Why are most breeders not using economic breeding objectives?*

Luis A. Apiolaza and Bruce L. Greaves
CRC for Sustainable Production Forestry and
School of Plant Science
University of Tasmania
GPO Box 252-55, Hobart TAS 7001
Australia

Abstract

The direction of progress for a tree improvement program is determined by a formerly defined objective, that is the linear combination of traits to improve multiplied by their respective economic weights. These weights are derived from production functions, which simply describe the impact of trait change on some economic measure (usually profit). In this sense, they have relevance to both silviculture and breeding. Nevertheless, often objectives in forestry have either not been quantified or have been imprecisely defined, being more the expression of wishful thinking than the product of economic analysis. The CRC for Sustainable Production Forestry (CRC-SPF) has been at the forefront of the development of such objectives for vertically integrated *Eucalyptus globulus* and *Pinus radiata* industries.

We review basic theory, the current status of breeding objectives development and explore several issues that hinder their usefulness. Some of the problems affect the construction of the objective function (e.g. poor knowledge of the relationship between biological traits and end-product properties, uncertainty on both cost structure and future market prices), other problems affect the application of the objective in the selection process (e.g. lack of good estimates of relationship between selection criteria and objective traits) and, finally, some problems impact on transforming gain in the objective into economic advantage for the industry (e.g. poor market signals between layers of the industry).

We discuss these problems and suggest ways to overcome them and/or flag them as areas for further research. It seems to be that the major obstacle for developing formal breeding objectives is uncertainty. We postulate that breeders already have enough information to develop and use sensible breeding objectives.

Key words: breeding objectives, economic evaluation, selection criteria, risk.

*Paper presented at the IUFRO Symposium Developing the Eucalypt for the Future, Valdivia, Chile, September 10-14, 2001

Introduction

If breeders wanted to improve a single trait x, the breeding objective would simply be 'to improve x', and research on breeding objectives would be almost nonexistent. However, the effects of many traits on profit in the forest industry complicate any objective. About 60 years ago Hazel (1943) showed the need for an explicit definition of breeding objectives, which is a linear combination of breeding values for each trait weighted by their relative economic importance.

Borges (1962) wrote that '...universal history is the history of a handful of metaphors'. One of the metaphors in breeding is the formal definition of objectives, which often reappears in the literature (usually in conferences like this one!), for example Talbert (1986), Woolaston and Jarvis (1995), and Shelbourne et al. (1997). In spite of this, breeding programs without a formally defined objective are still the majority. Possible explanations for this are: (i) the forest processing industry is a complex system; (ii) it is difficult to determine the relationship between wood properties and final product quantity and quality; (iii) the long time for trees to grow creates uncertainty about their use; and (iv) breeding objectives are not perceived as a high priority (Apiolaza and Garrick 2001). Because of this situation, rather than preparing 'yet another definition of breeding objectives' or a pompous 'breeding objectives for the new millenium' we will review some basic theory and the current status of the problem to explore what we believe are the pending research issues in the area.

General concepts

First things first: Why are we breeding trees? The aim of breeding programs is to increase, or at least maintain, the competitiveness of forestry organizations, usually through profit maximization. Profit is a function of several traits, and is maximized by way of increased income, reduced cost, or both. The obvious questions are 'What traits do we want to improve' and 'What are the relative economic weights of those traits?'

The genetic basis for constructing selection indexes provides a useful framework within which to define breeding objectives. In this context, the objective (H) is defined as a linear combination of additive genetic values (a_i) weighted by their respective economic importance (w_i), i.e. $H = w_1 a_1 + w_2 a_2 + \ldots + w_n a_n$ or, using matrix notation, $H = \boldsymbol{w}'\boldsymbol{a}$. Thus, the central problem of objective definition reduces to the identification of the genetic values in $\boldsymbol{a}$ and the economic weights in $\boldsymbol{w}$.

The traits in H must have an economic impact on the system under study. This puts breeders in an uncomfortable position to say the least. On one side they can include as many traits as they can possibly imagine; however, the economic information available for some of the traits may be very limited and/or the payment between layers of the industry do not reflect the importance of the traits. On the other side, they can opt for a small number of well-known traits (for example volume and basic density), and most probably will be accused of being simplistic.

