Seed Orchards and Aspects on Supporting Tree Breeding

Dag Lindgren

Abstract The main quantitative output and work horse for plant breeding today and accumulated efforts since half a century is seed orchards. This document do not cover deployment of vegetatively propagated material or control crosses (less than 2 % of number of Swedish forest plants produced) or GMO or genomic based selections (zero plant production) and focus mainly on Sweden. Seed orchards established now are mainly with tested grafted clones. With Norway spruce, where vegetative propagation of young plants is easy, current testing and seed orchard deployment is based on testing clonal performance. For Scots pine it is progeny tested clones, but progeny testing is a painfully slow and seemingly inefficient procedure. The number of clones is typically 20 or slightly more when clones are unrelated. It is more efficient to deploy clones in different proportions and it is not economic to strive for equal proportions. Pollen contamination is an important aspect of seed orchards, a practical remedy has not been found. However, seed orchard crops from genetically young seed orchards with 100 % contamination are still better than crops from mature but genetically outdated alternatives. Earlier deployed clones were unrelated, but it seems to become inefficient avoiding related clones after the first generations. Genetic thinning is rare and difficult to defend from a gain point of view, but selective harvesting becomes increasingly common. The breeding population (typically 1,000) is shared in compartments (typically 50) and seed orchards draw on several compartments. Probably both seed orchards and breeding would benefit from a larger "breeding population". There would be advantages if breeding efforts and seed orchard establishment could be better synchronized. New cohorts of recently selected clones should be deployed to pine seed orchards more often, they tend to be genetically worn out and expensive to harvest.

D. Lindgren (✉)
Swedish University of Agricultural Sciences, Umeå, Sweden
e-mail: Dag.Lindgren@slu.se

T. Fenning (ed.), *Challenges and Opportunities for the World's Forests in the 21st Century*, Forestry Sciences 81, DOI 10.1007/978-94-007-7076-8_20,

Projections of the impact of seed orchards on the national forest harvest almost a century ahead in Sweden is 10 % assuming no technology change. The possible "ecological risks" with the seed orchard technology seem a small addition to that of plantation forestry.

1 Introduction

Seed orchards are still the major quantitative output and work horse for forest tree breeding. That is in spite of a more than half a century of history in support industrial conifer forestry from economically important programs and tremendous efforts to create more efficient outlets for the breeding effort. Seed orchards themselves have developed surprisingly little. Seed yield is typically less than a percent of what a grain farmer could produce. Less than a few percent of Swedish forest plant production uses clonal propagation techniques or controlled crosses. Even in conditions with long rotation times, the investment in seed orchards seems worthwhile. Swedish forestry supports seed orchard programs covering the full seed need. Some general references about seed orchards are Kang (2001), Prescher (2007) and Lindgren (2008).

2 Seed Orchards Have Advantages Besides Gain from Tree Breeding

Seed orchards generally bring together genotypes from different stands, which are not related and thus inbreeding and inbreeding depression tends to be lower than for stand seeds. Very probably there is a stimulating effect from heterosis. Seed orchards are a more reliable seed supply, in particular if origins from other areas or countries perform better than the areas intended for reforestation by the seed orchard.

Good seeds. Seed orchards are established in good climatic environment and suitable ground conditions. They are closely managed. Cone collection and seed storage is kept under good control. The seeds will usually be heavier, better filled and healthier, germinate faster and more uniform compared to stand seeds. The nursery crop will also develop faster and be more uniform. That results in plant crops which develop faster and more predictably, and are therefore easier to manage and more uniform. This results in a better tree crop which performs better both in growth and survival and gives a more uniform forest plantation. The physiological superiority of the seeds leads often to a stand that performs some percent better, besides the genetic advantages. If used for direct seeding the higher quality of the seeds will produce a better result with fewer seeds.

The Swedish Scots pine seed orchard Västerhus. Photo: Dag Lindgren

Generally seed orchards are pruned to limit their height, control crowns and sometimes to get cones down on ground. Thus cone harvest costs can be kept low. The seed supply will also often be larger, more reliable, more uniform and more predictable.

Domestication. Most modern seed orchards are based on selections based on results from experimental plantations. That means that trees are selected in – and often based on results from – environments, which are similar to what will be used in practical forestry. This in itself has an improvement effect.

