Frampton, J. 2001. Genetic improvement of Christmas trees. *American Christmas Tree Journal* 45(2):16-18,20-21.

Genetic Improvement of Christmas Trees

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Introduction

Worldwide, genetic improvement techniques are being employed on virtually all commercially important forest tree species to enhance economic returns from wood and paper products. In contrast, with a few notable exceptions, most genetic improvement efforts directed at Christmas tree production have been either superficial or non-sustained.

Currently, selection of the appropriate species and seed source are the only options available to most Christmas tree growers concerned about the genetic quality of their planting stock. Through testing and experience with various seed sources, growers can exploit the large geographic variation in growth, quality and adaptive traits that naturally exists in forest tree species.

Examples of widely recognized seed sources for Christmas tree production include Cibola for concolor fir, Roan Mountain for Fraser fir, Lincoln National Forest for Douglas-fir and Ambrolauria for Nordmann fir.

While seed source selection is an important initial step in the genetic improvement of Christmas trees, continuously returning to seed collections from natural stands precludes any further improvement in genetic quality. In addition, the genetic variation within most seed sources is tremendous and varies from year to year. In order for the Christmas tree industry to move past the current level of genetic improvement, techniques commonly used in forest and other plant crops need to be applied to Christmas trees.

This article presents an introduction to three aspects of applying genetic improvement techniques to Christmas trees: 1) the traditional tree improvement approach 2) additional approaches: cloning and biotechnology and 3) planting stock performance. Hopefully, the reader will gain a better perspective on, and enthusiasm for, the future of genetically improved Christmas trees.

The Traditional Tree Improvement Approach

Overview

Tree improvement is the application of genetic principles to increase the value of tree crops. It relies on understanding and using variation that naturally occurs in tree populations. Tree improvement increases the value of a tree species by 1) ***selecting*** the most desirable trees from natural stands or plantations, 2) ***breeding*** or mating these select trees and 3) ***testing*** the resulting progeny. The trees involved is this process are referred to as the ***breeding population.***

This three-step process is then continuously repeated to further improve the desired characteristics of the breeding population (Figure 1). Each selection, breeding and testing cycle of this improvement process is referred to as a ***generation.***

The ***production population*** is another group of trees established to meet commercial planting demands. Usually the production population is a ***seed orchard*** or group of trees at a single location managed specifically for seed production.

For species, which can be readily propagated using rooted cuttings, a ***hedge orchard*** managed to produce cutting material may serve as the production population. Seed and

