x 8-ft) spacing.

Study plots were established on the site during early March 1991. Three categories of rutting severity were identified— severe, moderate, and light. Most severe rutting occurred on primary skidtrails and was typified by deep ruts (figure 1) and considerable subsoil exposure (red B_t soil horizon). Most moderate rutting occurred on secondary skidtrails with clearly identifiable ruts, but little subsoil exposure. Light rutting occurred away from the main skidtrails and consisted of shallow ruts caused by a single pass of a skidder.

Figure 1—*View of a severely rutted area.*

Four plot centers (figure 2) were established in areas of each rutting severity category. The nearest 15 planted seedlings to the plot center were marked with wire flags and numbered tags (figure 3). Seedling location, relative to nearby ruts, was also recorded.

Seedling measurements. Each seedling was measured for height and groundline diameter at the beginning of the study before growth initiation, and again at the end of the first, second, and third growing seasons. First-year growth was calculated as the difference between the respective measurements for each tree at the beginning and end of the first growing season. Second-year and third-year growth was similarly calculated using the differences between measurements at the end of the previous and current growing seasons. Total 3-year growth was calculated as the sum of the growth in the first, second, and third growing seasons. Seedling survival was determined at the end of each growing season.

Figure 2—*Plot center in severely rutted area.*

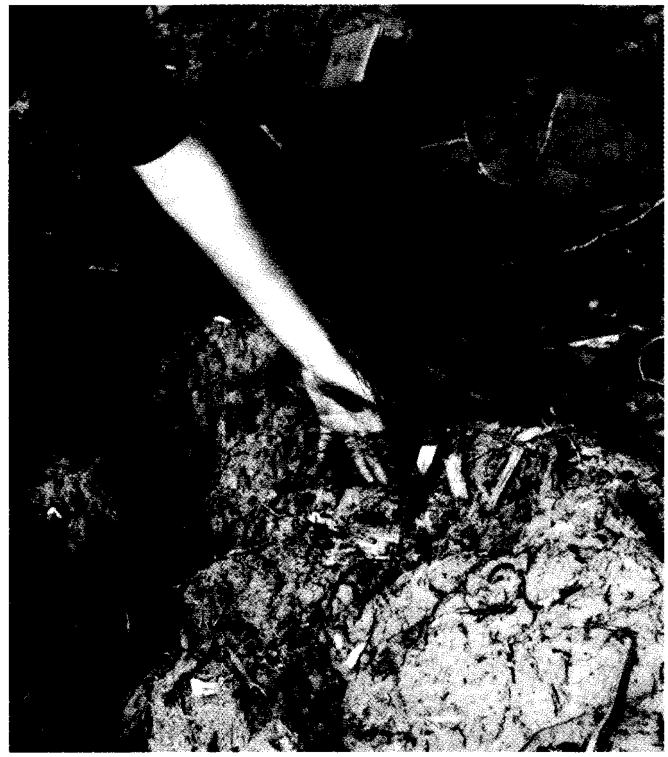

Figure 3—*Seedling growing on a berm showing flag and tag.*

Soil physical properties. Three representative ruts in each plot were measured for depth and width dimensions at the beginning of the study. The rutted microtopography was divided into three descriptive categories— ruts, berms (the frequently uplifted and disturbed edges of the ruts), and flats (the unrutted and relatively undisturbed areas of the plots). A soil bulk-density sample was taken, using a cylinder core sampler, from each of the microtopography positions on each plot, producing nine samples per plot.

Data analysis. Tree height and diameter growth data for the rutting severity categories and microtopography positions, and soil bulk density values were analyzed using analysis of variance and Tukey's mean separation procedure. Seedling survival data were analyzed using chi-square tests.

Results and Discussion

Rut characterization. Mean rut widths ranged from 67 cm (26 in) on the lightly rutted plots to 77 cm (30 in) on the moderately and severely rutted plots. Mean rut depths were 12, 20, and 24 cm (4.7, 7.9, and 9.4 in) on the light, moderate, and severe rutted plots, respectively. Soil bulk densities were significantly greater in the berm and rut microtopography positions compared to the relatively undisturbed flats (table 1).

Table 1 -*Mean soil bulk density values after harvesting on flats, berms, and in ruts on three levels of rutting intensity*

Rutting intensity	Soil bulk density (g/cm^3)		
	Flat	Berm	Rut
Light	0.91 a	1.06 a	0.96 a
Medium	1.00 a	1.22 ab	1.13 a
Severe	1.03 a	1.29 b	1.24 a

Note: Means in a column followed by the same letter are not significantly different at the 0.05 level of probability.

However, with the exception of berms, there was no significant difference in soil bulk densities among rutting intensities, probably due to a combination of three factors. First, the greatest increase in soil bulk density occurs during the first pass of heavy equipment. Repeated passes increase bulk density at decreasing increments (Hatchell and others 1970, Burger and others 1985). Secondly, because these soils were saturated during the disturbance, this moisture content was probably higher than the critical level that would result in maximum compaction (McKyes 1989). Finally, the sample size may have been inadequate to provide for detection of small differences among rutting intensities.