2.1 Flexibility

The client area and genetic output of a seed orchard is not engraved in stone once the establishment decision is made. If the environment changes, perhaps because of a warmer climate, the target area of the seed orchard can be modified. The genetic characteristics of the crop will change when the pollen production raises and pollen contamination decreases, thus a young orchard may be used for a different target area than a mature one. Genetic and selective harvesting thinning can improve the genetic quality of the crop. Supplementary pollination can improve the genetic quality of seed orchard crop and artificial crosses can readily be made in a seed orchard.

For some cases it may be beneficial to amplify the best part of the harvest by clonal propagation. Old seed orchards should be replaced with newer genetically improved material. But seed demand, the need for back-ups and often the need for ground for establishing new seed orchards regulate when old seed orchards are finally retired.

2.2 Seedling Seed Orchards

Most seed orchards are clonal, but seedling seed orchards constitute an alternative. Selfing will be less common than in clonal seed orchards, as there are no genetically identical replications. But inbreeding caused by milder relatedness will be more common, and this may be more harmful as it is more likely to result in marginally handicapped trees, which may ultimately cause larger production losses in the mature forest, as selfed genotypes seldom survive to maturity in a forest. Seeds collected following open pollination in selected trees are often used for seedling seed orchards. They do not have selected fathers, in a forest the pollen parents are unselected trees and even in a seed orchard many of the fathers are not from selected trees (contamination), this reduce the gain compared to grafts of selected trees. But seedling seed orchards can be based on controlled cross of selected trees, when it does not matter for gain if selections or their progeny are placed in a seed orchard. Seedling seed orchards can be combined with a tree improvement programme, so the orchard can fill several purposes. The seed, and in particular the pollen production, is delayed as compared to a grafted seed orchard with mature trees. This disadvantage may look greater than it is in the long run and in advanced generations trees will be less mature at selection and when the difference is probably small.

2.3 Protected Seed Production

For some species and circumstances seeds are produced under protected conditions like plastic tents. This offer advantages, including eliminating pollen contamination, but has not been wide-spread for most major species.

2.4 Pollen Contamination

Fertilizing pollen from outside the seed orchard is often an important factor. General and efficient remedies have been difficult to find where this contamination is large. Reducing or eliminating such contamination will probably get a higher priority, as long-term breeding raises the potential gain. Often seed orchards operators have to live with and adapt to pollen contamination: Deliberately choose locations where the expected contamination has a reasonable genetics; reduce the contamination with available methods even if they have limited effects; adjust the target area to predicted contamination; and welcome the positive effects of contamination (more seeds, more diversity and less inbreeding)!

2.5 Monoclonal Harvests

Clonal seed orchards may be harvested by clone. More uniform seeds are obtained, which is an advantage for plant production. Genetic differences between clones can be utilized. Genetically better clones can be used where the superiority results in the highest advantages, probably where site index is high. Seed price may be related to genetic quality. Lower ranking clones may be kept in storage as reserves. Still lower ranking clones may not be harvested years when the seed need is limited. Harvests from low ranking clones may be used for direct seeding. When a seed orchard becomes genetically outdated, seeds harvested from the best clones may still be competitive.

2.6 Genetic Diversity

Genetic diversity usually results in higher and safer biological production, but uniformity is sometimes preferred because a more uniform product; faster deployment of gain; and easier management. Genetic diversity is often demanded by legislation and it is desirable for public, costumer and authority acceptance or it may be the policy of the owner. Often diversity is expressed just as a clone number, it is more informative with some variant of "effective number". Extra diversity in a seed orchard offers options for later genetic thinning and selective harvesting. Sometimes seed orchards are blamed for their ecological impact, but plantation forestry may be the proper target for such criticism rather than tree improvement itself.

2.7 Genetic Diversity in Seed Orchards and Supporting Breeding

The reason for long term tree breeding is to support future deployment of genetically improved material to forestry. For most situations that means seed orchards, or at least that the option remains open. Genetic diversity in the breeding stock is the raw material of the breeder and a valuable resource which should be managed with care in a sustainable way and not exhausted. The genetic diversity and relatedness in the breeding stock should allow the best genetic material to be creamed for deployment to seed orchards with a high degree of improvement and sufficient diversity. To be able to make efficient selections with limited relatedness many generations ahead, it is important that the breeding population is large enough to limit genetic drift and that build-up of relatedness within the breeding population is minimal. A breeding program may appear more efficient in the short time if it sacrifices diversity for gain, but much of that extra gain may be lost later, as the gain in the final step to deployment as seed production will be reduced.