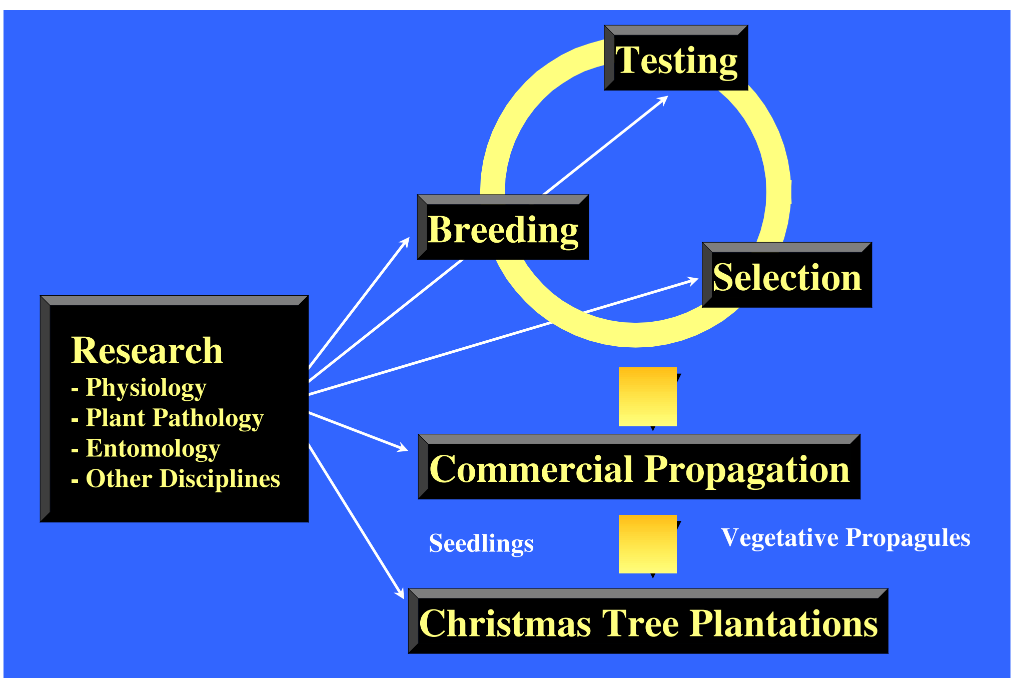

Figure 1. The tree improvement process consists of cycles of selection, breeding and testing in a breeding population. Elite selections from this population are used in a production population to propagate planting stock for Christmas tree plantations. Research efforts are necessary to improve the efficiency of each step in the process.

hedge orchards are established from grafts, rooted cuttings or seeds of the very best trees in the breeding population.

Selection

Tremendous variation exists in natural stands for many important Christmas tree characteristics such as growth rate, color, branching habit and pest resistance. Growers often encounter this variation in their Christmas tree plantations. Observed characteristics such as growth rate are referred to as the ***phenotype*** of a tree. A tree's phenotype is determined by both its genetic constitution, or ***genotype*** and the effect of the ***environment*** as described by the following equation:

$$\mathbf{P = G + E}$$

where,

> **P** = phenotype
> **G** = genotype
> **E** = environment.

When selecting trees, what you see is not necessarily what you get. Genetically inferior trees may sometimes appear phenotypically desirable because they grew in an unusually favorable micro-environment. Conversely, genetically superior trees may appear phenotypically undesirable due to poor environmental conditions.

Characteristics vary in the degree of genetic versus environmental influence. For example, genetic control of branching habit is stronger than for height growth so that the selection process is generally more effective for branching traits.

Initial selection of trees from natural stands or unimproved plantations is necessarily based solely on phenotype. Since the variation due to environmental effects is less in plantations than natural stands, selection is more effective in plantations. In order to ensure that the selection process is as effective as possible in unimproved stands, candidate trees are graded according to predetermined criteria.

Both the candidate tree and neighboring check trees are measured and compared in order to account for local environmental effects. Once a tree improvement program is underway, genetic information (performance of relatives) is used to increase the effectiveness of the selection process.

Breeding

The next step in the tree improvement process is mating or breeding among the select trees. For this purpose, branch tips or ***scion*** of each selection are grafted onto seedling ***rootstock*** to establish a ***breeding orchard. Control-pollinations*** are then performed among the selections.

Control-pollination starts with covering receptive female cones with bags during early spring to prevent natural pollination (Figure 2). Pollen collected from other select trees or mixed from a group of select trees is then injected into the pollination bag. After pollination has occurred, the bags are removed and the cones allowed to ripen.

Each cone-producing branch is labeled to ensure correct identification at cone harvest. Control-pollination is performed according to certain ***mating designs*** among the select trees in order to maximize the overall genetic information derived from the resulting progeny.

Figure 2. Control pollination bags on Fraser fir prevent contamination from natural pollen.

Testing

Seeds produced from tree improvement breeding efforts are used to establish progeny tests. The purpose of these tests are to 1) provide genetic information about the select parent trees and 2) provide an improved population of trees from which the next generation of select trees is made.

Tree families established in progeny tests are randomized and replicated in a designed manner to meet statistical and genetic criteria. Families are planted on several sites and in more than one year to sample an adequate number of environmental conditions.

Christmas tree progeny tests are intensively managed similarly to a typical Christmas tree plantation. Growth and quality measurements are made periodically in these tests until harvest. These data are entered into a database and analyzed.

The results are used to assess the genetic worth of the original selections, to make selections for the next generation and to make recommendations for establishing and upgrading seed and hedge orchards.

Additional Approaches

Two additional approaches to the genetic improvement of Christmas trees are cloning and biotechnology. These approaches should not be viewed as substitutes for, but rather, as powerful tools to supplement the traditional tree improvement approach.

Figure 3. Research is underway to clone Fraser fir by both tissue culture micropropagation (left) and rooted cuttings (right).

Cloning

Every Christmas tree grower has admired the “perfect Christmas tree” on his farm and longed to be able to grow an entire field of trees identical to it. The production of trees of identical genotypes, called **cloning**, is achieved through vegetative (rather than seed) propagation.

