

# Establishment of Coastal Douglas-fir Orchards

REFEREED PAPER

Keith J.S. Jayawickrama, Jim A.J. Smith, and Michael S. Crawford

*Director, Northwest Tree Improvement Cooperative, Department of Forest Ecosystems and Society, Oregon State University, Corvallis, OR; Geneticist, Plum Creek Timber Company, Cottage Grove, OR; Seed Orchard Program Manager, Travis Tyrell Seed Orchard, Bureau of Land Management, Lorane, OR*

## Abstract

Successful and cost-effective establishment of coastal Douglas-fir orchards is crucial for delivering genetic gain from tree improvement programs to the forest growers of western Oregon and Washington. Aspects of site selection, site preparation, grafting, planting, and early aftercare are described.

## Introduction

Coastal Douglas-fir is the most important timber species in western Oregon and Washington. The total reforestation need for this species for these two States currently exceeds 60 million seedlings per year. About 50 yr from the establishment of the very first seed orchards (Wheat 1969), and long after many of the grafted clonal orchards were established in the 1980s and 1990s, this demand is met almost entirely from seed orchard seed, which is now the industry standard.

There are several reasons to compile information now on establishing coastal Douglas-fir orchards in a usable and accessible format:

- Each year, older first-generation Douglas-fir seed orchards are being phased out, and new 1.5-generation or second-cycle production orchards and third-cycle breeding orchards are being established rapidly. For example, a survey of orchardists indicated that about 25,000 grafts were made in winter 2008–2009 in Oregon and Washington; at planting densities of 100 to 400 grafted trees per acre, that would translate to 62 to 250 ac of orchards (Jayawickrama, unpublished data).
- The ability of genetic improvement programs to deliver substantial gains has been established through realized genetic gain trials (e.g., St. Clair and others

2004) and comparison of full-sib crosses with woods-run lots in advanced-generation trials.

- In a competitive world wood market, forest growers need to keep costs under control. Seed costs being a component of reforestation expenses, information that helps reduce or manage seed production costs will benefit forest growers in the Pacific Northwest.
- The economic viability of a seed orchard depends on seed production. Effective and efficient management that shortens the time interval to the first seed crop, increases seed production per acre, or both will increase the profitability of the orchard.
- As better genetic material becomes available from breeding and testing programs, the time value of money even at moderate discount rates creates a strong incentive to replace production from older, lower gain orchards with seed from new, higher gain orchards as soon as reasonably possible.
- After a boom in the 1970s to 1980s, investment in seed orchard research has greatly diminished; at the same time, many experienced orchardists from that era either have retired or will soon retire. Yet very little has been published on the establishment of coastal Douglas-fir orchards, especially recently. For example, the Industrial Forestry Association (IFA) Tree Improvement Newsletter, a serial that documented advances in cooperative tree improvement, was discontinued 24 yr ago.

It is therefore desirable to compile the research and operational knowledge available at this time of transition to aid a new generation of seed orchardists, who will undoubtedly operate with smaller budgets and higher expectations than their predecessors. This article documents the establishment of an orchard up to the beginning of stimulation and seed production.

## Expected Seed Production per Acre and Sizing New Orchards

Just as expected demand and production capacity are determined before an industrial plant is designed, it is necessary to project future seed needs and seed production before establishing an orchard. The first of these is far from trivial, with harvest rates and locations fluctuating in ways hard to predict due to variation in log prices, leading to increased harvests as log prices increase and the opposite as prices decrease; land acquisition and sales; and catastrophic events, such as summer fires and winter storm blowdown. Seed needs from a given orchard can also depend on availability of alternative appropriate sources of seed. The second is equally challenging because precise predictions of seed production (i.e., a seed production model) have not been published. Overestimating future seed production can result in shortages of high-gain seed for many years, with a resulting high opportunity cost; at the other extreme, underestimating production can result in building excess orchard capacity and incurring unnecessary costs.