In forestry most traits in the objective will be expressed at harvest age (some exceptions would be traits affecting mid-rotation income or cost, e.g., affecting thinning yield). In spite of this, the assessment of progeny tests is normally carried out at early ages, in an attempt to reduce generation interval. Furthermore, most traits are too difficult or expensive to assess. A way around this problem is to assess other characters called selection criteria, genetically correlated with the objective traits, which are feasible to include in the routine evaluation of progeny tests. Thus, there is a clear distinction between traits and selection criteria. Traits have a direct influence on the models measuring profit, and are included in the breeding objective. Selection criteria are the characteristics assessed on the trees, and are used to predict the genetic values for the objective traits.

In the original work by Hazel the selection criteria's phenotypic information is combined to produce an index I with maximum correlation with H. Since a few years ago, BLUP has superseded the use of Hazel's method, but the basic principle is still the same: the additive genetic values calculated using BLUP are weighted by a set of coefficients calculated using economic and genetic information. Schneeberger et al. (1992) showed that, for BLUPs obtained from multivariate analysis, the vector of index coefficients (b) is:

$$\boldsymbol{b} = \boldsymbol{G_{ss}}^{-1}\boldsymbol{G_{so}}\boldsymbol{w} \tag{1}$$

where $\boldsymbol{G_{ss}}$ is the additive genetic covariance matrix for the selection criteria, $\boldsymbol{G_{so}}$ is the additive covariance matrix between selection criteria and objective traits, and $\boldsymbol{w}$ is the vector of economic weights. Then, the index is constructed as:

$$I = \boldsymbol{b}'\boldsymbol{a}^* \tag{2}$$

where $\boldsymbol{a}^*$ are the predicted breeding values for the selection criteria obtained using BLUP. Thus, the predicted values for the criteria are transformed into predicted values for objective traits.

The underlying theory is straightforward and it shows that the economic weights are at the core of the selection process. Traditionally, research on breeding strategies revolves around population size and structure, testing methods, etc (e.g., Cotterill 1989; White et al. 1993; Borralho and Dutkowski 1998). However, before embarking on the difficult art of designing a strategy it might be cautious to revisit the most basic questions: What do we want to breed for? and Is this objective desirable (profitable) for my organization? The fact that we can change the population mean for one or more traits does not mean that we should do it. In this way, the breeding strategy revolves around the profit maximization objective.

Current status

Tree breeding efforts mimic the preoccupations of the industry (some may argue that enlightened breeders are always ahead of these preoccupations!). Thus, early breeding work focused on choosing the right species and provenances. Based on these results, breeders selected superior trees, generated base populations and estimated useful genetic parameters, including degree of genetic control, association between traits and stability of the genotypes in different environments. Most of this work was directed towards improvement of growth and stem form traits. As the plantation industry expanded, some work was directed to fitness traits, especially related to performance in marginal sites and disease resistance. Later the industry faced (and this is a current problem) a huge amount of wood ready to be processed and the associated wood quality issues.

Although strictly speaking all breeding programs should have a formally defined objective (in terms of influence on profit), they have been developed mostly when there is a processing industry associated with the breeding program. Borralho et al. (1993) presented the first breeding objective for *Eucalyptus globulus*, with a model including the forest growing and pulping processes. They derived profit equations based on volume, basic density and pulp yield, and calculated economic weights under different sets of assumptions. Later, Greaves et al. (1997) incorporated stem form and went into more detail modeling an unbleached kraft pulp subsystem. A similar exercise was developed by Chambers et al. (1997) for thermomechanical pulping of *Pinus radiata*, including tracheid length, coarseness, wood density and brightness. All these considered cost minimization for production of a single product. However, when the model includes quantity and quality of products, or more than one product, it is necessary to use a profit maximization approach. Greaves (1999) developed a model accounting for structural grade of timber including mean annual increment, branch index, stem sweep and taper, basic density, timber stiffness, kraft pulp yield and liner board ring crush. Apiolaza and Garrick (2001) explored the effect of volume and basic density in a combination of growth model and vertically forest, sawmill and pulp mill vertically integrated industry. Figure (1) summarizes the evolution of breeding objectives development in forestry. a) shows some of the models tested by Borralho et al. (1993) and Greaves et al. (1997), b) it is represented in the same papers, while examples of models type c) are found in Greaves (1999) and Apiolaza and Garrick (2001).

