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CHOOSING SELECTION TRAITS FOR PROFITABILITY:

AN INTRODUCTION TO THE PROBLEM

C.J.A. Shelbourne

Report No. 25 November 1997

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EXECUTIVE SUMMARY

Selective breeding of trees is usually done to increase profits for the grower and for the processor who markets the end product, in this case kraft pulp from *Eucalyptus nitens*. Choosing the "right" traits for selection and weighting them correctly is critical for maximising the profitability of genetic gains.

Developing a "breeding objective" (a numerical combination of harvest-age traits, weighted by their economic value) is explained and illustrated by the work of Bruce Greaves (1997). His goal was reduction of total costs of production of unbleached kraft pulp. A kraft pulping model is shown with an associated plantation model where costs are determined by volume production per hectare, basic wood density, pulp yield and tree form, the costs determining the economic values for these traits in the breeding objective.

Provisional estimates of heritabilities and genetic correlations amongst the traits are then used to provide a selection index to combine the values of different traits for phenotypic selection of superior trees. Future development of a breeding objective for *E. nitens* in New Zealand is proposed which might include pulp and paper quality and value.

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INTRODUCTION

Selective breeding of trees and of animals and crop plants is usually done to increase profits for the grower and for the processor who markets the end product. In the case of eucalypts in New Zealand, the most important end product is kraft pulp and paper. Choosing the "right" traits and weighting them correctly, so selection of future parent trees gives maximum gain in profit, is critical to the success of the tree breeding programme.

It was an animal breeder, Lanoy Hazel, who proposed the concept of a "breeding objective" or "aggregate genotype", which is a numerical combination of the commercially-valuable traits of an animal, each weighted by its economic value (the amount by which net profit might be expected to increase for a unit improvement of that trait) (Hazel, 1943).

This is expressed by:

$$H \text{ (aggregate genotype)} = V_1 A_1 + V_2 A_2 \ldots\ldots + V_n A_n$$

Where the Vs are the economic values and the As are the genetic (breeding) values of each trait in the particular animal.

Each of the traits making up the breeding objective is called a "breeding objective trait", and they form the main components of profitability of the whole production system for that breed of animal. The same thing applies to a tree species being grown for a particular product, in this case

Eucalyptus nitens for kraft pulp and paper. The breeding objective traits, however, are those of the tree at harvest and those which are measurable during processing and in the final product. The breeder usually wants to assess progeny tests and make selections well before harvest age, and before direct measurement of processing and end-product traits is possible. The relationships between the traits he can measure, the "selection criteria", and the breeding objective traits must then be worked out. For this study we need to identify the main components of profitability of an *E. nitens* plantation, supplying pulpwood to a kraft pulpmill. This breeding objective will be specific to kraft pulping. If one wants to construct a breeding objective that covers several products, then the same process of identifying components of profitability for each product must be gone through before these can be aggregated.

It is indeed fortunate for us that Bruce Greaves' recently completed PhD thesis (Greaves, 1997; Greaves *et al.*, 1996, 1997; Greaves and Borralho, 1996) included the development of a breeding objective for *E. nitens* in southeastern Australia. This attempt of mine to write an explanation and guide on the choice of selection traits for the Eucalypt Breeding Cooperative is based largely on his thesis and the earlier work of his supervisor at the University of Tasmania, Nuno Borralho, who developed a breeding objective for *E. globulus* in Portugal (Borralho *et al.*, 1993). These are the first formally-derived breeding objectives for forest trees using the Hazel model that have been published. Although Mike Wilcox introduced the use of the Hazel-Lush selection index to NZ radiata pine breeding in 1974, we have never developed formal breeding objectives for this or other species.

A THEORETICAL KRAFT PULPING MODEL

Greaves developed the following model for kraft pulping that evaluated the effect of **pulp yield** and **basic wood density** of the pulpwood on each stage of the process.

The kraft pulping process can be broken down into several stages (Fig. 1)[(1)] . Roundwood is chipped and then digested in the presence of Effective Alkali (EA) (and small amounts of other chemicals), and then washed to leave unbleached pulp. The spent cooking liquor (black-liquor), containing spent Effective Alkali and dissolved lignin and other wood components (called organic black-liquor solids, OBLS) is then concentrated in the evaporators, burnt in a recovery boiler and the EA re-causticised for re-use. The energy from burning the OBLS is used to power part of the process.

