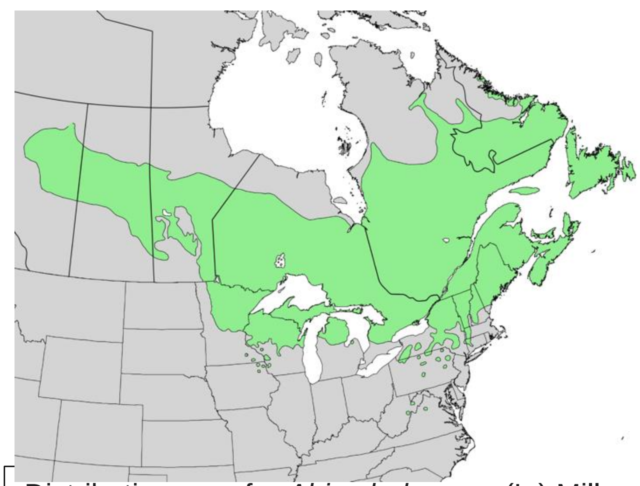
Christmas Tree Genetics

Introduction

Tree improvement programs seek to improve the return on trees in a broad long-term sense. In Christmas trees, this includes increasing the grade, value, and shortening the time to market. Other, less tangible benefits, include improving resilience to insects, disease, environmental stresses, and decreasing the need for shearing. The overall goal is to reduce the cost of production and increase profits for farmers. In comparison to tree improvement for reforestation, Christmas Tree improvements have a quick return on investment between 6 to 10 years.

Levels of Genetic Variation in Christmas Trees, Specifically Balsam Fir

Regional Variation:
This map depicts the native range of balsam fir. It stretches from Saskatchewan through Manitoba, Ontario, Quebec, and Atlantic Canada with the exception of northern Labrador. It goes into Minnesota, Wisconsin, upstate New York, Maine, New Hampshire, and through Vermont. Genetic variation at this level tends to be most associated with climate adaptation as it occurs over the climate gradient.



Distribution map for *Abies balsamea* (L.) Mill. - balsam fir (Little, 1971)

Stand Level Variation: This is the variation associated within a specific stand of balsam fir trees. There's quite often some level of stand level variation its related to stand history.

Within Stand Level Variation: This is the variation in individual balsam fir within a stand of trees. This level of variation is most often very large.

The improvement of Balsam fir Christmas trees involves harnessing both stand level and within stand level variation in our region.

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Traits of Interest for Christmas Tree Production

Both late frost hardiness and early winter hardiness are environmentally adaptive type traits. In 2018, growers had a very bad experience with a late frost in the middle of June.

Late frost tolerance is related to flushing (see the 7 stages of flushing below). Balsam fir flushing dates are heritable through range, though variation isn't vast between trees. Some level of late frost tolerance can be developed but other precautions should be taken to avoid late frosts, such as trying to avoid frost pockets when you're planting trees. There's more variation to the development of winter hardiness in balsam fir. This is the focal value to producers as it's well understood that this trait is associated with needle retention.

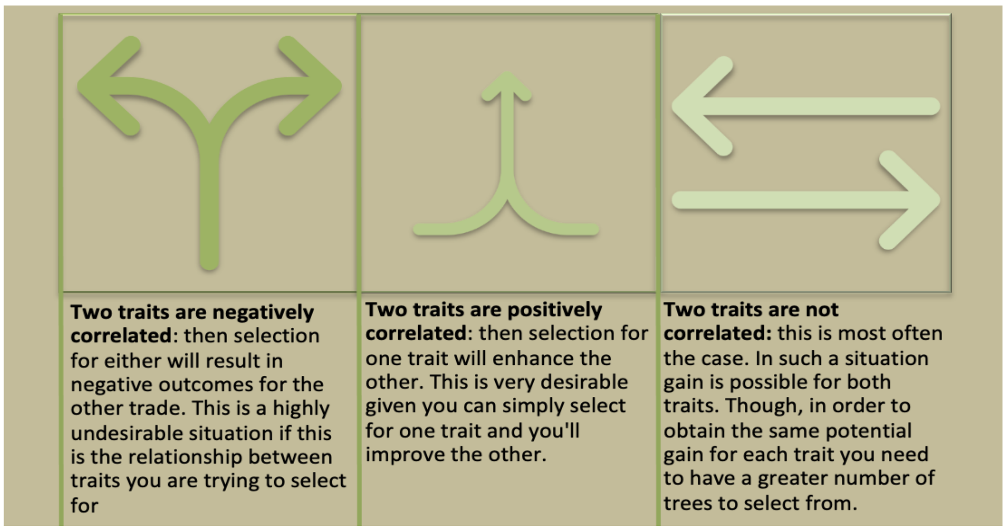
Genetic Gain for Individual Traits

To make genetic gain in planted seedlings you need to meet in the following prerequisites:

- There has to be variation in the trait that you want to improve.
- There needs to be a genetic basis for the variation. Meaning, the trade must be heritable.
- You need a large enough population to select from.
    - Gain= the amount of Variation X Heritability X Selection intensity.
- The efforts and tree improvement need to be sized in relation to the size of the planting program you have.

