Current Seed Orchard Techniques and Innovations

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Abstract: As applied forest tree improvement programs in the US Northwest move forward into the third cycle, seed orchards remain as the primary source of genetically improved forest tree seed used for reforestation. The vast majority of seed orchards in this region are coastal Douglas-fir (*Pseudotsuga menziesii* (Mirb.) Franco), consistent with the high economic importance of this species. However, productive seed orchards are also in place for western hemlock (*Tsuga heterophylla* (Raf.) Sarg.), noble fir (*Abies procera* Rehd.), western redcedar (*Thuja plicata* Donn), ponderosa pine (*Pinus ponderosa* Laws.), lodgepole pine (*Pinus contorta* Dougl.), western larch (*Larix occidentalis* Nutt.), western white pine (*Pinus monticola* Dougl.), sugar pine (*Pinus lambertiana* Dougl.), and Port-Orford-Cedar (*Chamaecyparis lawsoniana* (A. Murr.) Parl.). To be successful, seed orchards must be managed intensively, including: control of weeds, mammals, and cone and seed insects; graft and crown maintenance; strict identity control; irrigation; fertilization; crop stimulation; and ultimately, harvest of high quantities of genetically improved seed. Over the past 40+ years, seed orchard management practices have been developed to improve the reliability and size of cone and seed crops and reduce damage and loss from cone and seed insects, thereby increasing the efficiency of orchard operations. In this paper, we discuss the current state of the art in seed orchard management in the Northwest, with particular emphasis on Douglas-fir.

Keywords: graft compatible rootstock, flower stimulation, cone and seed insect control, irrigation, weed control, Douglas-fir

Introduction

Although people have harvested seeds and fruit from trees for centuries, only after World War II did the science and theories of forest genetics begin to be seriously applied to and practiced in operational forestry around the world. Early tree breeders and geneticists showed that traits important to the production of timber and pulpwood were inherited and, as such, could be improved to increase forest productivity and wood quality. At some point however, these genetic improvements, or gains, need to be captured, packaged, and mass produced so that these gains could be deployed in operational forestry systems. Since the mid-to-late 1950's through to today, the most common approach is the use of seed orchards.

A seed orchard may be defined as:

> "…a plantation of selected clones or progenies which is isolated or managed to avoid or reduce pollination from outside sources, and managed to produce frequent, abundant, and easily harvested crops of seed." (Feilburg and Soegaard 1975).

Today in the Northwestern US, much of the coastal Douglas-fir (*Peudotsuga menziesii* (Mirb.) Franco) and western hemlock (*Tsuga heterophylla* (Raf.) Sarg.) seed used for reforestation on industrial and some public forest lands is produced in seed orchards (Figure 1). Many of these seed orchards comprise second generation (or cycle) selected material from progeny tests, and either are, or soon will be, producing seed with genetic gain estimates in the range of 20-30% for volume. Seed for a number of "minor" species is also being produced in Northwest US seed orchards, including:

1. Noble fir *(Abies procera* Rehd.)
2. Western redcedar (*Thuja plicata* Donn)
3. Ponderosa pine (*Pinus ponderosa* Laws.)
4. Lodgepole pine (*Pinus contorta* Dougl.)
5. Western larch (*Larix occidentalis* Nutt.)
6. Western white pine (*Pinus monticola* Dougl.)
7. Sugar pine (*Pinus lambertiana* Dougl.)
8. Port-Orford-Cedar (*Chamaecyparis lawsoniana* (A. Murr.) (Parl.)
9. Sitka spruce (*Picea sitchensis* (Bong.) Carr.)

Figure 1. The production of genetically improved seed in orchards is robust, mature technology.

Much of the current management practices in Northwest US seed orchards have been adapted from those first developed in southern pine orchards. In proportion to its economic importance, most of seed orchard research and application in this region has been devoted to Douglas-fir. Many of the techniques and practices used on Douglas-fir are also used successfully with other Northwest species, but there are a number of distinct differences. In this paper, we will discuss current advancements in seed orchard management in the Northwest, with particular emphasis on Douglas-fir. We will outline key practices that are important in successful seed orchards and briefly discuss areas of ongoing operational research.

Graft Compatible Rootstock

When forest geneticists identify phenotypically superior selections, elite (proven superior) material, or both, we want to make multiple copies of each selection for inclusion in the seed orchard. By far the most common method of vegetative propagation used in seed orchards is grafting. Grafting is a time-honored, very successful process of vegetative propagation used broadly in fruit and nut orchards and in forest tree seed orchards. It works well, is relatively simple, and very quickly can produce multiple copies of elite selections. That is of course, in almost all tree species except Douglas-fir.