The total cost of pulping is a sum of the costs, both capital and operating, of chipping, digestion, chemicals consumed (not EA), evaporation of black liquor, recovery furnace and recausticising the EA. These costs can all be expressed in **US$$ per tonne of oven-dry, unbleached kraft pulp**. Each of these costs, Greaves shows, is a function of one or both of basic wood density and pulp yield; density is measured as dry weight per unit of green volume (tonnes/m^3) and pulp yield as dry weight of pulp per dry weight of wood required to make it (oven-dry tonnes of unbleached pulp/oven-dry tonne of wood).

The relationships between the cost of each part of the kraft process and pulp yield and density are shown in Table 1 (Greaves gives the rationale in more detail).

[(1)] Figures and Tables in this report are reprinted from Greaves (1997), with permission of the author.

PLANTATION, HARVESTING AND TRANSPORT COSTS

The next step is to define the costs of growing the plantation and those of harvesting and transport of the wood to the pulpmill. The goal that is assumed throughout is the **reduction of total production costs of unbleached kraft pulp**, and the production function assumed includes standing volume at harvest (VOL), basic wood density at harvest (DENS), pulp yield (PY) and stem form (FORM), a six point subjective score for bole straightness and branch size. These traits are the **breeding objective traits** (at harvest).

The costs of growing pulpwood include costs of land, establishment and maintenance; each expressed per tonne of dry pulp produced. They are each inversely proportional to VOL, DENS and PY:

$$C_{land} + C_{estab} + C_{maint} \propto \frac{1}{VOL.DENS.PY}$$

In the costs of harvesting, increasing density and pulp yield both increase the weight of pulp produced per m^3 of wood harvested, thus decreasing costs. Large trees reduce costs of harvesting and so do straighter, light-branched trees.

Thus $$C_{harv} \propto \frac{1}{VOL^{0.2}.DENS.PY.FORM^{0.1}}$$

Transport is limited by the weight of wood a truck can carry and not by volume or bole straightness.

Thus $$C_{trans} \propto \frac{1}{DENS.PY}$$

Pulping costs are independent of volume per hectare growth in the plantation and largely independent of the form of the tree. Pulping costs, as shown above, are all related to basic density and for pulp yield.

All costs are shown in Table 2. It is noteworthy that growing costs total \$27 per OD tonne of unbleached pulp, harvesting and transport amount to \$120 and pulping costs total \$200, making respectively 8%, 35% and 58% of the total cost of \$347 per tonne of unbleached kraft pulp (all US dollars).

ECONOMIC VALUES FOR BREEDING OBJECTIVE TRAITS

Economic values, defined as the "savings in total pulp cost with unit increase in each trait" were calculated from all the cost data. The breeding objective (which applies to harvest age traits) is therefore:

$$G = 0.269\,(VOL_a) + 349(DENS_a) + 411\,(Py_a) + 1.15\,(FORM_a)$$

Where G is the gain (discounted to the time of planting) and where VOL_a, $DENS_a$ etc. are breeding values expressed as (positive) deviations from the population means at harvest age. These breeding values are dependent for their calculation on the heritabilities of, and genetic correlations amongst the breeding objective traits. These were derived by Greaves from three sources, a study of 18 open-pollinated *E. globulus* families, 10 trees per family aged 8 years (from 14 provenances), growing near Smithton, Tasmania (Dean, French and Tibbits, 1990), his own thesis research on pilodyn and wood density and other unpublished data, and are shown in Table 3. These genetic parameter estimates may not be precise, particularly those involving pulp yield, because they were estimated from small numbers of families. They will control the selection index, etc. However, the economic values in the breeding objective above, are independently arrived at, from the cost data.

The breeding objective can also be expressed in terms of the phenotypic mean values for each trait by calculating a selection index:

$$G = 0.084\,(VOL_p) + 221\,(DENS_p) + 214\,(Py_p) + 1.81\,(FORM_p)$$

Where VOL_p etc. are phenotypic values.

The selection index coefficients shown above are based on the genetic parameters, that is heritability of and genetic correlations between the (harvest-age) traits.