Examples of vegetative propagation methods include rooting cuttings, air-layering, grafting, tissue culture micropropagation and somatic embryogenesis (Figure 3). The details and success rates of each of these methods vary widely among species and are too involved to cover here.

Potential benefits of cloning Christmas trees include:

1) capturing more genetic gain,
2) using select material quicker,
3) increasing uniformity among trees,
4) combining desirable characteristics more readily and
5) meeting customers' needs with greater flexibility.

Some clones that are currently propagated as rooted cuttings and used in the Christmas tree industry in the South include the Leyland cypress cultivar, ‘Leighton Green’, and the Arizona cypress cultivars, ‘Carolina Sapphire’ and ‘Clemson Greenspire’. However, the commercial vegetative propagation of most Christmas tree species is hampered by a number of problems including:

1) detrimental maturation effects,
2) low multiplication rates,
3) the need for additional facilities and expertise and
4) increased planting stock costs.

Maturation effects present the biggest obstacle to large-scale propagation of most coniferous species and contribute to the other problems listed. **Maturation** is the developmental succession of changes from juvenile to adult state including increased bud size, reduction in number of branches, loss of rooting ability, slower growth and the onset of flowering.

Thus, maturation creates a dilemma in that once trees are old enough to select for desirable characteristics, they are difficult to vegetatively propagate and their vegetatively produced offspring may exhibit slow and/or plagiotropic (horizontal, branch-like) growth.

Source: Science 286:1662-1668.	Millions of Acres	
	1998	1999
---------- Crop ----------		
Soybean	35.8	53.4
Corn	20.5	27.4
Cotton	6.2	9.1
Canola	5.9	8.4
Potato	<0.2	<0.2
Squash	0.0	<0.2
Papaya	0.0	<0.2
---------- Trait ----------		
Herbicide tolerance	48.9	69.4
Insect resistance (Bt)	19.0	22.0
Bt/Herbicide tolerance	0.7	7.2
Virus resistance/Other	<0.2	<0.2

Figure 4. The use of genetically modified agricultural crops in the United States has become large-scale in recent years.

Aggressive research into circumventing vegetative propagation problems by either maintaining juvenility while clones are being field-tested, or by rejuvenating older select trees, is underway in the forest industry. Commercial clonal propagation of some conifer species is underway and doubtless, in the future, Christmas tree growers will be able to benefit from cloning.

Biotechnology

Biotechnology is a term that can be used in a general and more specific sense. In the **general sense**, **biotechnology** is the use of living organisms to solve problems and make useful products. In this sense, everything associated with Christmas tree production (planting, fertilization, shearing, etc.) is regarded as biotechnology.

Biotechnology, however, is more commonly, used in the **specific sense**. This refers to a collection of technologies that use living cells and/or biological molecules to solve problems and make useful products. One of these technologies, **genetic engineering** is the technique of removing, modifying or adding genes to a DNA molecule in order to change the information it contains.

The use of biotechnology in medicine, agriculture, forensics, and many other fields has dramatically increased during the last decade. Currently, agricultural crops bioengineered to be resistant to herbicides and insects are increasing (Figure 4) although their use is sometimes controversial.