Douglas-fir stands alone as the only major forest tree species that suffers from serious graft incompatibility (Figure 2). Graft incompatibility is analogous to tissue or organ rejection in human transplant cases. In the late 1960's to early 1970's, early tree improvement workers hopes for success were cruelly dashed when, one by one, they watched grafted Douglas-fir in first generation seed orchards begin to die from graft incompatibility. In some of these early orchards, mortality from graft incompatibility ran 80% or more, leaving an uneconomical enterprise in its wake. Graft incompatibility was so bad in early Northwest seed orchards that many landowners switched to seedling seed orchards. This compromised genetic gain, but at least the orchard trees survived to produce seed!

Figure 2. Graft incompatibility in Douglas-fir.

However, one researcher at the PNW Research Station in Corvallis didn't throw in the towel. Over the course of more than 20 years, Don Copes conducted research designed to identify specific genotypes that were highly graft compatible. By the late 1970's, he identified 16 clones that were highly graft compatible. These were propagated in the thousands as rooted cuttings, and used as rootstock for new orchard establishment (Copes 1981). Later, controlled crosses were made between the compatible selections to produce highly graft compatible seed. Use of this seed for the production of Douglas-fir rootstock is standard practice, and has allowed the rapid development of new seed orchards. There is probably no other Douglas-fir seed orchard practice that has had more positive effect on program success than has the Copes graft compatible rootstock.

Flower Stimulation

Although it is taxonomically imprecise, tree breeders commonly use the term, "flowers" when referring to floral structures in trees. Thus, female flowers produce cones, and male flowers produce pollen. To efficiently produce seed, the only important goal of the seed orchard, trees must flower at an early age, reliably, and heavily. In natural stands, flowering occurs periodically and erratically, 3-7 or more years apart. In a seed orchard, such performance is unacceptable.

Thus, early researchers began looking into practices that might improve both the regularity and the abundance of flowering. Flower stimulation includes practices applied at key developmental points in year 1, which lead to significantly increased flowering in the spring of year 2. Looking to practices used in the US South, fertilization was tried with some success. However, the results weren't consistent across orchards, and applying the large amount of fertilizer needed for larger orchard trees has gotten quite expensive. Eventually, two practices were developed that consistently resulted in regular and abundant flowering – partial girdling and application of gibberellic acid (GA).

Partial Girdling

In many lower elevation coastal Douglas-fir seed orchards, partial girdling is a very safe, low cost, very predictable technique for stimulating consistent and reliable flower crops. It can be applied when the trees are at least 2 inches (5 cm) in diameter at the base, although in practice, most orchard managers wait until orchard trees are 6-7 years old. There are varying recommendations regarding optimal dates: at the time of vegetative bud swell (Ross and Bower 1989; Ross and Bower 1991), 6 weeks before vegetative bud break (Clemo, personal communication), 1-3 weeks before vegetative bud flush (Woods 1989), or at the beginning of pollen bud swell (Reno 2008). Orchard managers typically test different application dates, then settle on the time that works best for their orchard.

Girdling involves the application of two overlapping half-circumferential saw cuts that go through the bark and cambium just until the saw teeth reach the xylem (wood). The first girdle should be placed at a comfortable working height, with the second cut being placed roughly 1.5 times the stem diameter above or below the first cut (Figure 3). For large trees, cuts are spaced no more than a foot apart. Each year, girdles are made in fresh wood, not in old scars. Practiced with care on otherwise healthy trees, girdling can be applied every other year, producing very predictable flowering and cone crops. In orchard complexes containing multiple blocks of different material, undesirable cross pollination between blocks can be managed by the schedule of girdling. If we do not want Orchard A pollinating the trees in Orchard B, we simply girdle these orchards in alternating years. The flowering response occurs the following year, thereby minimizing pollen contamination.

Figure 3. Double, overlapping, partial girdling is a very successful means of flower stimulation in low elevation west side orchards.

Partial girdling works very well in Douglas-fir, but has been less predictable in other species. For some of these species, the application of GA has been shown to work well.