Both in seed orchards and in the supporting breeding programme it is beneficial if deployment from the recruitment population utilizes somewhat more of the genetically better genomes and founder genomes than is done by truncation (either select or reject). It is not efficient or practical to overemphasize equal utilization of clones or genomes, but better to use them in a more gradual way.

The most attractive share of the recruitment population for seed orchard deployment will become more related as generations pass. It is possible to arrange the breeding stock so for example twenty unrelated selections will remain available (sublining), but this does not look like good breeding economy. It seems more optimal to use few sublines and allow some slight inbreeding by deploying relatives. To keep such inbreeding low is an argument in favor of starting long term breeding efforts with many genotypes and restricting the loss of diversity in long term breeding.

Some current typical values for the major conifers in Sweden are given: Typical young seed orchards recruited from the breeding population have around 20 clones deployed in slightly different proportions. The Swedish national breeding metapopulation comprises slightly more than 1,000 genotypes structured in subpopulations of 50 each. Selection has a large within family component. The subpopulations have slightly different target areas and characteristics. A seed orchard is typically recruited from around four adjacent subpopulations. It has been projected that seed orchards will raise the national annual forest harvest in Sweden by about 10 % till year 2100.

2.8 Clonal Testing

Long term breeding is theoretically most efficiently performed by using clonal copies rather than being guided by progeny performance, but of course information from relatives should also be used when primary testing is done using clones. Tested clones may be used as parent trees in seed orchards. Alternatively, superior tested clones in seed orchards may be mated and the seeds (or embryos) clonally propagated, in that way the latest information from clone testing may reach the forest much faster than would otherwise be the case. Such approaches are utilized with Norway spruce in Sweden.

2.9 Seed Orchard Rotation

It is generally inefficient to use a seed orchard for a very long time. One reason is that the cost of harvesting the seeds and the effort required often increases steeply with the height of the trees, which increases as the trees age, of course. Harvest costs are often the dominating factor in the cost of the seeds, usually more than the capital costs. Another reason is that a seed orchard gets genetically outdated, as newly improved breeding stock becomes available. Normally a seed orchard program should be supported by a long term breeding program, and the potential to harvest gain from that breeding program increases by time. The age of some Swedish seed orchards seem to indicate that optimally short rotation has not been planned for. Seed orchard establishment should interface with breeding efforts so the breeding stock can be efficiently creamed at the right moment. Replacement of retired seed orchards serves to introduce new clones as parents to forests, and thus contribute to genetic diversity on the regional level.

It takes considerable time for pollen production to rise in a seed orchard, but if the breeding stock is good and the location has a genetically reasonable pollen cloud, seeds from a young seed orchard may still be genetically superior to seeds that can be obtained from alternative seed sources. It may be a good idea to maintain the mature seed orchard for some years extra in case the performance of the new orchards should fall below prediction or the demand for seed increases. The seeds harvested from the best clones from the overly mature seed orchard might also still be genetically compatible with harvests from a young seed orchard.

2.10 Seed Orchards and the Future of Mankind

Forests create the very materials that Man needs from air, water and sunshine and recycle it back to air and water after use. Seed orchard forestry is not mining, but sustainable and renewable; and actually better than that. Seed orchards improve the green production apparatus each time they are harvested and create additional resources in an environmental friendly way. Seed orchards form the foundation for much of the future physical and ecological realities in our countries and are part of what we give to the people coming after us, and so may be seen as a moral activity.

Seed orchards are used for land managed as production or cultivated forest by planting or direct seeding, but good seed orchards raise the production on such land, and thus give more room for other land uses including "conservation" needs. Better economic output from cultivated forests will also offer forest operators more room for using land for other purposes.

Seed orchards is a safe and mature technology (although still with room for improvement) and is able to benefit from the development of improved technologies like genomics, flower stimulation, exotics and GMO, but are not dependent on them. Clonal propagation or crossing technology may replace seed orchards, geneticists certainly see advantages in that. But most of these high expectations have failed in the past, and a cautious attitude seems advisable.

References

Kang, KS (2001) Genetic gain and gene diversity of seed orchard crops. Acta Universitatis Agriculturae Sueciae. Silvestria 187 75pp+11 chapters

Lindgren, D (ed) (2008) Proceedings of a seed orchard conference, Umeå, Sweden, 26–28 September 2007. ISBN: 978-91-85911-28-8. 256 pp

Prescher, F (2007) Seed orchards – genetic considerations on function, management and seed procurement. Acta Universitatis Agriculturae Sueciae 2007:75. ISBN: 978-91-576-7374-9