Seedling survival and growth. Seedling survival was not significantly different among the three rutting severity categories at the end of the first growing season (table 2). By the end of the second growing season, however, significant differences in survival among the rutting intensities did exist. Unexpectedly the highest survival was in the severely rutted areas. One possible explanation is that the greater soil disturbance on the rutted plots reduced the number of competing plants and thereby enhanced seedling survival. This also indicates that soil displacement from rutting, even when severe, does not impact survival of planted loblolly pine seedlings. However, during the first two growing seasons, favorable precipitation patterns existed, providing good survival conditions for the newly planted seedlings.

Rutting severity did not significantly affect seedling height or diameter growth during the first growing season (table 3). However, height and diameter growth during the second growing season was reduced by 26 and 21 %, respectively, on the severely rutted areas compared to the lightly rutted areas. Cumulative height growth over three growing seasons was reduced 17% on the severely rutted areas (figure 4).

Within each of the rutting severity categories some seedlings were planted on the undisturbed flat areas between ruts, others were located in berms immediately adjacent to ruts, and others were planted directly in ruts. To determine the effect of these microtopography positions on seedling survival and growth, data for these three locations, combining the three rutting severities, were compared (table 4). Seedling survival after three growing seasons was not different among microtopography positions. Seedling mean height was 15.6% lower among trees planted in ruts than those on undisturbed flats, but the difference was not statistically significant, probably due to insufficient sample size in the rut located seedlings. Trees growing on berms were intermediate in growth.

Table 2-*Survival (number and percentage of original number) of loblolly pine seedlings at the end of the first, second, and third growing seasons*

Rutting intensity	Year 1		Year 2		Year 3	
	No.	%	No.	%	No.	%
Light	48	80	43	72	43	72
Moderate	53	88	53	88	53	88
Severe	56	93	56	93	54	90

Note: Chi-square *P*-values were 0.09, 0.003, and 0.01 for years 1, 2, and 3, respectively.

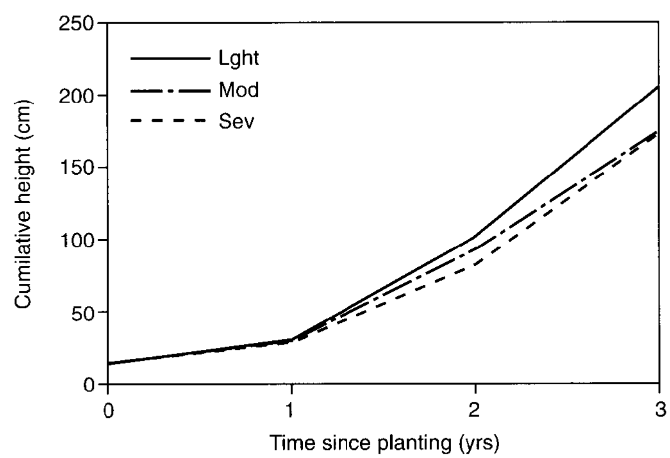

Figure 4—*Cumulative height growth of planted loblolly pine seedlings on areas of three intensities of rutting soil disturbance.*

Table 3-*Height and diameter growth over 3 years of planted loblolly pine seedlings on three different intensities of rutted soil*

Rutting severity	Year 1		Year 2		Year 3		Total	
Height	(cm)	(in)	(cm)	(in)	(cm)	(in)	(cm)	(in)
Light	15.4 a	5.9	70.4 a	27.7	98 .1 a	38.6	185.8 a	73.1
Moderate	16.4 a	6.5	60.7 ab	23.9	88.0 ab	34.6	155.8 b	61.3
Severe	13.2 a	5.25	2.0 b	20.5	79.6 b	31.3	153.7 b	60.5
Diameter	(mm)	(in)	(mm)	(in)	(m m)	(in)	(mm)	(in)
Light	1.9 a	0.07	12.5 a	0.49	22.3 a	0.88	35.7 a	1.41
Moderate	1.9 a	0.07	9.5 b	0.37	19.3 a	0.76	30.6 b	1.20
Severe	2.1 a	0.08	9.9 ab	0.39	20.8 a	0.82	32.9 ab	1.29

Note: Means in a column followed by the same letter are not significantly different at the 0.05 level of probability.

Table 4-*Three-year survival, height, and diameter growth of planted loblolly pine seedlings on flats, berms, and in ruts*

Seedling location	No. seedlings planted	% survival	Height		Diameter	
			cm	in	cm	in
Flat	79	86	71.3 a	67.4	13.0 a	5.1
Berm	62	81	165.4 a	65.1	13.1 a	5.2
Rut	39	82	144.5 a	56.9	10.0 a	3.9

Note: Means in a column followed by the same letter are not significantly different at the 0.05 level.

Conclusions

Severe rutting of forest sites should be avoided because of probable site productivity decline, as well as for apparent aesthetic reasons. Harvesting and site preparation operations should be carried out when the soils are dry enough to prevent rutting or with specialized equipment that minimizes soil displacement. On severely rutted sites, seedlings should probably not be planted directly in the ruts themselves to avoid possible growth reductions.

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