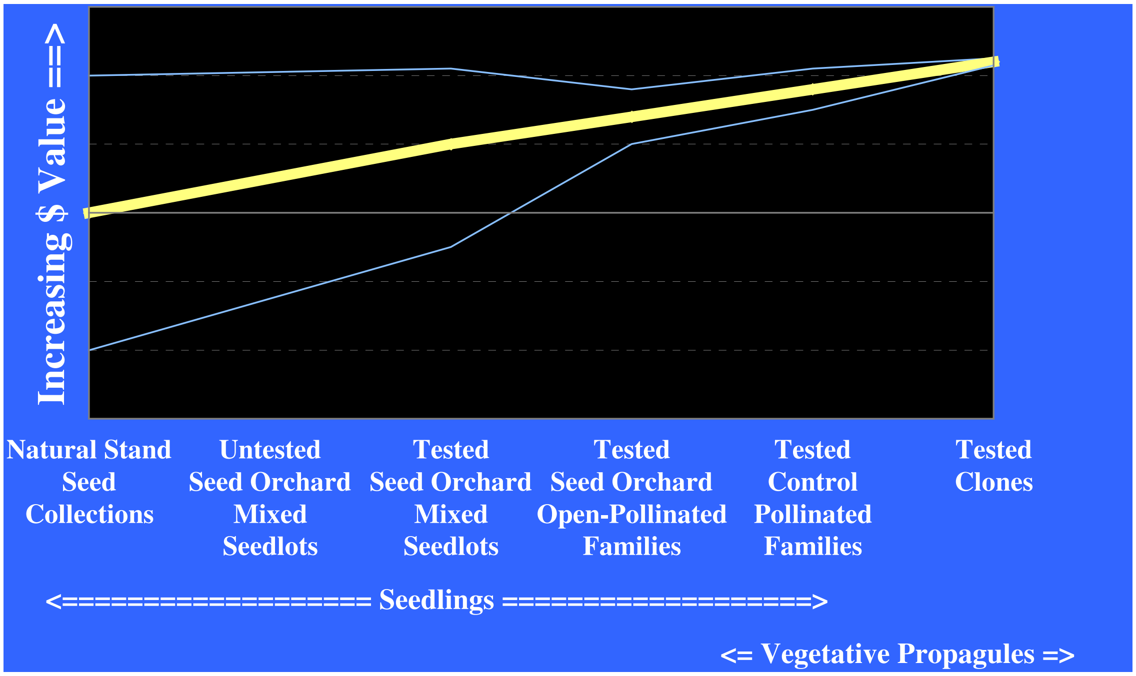

Figure 5. Both the commercial value (yellow line) and uniformity (area between blue lines) of Christmas trees increase with increasing levels of genetic selection and corresponding reduced levels of genetic variation in the planting stock used.

The forest industry is currently pursuing biotechnology research. In the future, Christmas tree growers may also benefit from this research. As in agriculture, one of the first applications is likely to be available is resistance to glyphosate (Roundup®). Another likely first application, also currently being used in agriculture, is the incorporation of insect resistance from the Bt bacterium (*Bacillus thuringiensis*) into trees.

Currently, legal ownership of techniques, high research and development costs, and the lack of commercially viable cloning techniques hinder the development of bioengineered Christmas trees.

Planting Stock Performance

In general, the commercial value and uniformity of Christmas trees increase with increasing levels of genetic selection (Figure 5). Seed collections from natural stands are the most variable and yield the least genetic gain. Planting tested clones yields the highest genetic gain and the most uniformity.

Growers need to be aware that seeds from orchards vary in the amount of improvement in value and uniformity relative to that of natural stands. In fact, some orchard seeds may be similar or poorer in value and uniformity than those from natural stands. In the Christmas tree industry, seed orchards are established in several ways: 1) transplanting wild or plantation seedlings with or without selection, 2) leaving selections from a Christmas tree plantation and 3) grafting scions from selections onto seedlings.

The intensity of the selection process, the uniformity of the site(s) where selections were made and the amount of genetic control of the trait(s) selected will all influence the amount of genetic gain derived from an orchard. Of course, even an unimproved seed orchard offers convenience and less yearly variation than returning to natural stands for seed collections.

Testing the seedlings produced from individual parent trees in seed orchards is the next logical step in the tree improvement process, but one rarely pursued in the Christmas tree industry. This step could yield additional genetic gain by allowing poorer quality parent trees to be removed (rogued) from the orchard. Further, open-pollinated seed could be planted from the best orchard parents for additional genetic gain and a reduction in planting stock variability.

Conclusion

Due to the nature of trees, the genetic improvement process requires both a large-scale effort and a relatively long time-frame to achieve results. Since the process is also labor intensive and requires considerable research and technical expertise, most Christmas tree growers are not in a position to individually undertake this process. However, through cooperation among growers, universities and state agencies, these efforts become feasible.

While the Christmas tree industry stands to reap tremendous benefits from genetic improvement, it should not be viewed as a panacea. Genetics is one of many tools needed to continue to improve the productivity and quality of Christmas trees crops. Growers must continue to use the best available technology to manage their plantations. In fact, the greatest benefits from genetic improvement will be achieved on the best sites receiving the best management.

The industry must cooperate to ensure that these results are realized as rapidly as possible. While hard work and patience will be required, the Christmas tree industry will be rewarded with new standards of productivity, quality and profitability.

A portion of this article was modified from *Limbs & Needles*. 1996. Vol. 23(4):10,12,14.