Application of Gibberellic Acid (GA)

Much of the research on flowering and GA was done with Douglas-fir in British Columbia in the 1970's and 80's (Ross and Bower 1989). This research showed that proper timing, technique, and choice of GA are the keys to success. There are many GAs, usually designated by number. The combination of GA4 and GA7 has been shown to be very effective in stimulating flower production in Douglas-fir. GA 4/7 is available in either crystalline, or in liquid, ready-to-use formulations. Crystalline GA must be dissolved in ethyl alcohol before use. The liquid form is known by the trade name, ProCone™ (Valent Corporation), and is considered the industry standard. As with all chemicals, consult the label for safe and proper use.

Application is accomplished by drilling holes in each tree, and injecting a pre-measured amount of ProCone in each hole (Figure 4). The application rate is based on the cross-sectional area at the point of injection. First treatments can usually start when ramets are three or four years from grafting. A recent study indicated that some treatments applied 2 years after grafting could be effective (Cherry and others 2007). There are different opinions on best timing: two weeks before vegetative budbreak (Reno 2008), about the time of vegetative budbreak (Cherry and others 2007), when 50% of the trees have flushed (Ross and Bower 1991), when most of the trees have flushed (Ross and Bower 1989), and up to the time of that 50 - 90% of the year's vegetative growth has occurred (ProCone label). Best results are usually obtained when using freshly purchased ProCone.

Figure 4. Gibberellic acid is also used to stimulate flowering.

In low elevation coastal Douglas-fir, GA 4/7 is used more in breeding orchards, where trees are smaller and younger, and could be damaged by girdling. However, GA gives excellent results in western hemlock, and has shown promise in ponderosa pine and noble fir.

GA is also used to stimulate flowering in western redcedar and Port-Orford-Cedar, but both the formulation and the method of application is different. For these species, research shows that GA 3 applied as a foliar spray in mid-summer stimulates significant flowering the following spring (Russell and Hak 2007).

Control of Cone and Seed Insects

A thorough discussion of seed and cone insect control is beyond the scope of this paper, so only a brief outline of key management practices will be presented. Successful seed orchards are intensively managed plantations, where maximum seed production per acre is the goal. Thus, anything that reduces seed yield negatively affects economic rate of return. Because orchards flower and produce cones much more frequently and more heavily than natural stands, damaging insect populations can build up and cause significant damage to developing crops. Seed orchard managers must become experts on the detection and control of a wide variety of insect pests. With time and experience, managers learn which insect pests are most important, and usually focus their control efforts accordingly.

The first step in any control program is to know which insect is causing damage to cones and loss of seed. An excellent reference for identifying cone and seed insects is "Cone and Seed Insects of North American Conifers" (Hedlin and others 1980). In the Northwest, several of the state forestry and natural resource departments have entomologists on staff that can assist with identification and control options. The USDA Forest Service also has trained staff, which may be able to help.

Over the years, control strategies for the most important cone and seed insects have been developed. Forestry is a small business compared to agriculture, so the available list of insecticides labeled for use in seed orchards is limited, and tends to change with time. No attempt will be made in this paper to list individual insecticides – it is better to work with other seed orchard managers and entomologists to determine which are labeled for use, and known to be effective. Rather, we will focus on application practices commonly in use in Northwest US seed orchards. As well, there are some technologies relatively new to forestry that may well become established as common use in the not-too-distant future.

Application Practices

Aerial Application

Where the surrounding landscape permits, aerial application is very effective and clearly the most cost effective means of applying insecticides to seed orchards in the US Northwest. Helicopters are used most often, effective in treating trees in blocks with widely different ages and thus, tree heights. Excluding ferry time, aerial application is very fast, which is helpful when the window for wind speed is open for only a short period of time (Figure 5).

Figure 5. Aerial spraying provides excellent, low cost control of cone and seed insects.

Ground Application

Where neighbor issues make aerial spraying problematic, ground systems using high pressure mist blowers are an effective alternative. Such equipment makes efficient use of chemical, but small droplet size means that drift must be carefully monitored. Maximum tree height is a limitation, so orchards should be managed for height with due consideration to performance of the available mist blower. Ground application is much slower than aerial, so spraying mat be stretched out over several days because of wind speed limitations. Hydraulic sprayers may also be used to apply insecticides in seed orchards, but these high volume systems are slow and have a higher risk of worker exposure.

Individual Tree Application

In cases where either non-farm land use begins to encroach on seed orchard sites, or internal organization policies prohibit aerial and ground spraying, some technologies relatively new in forestry are being considered, and used in some cases. Individual tree treatments typically involve stem injections of systemic insecticides, and come to forestry from the landscape and horticulture industry. When Dutch elm disease was killing American elm trees across much of the Eastern US, some towns and cities were able to keep large boulevard trees alive longer with stem injections to control the disease vector, the European elm bark beetle. Individual tree treatment is slow and expensive, but given the high value of trees in cities, the cost could often be justified.