With an initial planting density of 200 ramets per acre (480 ramets ha<sup>-1</sup>), we can expect seed production on a productive site to begin around 5 yr<sup>-1</sup> from grafting and to increase to about 25 lb ac<sup>-1</sup>yr<sup>-1</sup> or 27 kg ha<sup>-1</sup>yr<sup>-1</sup> (50 lb ac<sup>-1</sup> or 54 kg ha<sup>-1</sup> per harvest, assuming stimulation of the orchard every 2 yr) between age 10 and age 15 from grafting. (A ramet is a grafted tree, obtained by grafting a branch or *scion* of a desirable tree onto the base of a seedling called a *rootstock*.) Planting at this spacing will result in the orchard needing to be rogued at around age 10. The maximum harvests reported from mature orchards (20 yr or older) are about 80 lb ac<sup>-1</sup> (87 kg ha<sup>-1</sup>) per harvest. This kind of production is not guaranteed and will not occur every year or on every site. In rare years such as 2005, seed production can drop to almost zero on a regional scale (typically due to weather conditions that hamper development or pollination of cones).

## Planning the Orchard Life-Cycle

As is the case for any major business investment, it is advisable to calculate the expected useful/productive life of the orchard at the design stage. The cumulative total cost of seed production (total costs incurred/total seed production) decreases dramatically from the first harvest to the large crops seen by age 15 or so. This trend would encourage organizations to keep orchards going for 20 yr

or more; some orchards have, in fact, stayed in production for 40 yr. Staying with a mature orchard also postpones the high costs of replacing an orchard (felling, site preparation, grafting, etc.). The opposing consideration is that newer, higher gain genetic material will come available, at least in areas served by active breeding programs, motivating us to phase out older orchards.

These two factors, essentially cost versus gain, need to be balanced. Each organization building a new seed orchard, either singly or in a cooperative, operates under its own specific business model (discount rate, willingness to take risk, etc.). Decisions on how large the orchard should be and how long it is run will vary by organization. In some cases, strategies that result in larger short-term costs could reduce the overall cost per pound of high-gain seed.

One sensible compromise is to establish new orchards adjacent to existing mature orchards of the same or roughly equivalent breeding zone, gradually eliminating most of the older orchard after about 15 yr, but roguing and leaving enough of it to provide pollen for the young orchard. This does not rule out the possibility of short-lived orchards, though they will be the exception rather than the norm; it would seem logical to keep establishment costs as low as possible in such orchards if large, late harvests are not obtained.

## Site Location of New Orchards

**Characteristics of successful sites.** Orchards have been established on a wide variety of sites, with Douglas-fir seed produced successfully on most of them. Problems have mainly been on (1) sites very close to the ocean, where frequent fog and heavy rain appear to interfere with pollination, leading to disappointing seed production; (2) frost-prone sites, where early establishment has been poor and subsequent seed production is affected by damage to flowers; (3) remote high-elevation sites, where access can be very difficult due to snow; (4) very droughty sites with no irrigation; and (5) areas completely out of the normal range of Douglas-fir. Early efforts to locate orchards outside the Douglas-fir zone (e.g., southern California) have been abandoned. In contrast to these problematic sites, notable successes have been seen in mild agricultural sites, such as the Willamette Valley, and in rain-shadow areas on the eastern Olympic peninsula.

Soils are an important factor in siting an orchard. For example, a well-drained soil with moderate fertility would

be far superior to a poorly drained soil retaining lots of water throughout the fall and winter. Little can be done to modify soil conditions at reasonable costs. The only moderately cost-effective treatments are ameliorating compaction by subsoiling, improving drainage by tiling, and incorporating organic matter in the planting spots. Even these could cost thousands of dollars for an orchard.

Because Douglas-fir pollen is ubiquitous, pollen contamination affects all orchards west of the Cascade Mountains to a lesser or greater degree and needs to be addressed in orchard management.