The Relationship Between Traits

A good rule of thumb is that the more traits in an improvement program, the more complicated it becomes. This is due to the relationships between traits. The following are the three possible manners in which traits interact with each other. Otherwise known as the relationship between traits.



Genetic Variance

Genetic variance is related to the production strategy that you choose. When you look at a tree in your Christmas tree lot, what you're looking at is what's called a phenotype.

The environmental component of the history of the Christmas tree includes all the site factors associated. Genetic field testing is measured to get the genetic variation in a normal population for the traits of interest in normal tree improvement. These two components are trying to be separated plus to environment. Most traits are controlled either positively or negatively by multiple genes which contribute to the genetic value of the individual. Genetic improvement programs involving seed production, like seed orchards, rely on the combination of positive genes contributed by parents for the population. This is termed **additive genetic variance**.

Another form of genetic variance results from the specific combination of genes in an individual. This is called **non-additive genetic variance**. Through sexual reproduction, producing seed, the genes are recombined. Taking into account non-additive variance is associated with specific combinations of genes. It's only possible to utilize non-adaptive variance through cloning.

Seed Orchards

Seed orchards start by identifying trees from across a region's Christmas tree lots that express desirable traits. Cuttings are taken from these trees and grafted on rootstock to clone those individuals. Thankfully, balsam fir is one of the easier trees to graft. These cloned phenotypes are used to establish seed orchards.

Next, breeding, field testing, and or clonal assessments need to be conducted to understand genetic variants. The goal is to identify genetically superior and inferior trees. The inferior trees should be culled to improve the overall genetic quality of the orchard.

The last step after the genetically superior trees have been identified is to use them to initiate the next breeding cycle. Some of the older tree improvement programs around the world are on their 4th generation. It takes decades to turn over a generation in traditional tree improvement programs because of the growth time and testing required. Patience is rewarded as the genetic gains are increased with each generation when a seed orchard is run properly.

Grafted trees in orchards are not suitable for evaluating all traits. This is because they're grown in very open conditions for seed production, and they are grafted trees. Though, seed orchards can be useful for evaluating pest resistance, adaptive traits, and needle retention. This is not just a matter of finding trees with the right trait, you really need to systematically evaluate all the ramets in the orchard. Score them and then analyze the data.

Sometimes crown management is done in a seed orchard that interferes one's ability to judge growth rate and the crown of trees. Quite often the trees in seed orchards are topped in order to make it easier to pick the cones. Even when trees are not topped, and a helicopter is used to collect seed this process still impacts the crown of the tree as branches are often broken.

This is a photo of a helicopter being used to collect cones from the Debert Christmas tree orchard with a cone rake in 2019.

Somatic Embryogenesis

Another method of genetic improvement in Christmas trees is somatic embryogenesis. A lot of work has gone into the SMART Christmas tree project that uses somatic embryogenesis. Somatic embryogenesis enables the genetic gain from non-additive and additive genetic variance to be captured. It starts by identifying the trees which are believed to produce superior seed. Theses parent trees are used to make controlled crosses, being seedlings where parents have been purposefully selected. This produces crosses amongst a number of parents from which you get a small handful of seed from each one of the crosses. From every one of the seeds, you take out the embryo and put it on a tissue culture medium which under the right conditions it will grow cell mass. All of these cells have the potential to develop into a whole tree. Most of these cells are frozen in cryo storage for basically as long as you want to store it.

(Park et al., 2016)

At the same time, some of the callus from the embryos that is excised is taken and placed on a different medium that allows the embryos to mature. These mature embryos derived from somatic embryo genesis callous are genetically identical. You can take some of those trees and produce seedlings in order to establish field tests. Using the test results, the very best combinations can be pinpointed of both the non-additive and additive genetic variance. Once the top performing seedlings have been selected the callus is retrieved from cryo storage, and using the same process start mass producing seedlings (see photo).

The advantage of making a cross between good parents is the progeny, which will be above average overall. Though, in the same way that brothers, and sisters don't look the same there's still huge variation within the seedlings of the same parents. Though, with a greater number of clones produced, there's a higher probability of finding clones of high value for all the traits of interest. The disadvantage is not every seed from every family responds, and it requires skill and effort to produce many lines. It requires more effort to grow a somatic seedling compared to just collecting cones and sowing seeds. Due to these higher production costs, you must ensure gains are sufficient to make it all worthwhile.

Status of Genetic Improvements in Christmas Tress Seed Orchards

Locally seed orchards were established in the 90s in Kingsclear, New Brunswick and Debert, Nova Scotia. Also, a relatively new orchard was established at Plumdale (Bible Hill) in Nova Scotia which is part of the SMART Tree program. Focusing on the Debert orchard, around 400 selections were initially made at the Debert orchard and since then other selection efforts have commenced in Nova Scotia. These efforts were made in collaboration with producers, the provincial government, and tree improvement staff. The initial selections were made by evaluating individual trees to determined which trees were believed to be of quality grade for Christmas tree selection.

References

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