In spite of this evolution, breeding objectives where profit is maximized (e.g. Greaves 1999) are limited in that they draw their conclusions from existing quality grade-price structures. But if the entire sector faces a quality change, on the long run the quality grade-price structure will probably change. Borralho et al. (1993) objective which sought to minimize costs might be a better approach - if a product can be made more cheaply then the society is better off. But how the benefits are shared between consumer and producer may influence investment in improvement: for example, if a technology reduces pulp production cost, and the technology is broadly adopted by the industry, price will probably fall and the producer may not derive profit benefit from the technology over and above the benefit of staying in business.

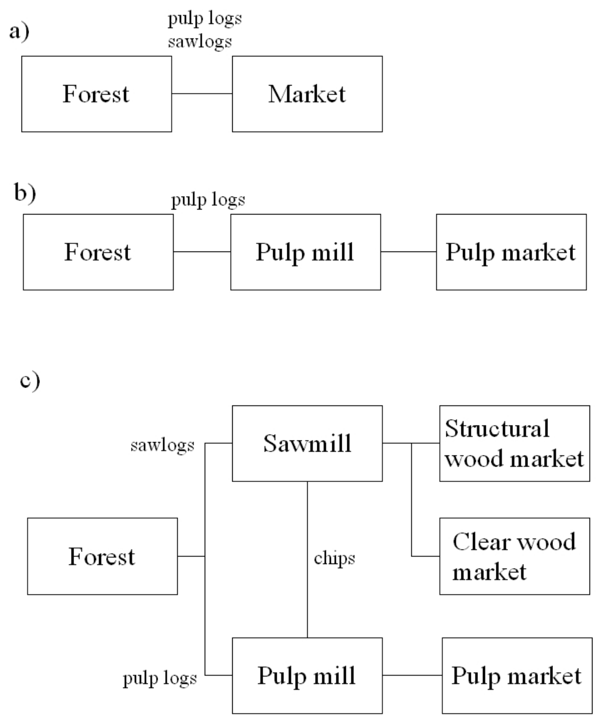

Figure 1: Evolution of breeding objectives from a) forest grower, b) vertically integrated pulp mill, to c) vertically integrated multiple processes and products.

Problems and challenges

Despite extensive work developing more comprehensive tree improvement objectives, there are several issues that hinder their usefulness. Some of the problems affect the construction of the objective function, other problems affect the application of the objective in the selection process and, finally, some problems impact on transforming gain in the objective into economic advantage for the industry.

Problems in w

Most breeding objectives take a vertically integrated industry point of view; i.e., they consider that a company owns both the forest and the processing side, with no transfer price between segments. In this way, the breeding objective is defined to maximize profit of the system as a whole. In contrast, the structure of the industry is more complicated and, although there are vertically integrated industries, the segments use pricing systems that are very simple to implement, but do not necessarily reflect the effect of raw materials quality on profit. A solution for the latter could be explored using a payment system where the impact from changes in a given trait is calculated with zero transaction cost, and then the profit is divided between layers of the industry.

While unit increases of some traits do not affect the size of the industry (e.g. pulp yield), others require re-scaling of the mills. For example, breeding for pulp yield (%) will increase the yield in the pulp mill, but it will not require any changes to the processing facilities. On the other hand, improving volume (m^3/ha) will provide the industry with potentially more volume than the maximum mill capacity. Some workarounds for this problem are: (i) assume a fixed output and modify the plantation area, so the level of improvement is reflected as a change of planted area; (ii) assume there is a substitution effect, so the processing company reduces the purchases of raw materials from third parties; and (iii) assume that we can increase processing facilities.