Neither of these expressions allow easy interpretation of the importance of the traits for breeding. For instance, the economic value for density of \$349 represents an increase in density of 1000 kg/m^3, for example, from 500 to 1500 kg/m^3 (!), whereas the actual range of density is from about 400 to 600 kg/m^3. In addition the variances, both genetic and phenotypic, and the heritabilities differ amongst traits. A more convenient and interpretable way of expressing the economic values is as a relative value, as a proportion of the phenotypic standard deviation as follows:

VOL	3.2
DENS	3.6
PY	1.9
FORM	1.0

These values take account of the heritabilities and genetic correlations amongst the breeding objective traits and thus are specific to the genetic parameters in Table 3. Another way of looking at the situation, which again depends on the particular heritabilities and genetic correlations between traits that have been used, is through the gains from different proportions of the population selected, from multitrait index selection and from selection for single traits (Figure 4).

From these data, for example, if 10% of the trees were selected, the expected gain (savings in pulp cost) would be \$17.3 per ODt of pulp for multitrait selection, versus \$12.6 per ODt for VOL alone, \$6.5 per ODt for PY alone and \$14 for density alone (all figures are discounted to year 1 of plantation). Savings (not discounted) at end of rotation, are about double these numbers.

FUTURE DEVELOPMENTS

The apparent lower importance of pulp yield in Greaves' breeding objective results, in part, from the positive genetic correlation of 0.3 with density, which means that selecting for density alone utilises a considerable correlated response in pulp yield. If the genetic correlation between pulp yield and density was near zero, pulp yield might become a more important trait to select for, provided its heritability was still reasonably high.

The breeding objective is composed of harvest-age traits and their breeding values. Further work is needed to relate potential **selection criteria** at about half rotation age (6 years) such as dbh, height, wood density, pilodyn, pulp yield (and its surrogates, lignin and cellulose content, and NMIR spectra) to the breeding objective traits.

Greaves' breeding objective is for **reducing costs of production of unbleached kraft pulp**. It takes no account of pulp quality or paper quality. Recent work on the 29-tree-study of *E. nitens* for this Cooperative showed that wood density alone or combined with pulp yield and fibre length were good predictors of handsheet properties, particularly of handsheet bulk. Wood density may have an additional role in a future breeding objective for *E. nitens* in New Zealand which might include increased quality and value of paper products. Future availability of SilviScan for measuring wood-fibre dimensions non-destructively would facilitate selection for handsheet quality.

To develop a breeding objective of this kind for *E. nitens* in New Zealand would require some more work, to put the objective together and to obtain some better estimates of genetic parameters. Construction of a well-based breeding objective on which to base the choice of clones for orchards can dramatically improve the profitability of planting improved stock, for a relatively small investment.

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Table 1: The cost of each stage of production as a function of pulp yield (PY) and density ($DENS$). The constants k_1 and k_2 for the evaporator cost are approximately 1.6 and 0.7 respectively.

production stage	cost function - $COST \propto f(DENS, PY)$
chipping	$C_{chip} \propto \frac{1}{PY}$
digester	$C_{dig} \propto \frac{1}{PY.DENS}$
digester chemical (excluding EA)	$C_{chem} \propto \frac{1}{PY}$
evaporators	$C_{evap} \propto \frac{\frac{1}{DENS} + k_1.(1-PY) - k_2}{PY}$
recovery	$C_{rec} \propto \frac{(1-PY)}{PY}$
recausticize	$C_{recaust} \propto \frac{(1-PY)}{PY}$

Table 2 : The cost of each stage of production, in US dollars per oven-dry tonne of unbleached eucalypt kraft pulp i.e. $ per ODt UBEK, as a function of standing volume at harvest (*VOL*), stem form (*FORM*), pulp yield (*PY*) and density (*DENS*). Costs of pulping stages are split into total operating cost and capital cost (*operating/capital*), and numbers in parenthesis are negative.

production stage	cost function - $COST \propto f(VOL, DENS, PY, FORM)$	base cost ($US per ODt UBEK)	timing of cost
cost of land	$C_{land} \propto \frac{1}{VOL.PY.DENS}$	1.6	annual cost
plantation establishment	$C_{est} \propto \frac{1}{VOL.PY.DENS}$	24	rotation start
plantation maintenance	$C_{main} \propto \frac{1}{VOL.PY.DENS}$	1.6	annual cost
harvesting	$C_{harv} \propto \frac{1}{VOL^{0.2}.FORM^{0.1}.PY.DENS}$	80	rotation end
transport	$C_{trans} \propto \frac{1}{PY.DENS}$	40	rotation end
chipping	$C_{chip} \propto \frac{1}{PY}$	20/15	rotation end
digester	$C_{dig} \propto \frac{1}{PY.DENS}$	30/50	rotation end
chemical (excluding EA)	$C_{chem} \propto \frac{1}{PY}$	5/10	rotation end
evaporators	$C_{evap} \propto \frac{\frac{1}{DENS} + 1.6(1-PY) - 0.7}{PY}$	40/15	rotation end
recovery	$C_{rec} \propto \frac{(1-PY)}{PY}$	(50)/35	rotation end
recausticize	$C_{recaust} \propto \frac{(1-PY)}{PY}$	15/15	rotation end

