TREE IMPROVEMENT

DESIGNING A LONG-TERM TREE IMPROVEMENT PROGRAM FOR KOA

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Paper Title: Making a Good Tree Better: How to "Improve" *Acacia koa* Through Traditional Selection and Breeding

The primary goal of a tree improvement program is to develop seed orchards that produce quality seed for reforestation. Tree improvement programs start by selecting trees from natural populations. Seeds of various mother trees are collected and tested in common gardens to determine their relative worth. Tree improvement programs have been successful at improving the quality of seed from native trees with high ecological value as well as for commercial species and are highly applicable to *Acacia koa* in Hawai'i.

Tree planting in Hawai'i dates back to the early 1900s, but attempts to make genetic improvements originated in the late 1980s. The prior work of Brewbaker, Sun, Dudley, Krauss and others demonstrated that traits are heritable, and resulted in the establishment of common garden tests at multiple sites across Hawai'i. Most common gardens utilize a multi-site, randomized complete block design so that each genetic family (trees that share a common mother) experiences the full suite of environmental conditions within a given site and across sites to enable calculations of genotype by environment (gxe) interactions. This 'gxe' interaction is useful to test whether families are broadly adapted (no gxe interaction), or adapted to specific sites or conditions.

How do we select genotypes from a common garden study for inclusion in a seed orchard? Traits are assumed to be normally distributed, but binary traits can be incorporated as well. Traits that are skewed can either be transformed or analyzed non-parametrically. Breeding values, akin to a least-squared mean for each family, are calculated. The orchard manager chooses a threshold value: all families exceeding the threshold breeding value are selected for a new orchard. By selecting from one end of the distribution, we can shift the mean in one direction provided that the heritability exceeds zero. The extent of improvement from selection is measured with the "breeders' equation," which measures the response (expected change in mean) to selection. The response, or genetic gain, is symbolized as Delta G, ΔG (Δ= Greek Delta, or the change, G=gain).

Genetic gains can be calculated as the product of the phenotypic standard deviation (how much variation is present in the trait), the heritability (the percent of similarity among half sibs), and the selection differential (i), expressed as the number of standard deviations beyond than the mean.

Genetic gains are expressed in the same units as the trait. For example, if $\Delta G = 1.05$ meters in height, then selected families are expected to be 1.05 meters taller than the unselected sources at that age. Usually, ΔG is expressed as a percentage of the mean for simplicity. Heritability values in a high elevation population of *A koa* at nine years ranged from 0.1 (height to first fork) to 0.9 (survival) (Krauss 2013). Straightness and branch angle were lower than diameter and height, but greater than 0.1. In recent years, a program to improve resistance to wilt disease has been developed with promising early results.

A tree improvement program that incorporates multiple traits requires a large base population. When multiple traits are desirable for inclusion, genetic correlations between trait pairs are necessary to calculate possible tradeoffs. In other words, improvements for one trait (for example height) could be in tandem with frost resistance (positively correlated), in which case trees that are tall may also contain frost resistance. Alternatively, if genetic correlation between traits are negative, then the breeder must choose one trait over the other. In the example provided, stem straightness was correlated positively with basal diameter, implying that selection for *A koa* that combine both good diameter growth and straightness is possible.

Tree improvement programs require a great deal of coordination to succeed. These programs are often administered in a cooperative model to facilitate a standardized strategy for record-keeping, and regular communication among vested cooperators. Coordination between silviculturists and geneticists is necessary to ensure that genetic gains in progeny tests are expressed in actual field settings. Since koa seeds can be stored for many years, progeny tests should contain a large number of families replicated across a range of elevation and climate gradients. Orchards should be developed for different seed zones, largely based on elevation gradients. Lastly, nursery growing practices should be optimized so that planted trees are as healthy and vigorous as possible when planting.

Figure 1: Eight-year-old *Acacia koa* seed orchard (HARC A) on Mauna Kea at initial planting density before thinning.

Figure 2: Nine-year-old *Acacia koa* seed orchard (HARC A) on Mauna Kea after 90% of the individual trees were removed to keep the top half of all families planted and top tree in each family.