Today, individual tree treatment is still practiced on town and city trees, but targets now include emerald ash borer, hemlock woolly adelgid, and mountain pine beetle (Doccola and others 2012). Fortunately for seed orchard use, techniques and equipment have been significantly improved, making application much faster per tree than in the past (Figure 6). Individual tree treatment is still quite slow, when compared to aerial and ground application, but in some orchard locations it may be the only viable method available to the seed orchard manager. Current technologies still rely upon drilling several holes in each tree, but the injectors used are considerably faster than previous versions. This technology holds considerable promise because some

Figure 6. Where aerial spraying cannot be practiced, individual injection provides another option.

of the research suggests that the control effect may last for several years (McCollough and others 2009). If multiple year control is achieved, the cost effectiveness of individual tree treatment will improve significantly.

Vegetation Management

When seed orchards are established, it is important to control vegetation within the newly planted tree rows so that the trees grow as free as possible from competition. The date of first flowering and cone production is correlated with tree size, so the sooner trees get bigger, the sooner genetically improved seed will be produced. Seed orchard managers typically use readily available forestry herbicides to maintain a weed free strip within the tree row. This weed free strip also reduces habitat for voles, which can cause significant damage to newly planted grafts.

Between rows, it is important to maintain a good running surface to lessen compaction and possible rutting from the regular equipment travel necessary in everyday orchard management. For many years, orchard managers would accept whatever grass came up between rows, spending much of each summer mowing to maintain access and reduce fire danger. Mowing is a necessary and often costly expense. Some orchards have established cover crops that are low growing to reduce mowing costs. More recently, short growing grass varieties classically bred to be tolerant of glyphosate have become available, and some managers are establishing new cover crops with this seed (Figure 7). Orchards containing this grass need to be mown once, rarely twice, and the grass never gets any taller than about knee high. Weeds between rows are easily cleaned up with glyphosate. In orchards where this grass variety has been established, mowing costs have dropped significantly.

Figure 7. Low growing grass varieties, classically bred to be tolerant of glyphosate, create an excellent orchard cover crop.

Crown Management

In the US Northwest, the tree species established in seed orchards have the inherent ability to grow quite tall. Harvesting cones from trees as they grow taller increases in cost as man lifts with greater reach must be either rented or acquired. The equipment needed to harvest trees that are 15-20 feet (4.5-6 m) tall is much less costly than that needed for trees 50-60 feet (15-18 m) tall. Thus some managers are testing the feasibility of regular tree topping to manage the height of their trees. One orchard is using a sickle bar mounted on a loader to accomplish automated topping of Douglas-fir (Figure 8). In this system, the orchard tree height is being managed so that all cone harvesting may be done from the ground or from short ladders. No man lift equipment will be needed. However, because cone production is correlated to tree size, shorter trees produce fewer cones. Thus, to increase cone production in such topped orchards, planting density must be increased. Compared to more traditional spaced orchard that may have 50-100 trees per acre (tpa; 125-250 trees per hectare), a topped orchard may have up to 500 tpa (1250 tph).

Figure 8. Sickle bar mower for automated tree topping in a Douglas-fir seed orchard.

Other Douglas-fir orchards are being managed with lower density, and allow the trees to get proportionally taller. As these trees grow, man lifts are needed for cone harvest. However, large trees produce more cones than small trees, so the added cost of mechanized lifts may be justified (Figure 2).

For other species, topping has been shown to actually enhance cone and seed production. An example of this is western larch. While western larch is a regionally important reforestation species in the Interior West, until recently there were very few seed orchards, and none were producing. Again in an attempt to manage tree height to control cone harvesting costs, western larch orchard trees were topped to maintain a maximum height of 15 feet (4.5 m). In doing so, the orchard trees were stimulated to produce a higher proportion of so-called "hanger" branches, from which most larch flowers arise (Figure 5). With this result, topping is now standard practice in western larch seed orchards that are actively managed.

Topping has also been shown to work quite well in western hemlock orchards (Ross 1989), and is used on occasion with Sitka spruce, western redcedar, and lodgepole pine.