**Options in siting new orchards.** Currently, one important option for industrial forest growers is locating suitable acreage of mature timber within their ownership, preferably with relatively flat terrain and within easy access to an office belonging to the organization. The main advantages of such an arrangement are (1) no upfront land purchase costs; (2) little or no interference by residential neighbors on operations such as spraying for cone and seed insects; (3) relative ease of access; and (4) ability to control the management of the surrounding timber lands, such as harvesting standing mature timber and replacing with young plantations (preferably with a different species to create a pollen buffer, or with high-gain orchard seedlings). The main potential disadvantages include (1) increased risk of damage from wildfire; (2) high cost of land clearing and site preparation; (3) some degree of pollen contamination; (4) lack of viable irrigation options; (5) terrain too rough for tractor-based activities, such as mowing or spraying; and (6) damage from deer, elk, mountain beaver, and rabbits, unless expensive fencing, control measures, or both are used.

Another option is purchase of agricultural land in a designated farming area with no residential neighbors and tight zoning restrictions that prevent urbanization. Such a site can have several advantages.

- Irrigation may be possible if there is adequate ground water and water rights.
- A pool of labor and contractors accustomed to agricultural work may be available.
- The ground is typically flat to gently undulating.
- High fertility can lead to rapid early growth.
- Likelihood of damage from wildfire is very low.

Disadvantages can include the following.

- There may be high purchase costs of such land and ongoing expenses, such as property taxes.
- Low-lying areas may flood.
- Heavy clay soils can be simultaneously waterlogged in winter (requiring drain tiling) and droughty in summer.
- Droughty soils can cause establishment problems for 1-yr-old rootstock seedlings (these problems can be overcome with larger seedlings and/or irrigation).
- There can be problems from gophers or periodic epidemics of voles on such sites, causing mortality to the seedlings and requiring intensive control.
- The pressure to sell such orchards for development can become very high, especially if the zoning changes, parts of the owning company are sold, or both.

Regardless of which option is preferred, some precautionary measures are mandatory. It is important to examine the soils and topography for water drainage issues, as well as incidence of root rot or other diseases in ex-forest sites. It is advisable to dig soil pits and conduct soil tests to determine clay content and fertility. Propensity for ponding of cold air, which can result in frequent damaging frosts, must also be checked.

A third option is buying an existing Douglas-fir orchard, roguing and modifying it as needed. This will often be expensive but can expedite arriving at the desired production of high-gain seed.

## Site Preparation and Infrastructure

If the cleared timber land option described above is chosen, the land will need to be cleared following timber harvest (figures 1, 2). Removing stumps can sometimes be expensive (over \$1,000 ac<sup>-1</sup> on occasion), but avoids the operational and safety issues of trying to drive equipment (tractors, lifts) over tree stumps and uneven ground. Cutting off the stump close to the ground is sometimes suggested as a cost-saving measure, but this is unlikely to be enough; the ground will still be uneven, and holes in decaying stumps can be a hazard. One option is to push the trees over with heavy equipment such as a loader (rather than severing them), as the root wad usually comes out of the ground quite easily. The trees can then be moved to a landing and bucked to appropriate length, or the material can be chipped and hauled from the site.

Low-budget operations where no equipment will be driven on the orchard have managed to proceed without removing the stumps. In the case of former agricultural land, subsoiling to break up hardpans from years of farming or grazing livestock will usually be beneficial (figure 3). If stumps are removed, the site will need to be leveled to fill in the resulting holes and the whole surface will need to be smoothed and tilled.

Intensive operations, especially large ones, will usually add some or all of the following infrastructure: (1) perimeter fences; (2) a well and pump house; (3) irrigation lines to the individual ramets; (4) all-weather gravel roads to key locations; (5) a cone-drying shed; (6) an equipment shed; (7) an office; (8) windbreaks for coastal areas, such as Whidbey Island, with consistent and strong winds; and (9) some measure of security (gate alarms, video surveillance cameras, on-site hosts, etc.). In contrast, small low-budget orchards have been established with very few of these amenities; in such instances, orchard equipment has to be hauled in each time work is planned.