Returning to the more complex vertically integrated model (Figure 1-c), depending on the range of trait changes, raw materials and end-product prices, the final use of logs will change. If this change is due to breeding, that should be considered in the estimation of economic weights, and it is an opportunity to include optimization of multiple end-products systems in the modeling process. This problem is certainly more complex than the plain vanilla definition of objectives, but there is a lot of scope to contribute to the understanding of the impact of breeding.

Non linearity of the economic weight is perceived to be a difficult problem. For example, the grade-price structure for structural sawn timber is non-linear, and a cubic meter of sawn timber gains more in value from F4 to F5 (Australian Basic Working Strength) than it does from F8 to F11. Similarly with spiral grain there are thresholds, below which there is little perceived value in improvement. Still, these non-linearities are not extreme as, for example fat content in cows which has an optimum, with the economic weight being negative for both a decrease and an increase in fat content (Goddard 1998). The value of a trait movement (e.g. MOE) across a non-linear grade-price structure can be estimated by 'sliding' the assumed distribution of the trait and recalculating the average value from the new volumes in each grade, assuming that trait change has not itself altered the grade-price structure.

Some alternative methods for the elicitation of economic weights have been proposed. Kempthorne and Nordskog (1959) introduced restricted selection indices, where in the derivation of the indices some restriction on the level of response (gain) for some traits are imposed (see for discussions Brascamp 1984; Cotterill and Jackson 1985a and Cotterill and Jackson 1985b). Pešek and Baker (1969) developed a restricted index were weights are calculated to maximize gain according to breeder's desires. These indices are not optimal, because if we are introducing restrictions to changes in response it means that the current economic weights are not appropriate.

Problems in selection criteria

$\boldsymbol{G_{ss}}$, the covariance matrix between selection criteria, is relatively well understood, at least for growth and form traits. The most important effort in this field is the development of intelligent sampling strategies for wood properties (see, for example, Greaves et al. 1996 and Raymond et al. (1998)).

Problems in criteria/objectives

$\boldsymbol{G_{so}}$, which often involves age-age correlations, has been subject of many research efforts to facilitate early selection, and there is lack of information. There have been attempts to use other methods to allow for early selection (e.g., Magnussen 1993). Some researchers have argued that there are non-genetic models (e.g. growth models) that are far more developed than any age-age calculation obtained from progeny trials. Thus, Carson et al. (1999) introduced the concept of 'genetic multipliers', including breeding values in growth models, allowing the calculation of profit change when using improved material. There is scope for important research modeling wood properties using this approach.

Revisiting Equation (1), it is clear that the degree of understanding (and certainty) of its components is quite different, each component presenting different research opportunities.

Final remarks

In summary, why are so many breeders not yet using economic objectives? It might be possible that they are waiting to have enough information to be certain of all relationships in Equation (1). Unfortunately, effective decision making requires not only accurate but also timely decisions.

Research on the topic clearly shows that breeding objectives can be defined with different levels of detail, and that there is a clear need to update them on a regular basis, as soon as new research results are available. Additionally, sensitivity analysis is an integral part of the work in breeding objectives, and can contribute to understand the impact of different sets of assumptions in the results of the economic model. Some studies (e.g. Greaves unpublished) have shown that economic weights are rather insensitive to a range of different assumptions.

It might be helpful to see breeding strategies as an exercise on the use of information for risk management. Risk encompasses uncertainty about the future in terms of both positive and negative outcomes; therefore, risk involves opportunities and threats. Breeding programs face environment risks (e.g. changing markets for forest products, political trends about the use of genetic material, emergence of new pests and diseases) as well as decision making risk (related to the accuracy of the genetic and economic information) for breeding and deployment.

Breeding programs must respond to ever increasing demands from the forest sector, including new traits to be assessed, reductions of operational costs and even justification of the existence of the program. The answers to all of these questions rely on the prediction of gains obtained with the breeding program, and consequently on the economic importance of changes in all the traits affected by breeding.

Programs that do define objectives are taking risks, but also are the programs that choose not to explicitly define them. However, when defining the objectives breeders will gain a better understanding of the effects of their decision making. Better we just get used to an uncertain environment.

Acknowledgment

Thanks to G.W. Dutkowski for comments on the manuscript.

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