Controlled Mass Pollination (CMP)

In the US West, seed orchards not uncommonly comprise 30 clones, sometimes as many as 60-80. The genetic gain estimates for the individual clones in the orchard often vary widely, from very high to modest. Most orchards rely upon open, wind pollination amongst the orchard trees, resulting in an averaging effect on overall genetic gain. Recently, some orchards have started to practice controlled mass pollination (CMP) on an operational scale to increase genetic gain.

With operational CMP, controlled crosses are made between only the very highest gain clones in the orchard, producing targeted amounts of very high genetic gain seed. Ahead of CMP, large volumes of pollen must be collected from high genetic gain clones, and stored for future use. In the spring, orchard workers apply hundreds to sometimes thousands of pollination bags to branches bearing female cone buds. When the flowers become receptive, pollen is applied to each bag. To achieve good seed set, it is often necessary to visit and pollinate each bag two times (Figure 9). CMP is

Figure 9. Controlled mass pollination (CMP) is employed to significantly increase genetic gain.

expensive, and the amount of seed produced to date has been modest, especially compared to open pollinated production. However, techniques have improved over the past several years, so that yields per bushel of cones often equal, and sometimes exceed that of open pollinated cones.

Irrigation

Many west side, low elevation seed orchards are located in areas with significant summer drought. Irrigation can be critical to early orchard survival and establishment, and later to producing large trees that bear more cones in a shorter time frame. Some orchards are establishing drip irrigation systems, either temporary or permanent, to meet these needs. Once an orchard becomes well established, temporary systems are designed to be rolled up and used in a new orchard (Figure 10).

Figure 10. Temporary drip irrigation may be used until newly planted trees are established, then moved to a new orchard.

More conventional overhead irrigation is also used in some seed orchards, primarily for bloom delay and frost protection in the spring. Overhead sprinkling of seed orchards on temperate days in the spring has a cooling effect, affecting flower phenology. Development of clones that tend to flower early in the spring is retarded, resulting in more clones in the orchard flowering synchronously. This produces a more diverse orchard pollen cloud and thus, reduces pollen contamination from outside sources and creates a broader range of open-pollinated combinations from the desired orchard trees (Fashler and Devitt 1980). Overhead sprinkling has been used for many years in fruit and nut orchards to protect flowers from freezing temperatures. This treatment has been used in forest tree seed orchards, but care must be taken to avoid breakage of tops and branches from ice loading.

DNA Fingerprinting

Since the 1960's, forestry organizations and forest industry have invested, collectively, many tens of millions of dollars in applied forest tree improvement in the US Northwest. Considerable progress has been made through two cycles of tree improvement, and several cooperative Douglas-fir and western hemlock programs are entering their third cycle of breeding, testing, and selection. These tree improvement programs are the source of new selections that are propagated and established in new seed orchards. It is critical to long term, sustainable genetic improvement that parents and selections are accurately identified, and that pedigrees contain no errors. Unfortunately, despite the best efforts of tree breeders and orchard managers, identification errors occasionally occur.

A detailed discussion of various DNA fingerprinting techniques is beyond the scope of this paper. Suffice it to say that protocols and procedures have been developed that are effective in confirming the genetic identities of parents, and their putative offspring. In other words, we have the ability to determine whether or not a given selection could be the progeny of the two parents listed in the pedigree. Furthermore, we can test multiple ramets of a clone, to determine if any have been mislabeled. This is key to long term improvement programs, because it is critical to know that a tagged tree is actually what we think it is. With DNA fingerprinting, when we apply pollen or use a tree as a female, we have confidence that the cross pedigree is 100% correct.

Summary

The production of genetically improved forest tree seed in seed orchards is a mature, robust technology. Starting with selections arising from a linked tree improvement program, the establishment and management of successful seed orchards requires intensive culture and close attention to detail. Over the past 40+ years, applied research and development programs have helped develop the orchard management regimes in widespread use today. Key practices in seed orchards include: the use of graft compatible rootstock for Douglas-fir; flower stimulation for regular and abundant cone and seed production; effective control of cone and seed insects; vegetation management; crown shaping techniques to assist cone production and harvesting; controlled mass pollination to increase genetic gain; irrigation to improve orchard establishment, increase individual tree growth, and manage orchard phenology; and DNA fingerprinting to ensure accurate identification of selections and maintain pedigree control. Using these practices and techniques, plus many more mundane daily tasks, seed orchard managers in the US Northwest are very successfully producing predictably large, abundant, and easily harvested crops of genetically improved seed for reforestation programs.

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