Figure 1. Clearing an area previously under trees.



Figure 2. Area cleared for a new orchard.



Figure 3. Using a winged subsoiler to break a hardpan in a previously cultivated property.

Wire perimeter fences to about 8 ft (2.4 m) in height, costing up to \$4 per ft, are mandatory to control deer and elk damage for forest-established orchards (figure 4); however, some orchards developed in agricultural areas have managed successfully without them. Animal protection tubing can provide some protection, but will be less effective than a big-game perimeter fence.

Irrigation is worth considering in some detail (figures 5 and 6). Many orchards have been established and managed successfully without irrigation, especially on more mesic sites with deep, well-drained soil. There will obviously be a cost saving as a result. In addition to installation costs, there is ongoing maintenance, addressing things such as clogged nozzles and driplines chewed through by coyotes. However, irrigation can (1) improve survival and establishment in very dry areas or on droughty or shallow soils; (2) help grow the foliage and crown needed to start producing large numbers of cones, thereby reducing the delay to onset of seed production; and (3) be used to delay bloom in the orchards (through overhead emitters)—



Figure 4. Big-game fence built around orchard in forest.



Figure 5. Rolling out dripline.



Figure 6. Details on a dripline near a ramet.

though in practice this has rarely been used in Oregon or Washington. The irrigation system must be able to deliver several gallons per ramet, usually in one session, at least once a week. A properly designed irrigation system (clean well water, proper chlorination and filtration system) will have very little problem with clogged emitters. Backflow prevention is required to prevent fertilizer or chemicals being pulled back into the water supply.

## Genetic Quality

Genetic material adapted to the area of reforestation and with the highest genetic quality available to the forest grower naturally should be used. Most of the timber land area in western Oregon and Washington is included in first-generation and second-cycle cooperative tree improvement programs from which members can obtain genetic material (Jayawickrama 2005).

## Use of Graft-Compatible Rootstock

The use of graft-compatible rootstock is now standard for coastal Douglas-fir. In Oregon and Washington, these are derived from Don Copes' breeding program based at the Forest Service Pacific Northwest Research Station in Corvallis (Copes 1999). The compatible parents have also been grafted at several other orchards, and there are vigorous efforts to produce adequate supplies of compatible rootstock seed. Incompatibility has been greatly reduced; it has not gone away, however, and a low level of mortality (1 or 2 percent per year) should be expected. Graft maintenance, especially in the first few years after grafting, is prudent for orchard success. In order to obtain good results, high-quality seedlings (good caliper, vigorous

lateral branches), trained grafters, and good maintenance are needed.

## Grafting Methods

Douglas-fir orchards are established using two rootstock growing approaches: pot-grafting and field grafting. Both methods utilize cleft grafting techniques and cost about \$3–5/graft for the actual grafting. When properly executed, both produce high-quality grafted stock.

**Pot-grafting.** Many organizations use pot-grafting (figure 7) almost exclusively to establish new orchards. In this method, containerized rootstock seedlings are grafted and outplanted after various lengths of time in greenhouses, shadehouses, or even cold storage. Advantages include the following.

- Grafting can be done indoors in sheltered conditions and at a convenient working height, a situation usually preferred by grafters.
- The planning horizon to obtain rootstock of graftable size is shorter.
- Graft unions can heal in controlled, mild conditions.
- There is a long grafting window, starting in December and continuing to as late as early April, if the rootstocks are kept from flushing.
- Orchard ground is not tied up while rootstock is growing to graftable size.
- Because the orchard can be started with a healthy graft at each planting spot, there are fewer problems with first-year mortality leaving vacant spaces in the orchard.



Figure 7. Successful potgrafts.

- Survival of large potted grafts is higher than that of smaller rootstock seedlings in some situations.
- All the ramets of a single clone can be grafted and labeled as one batch, reducing chances for error.
- Graft maintenance in the field is usually minor.

The key difference, compared to field-grafting, is that pot-grafting gives a higher probability of fully establishing an orchard on a known schedule. Greenhouse grafting can go from graft-compatible seed to grafted seed orchard in the ground in 20 mo to 2 yr. Field grafting cannot provide such a short or reliable time-frame. Depending on the situation, disadvantages can include (1) high repotting costs and growing charges for greenhouse use, if done at contract prices (as high as \$10 per graft); (2) lack of interest by greenhouse operations in taking on the extra effort and responsibility of growing large stock, providing facilities for grafting, and maintaining grafts; (3) plagiotropism (although one organization reports no issues with plagiotropism when using pot-grafts); and (4) larger logistical effort to transport and plant potted grafts.

There are several variations on the pot-grafting theme.

1. One-year-old container seedlings (515A, 615A, or similar) can be potted into a larger container in fall; they can also be lifted in winter and kept in cold storage until 2 wk before grafting, then taken out, potted and grafted.
2. The grafted ramets can be moved outdoors in the spring after the risk of frost is over; this reduces cost and prevents the trees from growing too tall in the first year. Conversely, they can be grown in the greenhouse that season, if it is possible to prune and stake them.
3. One organization is testing grafting on 1-yr-old container seedlings (e.g., 515A, 615A), keeping them in cold storage, and outplanting them the same winter; this avoids the expense of potting the grafts and growing them in a greenhouse or nursery but involves accepting lower survival and first-year growth.
4. Another organization uses 1015A container rootstock, grafted after 1 yr and outplanted in fall of the first growing season after grafting; the organization's experience is that Douglas-fir doesn't like to be in a container very long.

Staking and top-pruning (pruning of scion with excessive growth) may be needed if growth rates are not closely

monitored in the greenhouse. If the grafts are sufficiently vertical and firm, staking can be avoided (this also improves safety, since stakes can injure workers' eyes). With good timing, we would aim to top-prune the graft just once.

**Field-grafting.** A few organizations prefer field-grafting. Advantages include (1) rapid and healthy scion growth resulting from grafting on large, vigorous rootstock; (2) avoiding the high cost of growing potted grafts in greenhouses; (3) few issues with plagiotropism or large spindly grafts; (4) avoiding post-grafting transplanting shock, and (5) easy graft maintenance, because graft unions are relatively high above the ground (though, if the ramets are managed as short-hedged trees, a substantial proportion of the ramet would not be usable for seed production).

Disadvantages include (1) a long planning horizon to obtain rootstock of graftable size; (2) poor survival of planted rootstock due to drought or herbicide damage; (3) tying up valuable orchard ground while rootstock is growing to graftable size; (4) cold wet conditions and an inconvenient height when grafting outdoors, resulting in slower production and higher costs; (5) the need for grafters to carry scions from many clones through the orchard and ensure the right scion is grafted on a given location; (6) reduced grafting success if severe weather, such as very cold temperatures or desiccating winds, follows grafting; (7) a shorter grafting window, from February to April; and (8) potential issues with vacant spaces in the orchard resulting from first-year mortality.

For field grafting, 1-yr-old container seedlings (515A, 615A or similar) can be outplanted in place and grown under a suitable cultural regime. Such seedlings will be ready for grafting after 2 yr in the field. It may be possible to reduce this period to 1 yr by using very large container stock (815A, 1015A), but there is less experience grafting on such seedlings in Oregon and Washington. Grafting too early in the winter can lead to poor survival, as the scion cannot obtain nutrients and water from the rootstock until the graft union heals, and such healing does not take place until spring.

## Spacing

A variety of spacing regimes are reasonable, depending upon such considerations as the following:

- Acreage available: if more land is available, wider spacing is more feasible.

- Fixed cost per acre per year of orchard maintenance and ownership: the higher the cost, the greater the incentive to reduce spacing and maximize production per acre.
- Spacing between existing irrigation lines, if any.
- Equipment to be used (pickups, trailers, tractors and sprayers, translators, lifts): the larger the equipment, the wider the spacing needed.
- Expected life of orchard: the longer we expect to need it, the wider the spacing needed.
- Urgency to obtain seed: the greater the urgency, the greater the reason to pack in more ramets per acre until production per ramet reaches an acceptable level.
- Expected future management: development of large tree-form ramets [the default approach, with top heights from 30 to 50 ft (9.1 to 15.2 m)] requires wider spacing than does management of hedged orchards kept as low as 9 ft (2.7 m) (less frequent, but still a viable alternate).

There is no single “right” orchard spacing. Initial densities have ranged from 50 to 500 ramets ac<sup>-1</sup> (0.4 ha<sup>-1</sup>) and a great variety of spacings have been used [36 ft × 24 ft (10.9 m × 7.3 m), 18 ft × 12 ft (5.5 m × 3.6 m), 9 ft × 12 ft (2.7 m × 3.6 m), etc.]. Even more complex spacings have been used [e.g., three rows 8 ft (2.4 m) apart separated by about 15 ft (4.5 m) for large equipment access]. If herbicides are not available to control grass and weeds within rows, the orchard may need to be mowed in two directions, requiring standardized spacing [12 ft × 12 ft (3.6 m × 3.6 m), 15 ft × 15 ft (4.5 m × 4.5 m), etc.] to make equipment operation easier. A north-south orientation of the wider alley is generally preferred to allow better sunlight penetration.

Development of holding orchards (temporary establishment of ramets in one location with the intent to move them later to a permanent location) can reduce costs when annual per-acre orchard maintenance and ownership costs are high. For example, a holding orchard can be as tight as 6 ft (1.8m) within and between rows [1,200 ramets ac<sup>-1</sup> (500 ramets ha<sup>-1</sup>)] for a few years. If the costs of moving ramets (figure 8) from the holding orchard to the final location are high, however—very much the case if ramet movement is contracted out and if the ramets are large—these cost savings will be reduced. For example, moving 500 ramets at \$50 per ramet will cost \$25,000. It is advisable to develop holding orchards as close to the location of the permanent orchard as possible to reduce tree-moving

costs. Moving the ramets may shock the tree into flowering; this might be exploited by proper scheduling.

## Orchard Design

Related trees will tend to have similar phenology, and crosses between relatives will tend to have reasonable seed set; these two factors will work to produce some amount of inbred seed unless steps are taken to reduce it. It is therefore desirable that ramets of related clones (sibs, parent-offspring) are physically distant from each other to reduce related matings. In contrast, separating ramets of the same clone will be a lower priority because selfs are much less likely to produce viable seed. Several software programs are available to optimize separation of related clones.

## Planting and Early Aftercare

Whether established as pot-grafts or field-grafts, orchard plantings have many similarities to planting of progeny tests. These are expensive, high-value seedlings, so planting quality is very important to obtain a successful orchard (figure 9). Excellent record-keeping of where each ramet is planted is imperative because loss of identity or misidentification of ramets is very detrimental. Each ramet should be tagged with parent identification and Row/Column address. This information has to be mapped and entered into an orchard database that must be updated continually as changes occur from mortality, regrafting, etc. If a permanent irrigation system is not installed, temporary irrigation using water tanks may improve survival and early establishment on hot, dry sites.



**Figure 8.** Moving a ramet from a holding orchard to permanent location with a treespade.

Grass cover, such as perennial ryegrass, is typically established to reduce erosion and allow for easier year-round vehicular and equipment access. The use of slow-growing varieties will reduce the need for future mowing, although the grass has to be aggressive enough to compete with weeds and moss. There may be instances, however, where grass cover is not required (e.g., no vehicles will be driven over the orchard), or is even undesirable (e.g., areas with very low rainfall or other droughty sites with no irrigation, where grass cover will use all available moisture). One approach would be to develop sod only after the ramets are well established and have built up a strong root system. As mentioned before, it is customary to spray herbicide in the rows while trees are dormant; this reduces some of the competition for water from grass or other ground vegetation in the establishment phase. Where herbicides cannot be used, mulch matting [3 ft × 3 ft (0.91 m × 0.91 m) or 4 ft × 4 ft (1.2 m × 1.2 m)] can provide a suitable alternative.

Orchard mowing is commonly necessary to permit access, provide a measure of fire prevention, and help control noxious weeds. Although the idea of grazing livestock inside seed orchards, thereby taking advantage of lush grass and reducing the need to mow, can seem very attractive, livestock will destroy young grafts. Sheep, cattle, and horse grazing has been permitted in older established orchards, but requires very good cooperation with the permittee to ensure that grazing is closely controlled to limit damage. Livestock can cause problems even for mature orchards with large ramets by compacting the soil and damaging the roots, disturbing tree tags, and spreading noxious weeds.

Ramets require periodic maintenance during the first and second season after grafting, such as trimming the “ears” (any loose rootstock stem separating above the graft



Figure 9. A recently established orchard.

union), removing the first branch whorl above the graft union, and scoring bark to reduce and delay the incidence of incompatibility. Rootstock foliage is removed progressively as the scion foliage grows and becomes capable of supporting the entire graft. It is obviously important that all rootstock foliage is eliminated before seed production begins. Early rootstock pruning also extends the safe herbicide spraying period, as the chemical no longer contacts tree foliage. Painting the graft union and lower stem with light-colored latex paint can reduce damage due to sunscald.

Agricultural areas such as the Willamette Valley can experience difficulties due to periodic population explosions of voles; the voles often use the container media of the pot-grafts and vegetation control matting as habitat, damaging the grafts. Tilling the entire new orchard block (except for the area immediately surrounding the grafts) is one way to control or eliminate voles. At some point tilling would have to cease, as it would damage the root systems of the ramets and prevent establishment of sod. Trapping has also been used, but results have been mixed; this technique appears to be best suited for control of small populations. Several chemicals are registered for control of voles. Zinc phosphide, chlorophacinone, and diphacinone can be used in Washington and Oregon. (More details are available on the Washington State University Extension Web site (<http://gardening.wsu.edu/library/tree012/tree012.htm>) and the Oregon Department of Agriculture Web site (<http://www.oregon.gov/ODA/PEST/docs/pdf/meadowmouse.pdf>).

Orchards should be monitored periodically through soil and foliar testing to ensure nutrient health, and site-specific fertilizer mixes should be applied to ensure vigor and growth. Nutrition requirements can be met by either broadcasting granular fertilizers or injecting soluble nutrients into irrigation water.

**Address correspondence to:** Keith J.S. Jayawickrama, Department of Forest Ecosystems and Society, Oregon State University, Corvallis, OR 97331-5752; e-mail: [keith.jayawickrama@oregonstate.edu](mailto:keith.jayawickrama@oregonstate.edu); phone: 541-737-8432.

## Acknowledgments

Jeff DeBell (Washington Department of Natural Resources) provided useful suggestions for this manuscript. We also acknowledge the many colleagues from whom we have gathered perspectives and insights on

Douglas-fir seed orchard management over the years, those orchardists who answered the survey on orchard grafting, and reviewers who provided helpful suggestions.

---

## REFERENCES

Copes, D.L. 1999. Breeding graft-compatible Douglas-fir rootstocks (*Pseudotsuga menziesii* (Mirb.) Franco). *Silvae Genetica*. 48: 188–191.

Jayawickrama, K.J.S. 2005. Genetic improvement: boosting plantation productivity in the Pacific Northwest. *Western Forester*. May/June: 10–11.

St. Clair, J.B.; Mandel, N.L.; and Jayawickrama, K.J.S. 2004. Early realized genetic gains for coastal Douglas-fir in the Northern Oregon Cascades. *Western Journal of Applied Forestry*. 19: 195–201.

Wheat, J.W. 1969. Forest tree improvement work advances in Douglas fir region. *Forest Industries*. 96(5): 38–40.