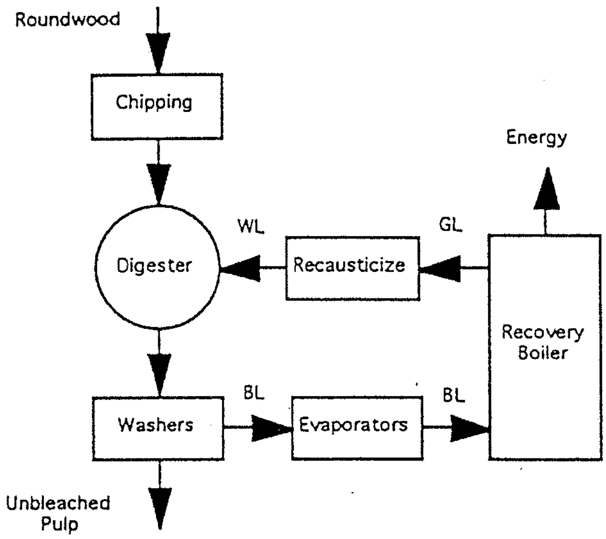

Figure 1: A diagrammatic representation of a kraft pulp-mill, where BL is black-liquor, WL is white-liquor, and GL is green-liquor.

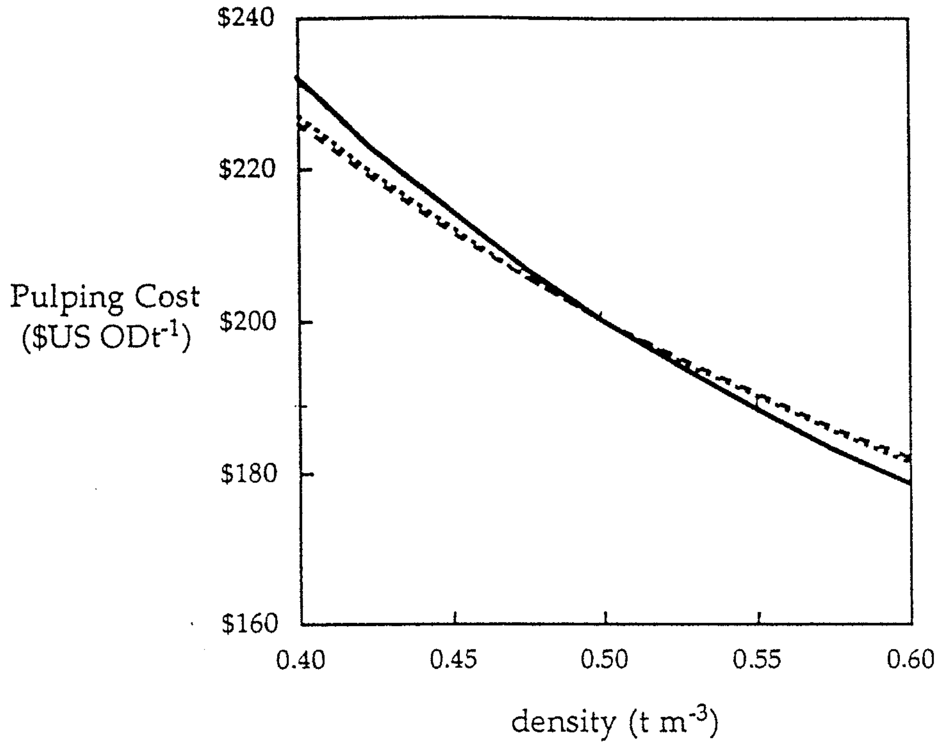

Figure 2: Total pulping cost (US dollars per oven-dry tonne of unbleached kraft pulp - US\$ ODt^{-1}) versus density, for three pulp-mill cost structures: high digester costs (———); high recovery returns (..........); and intermediate costs (- - - - -).

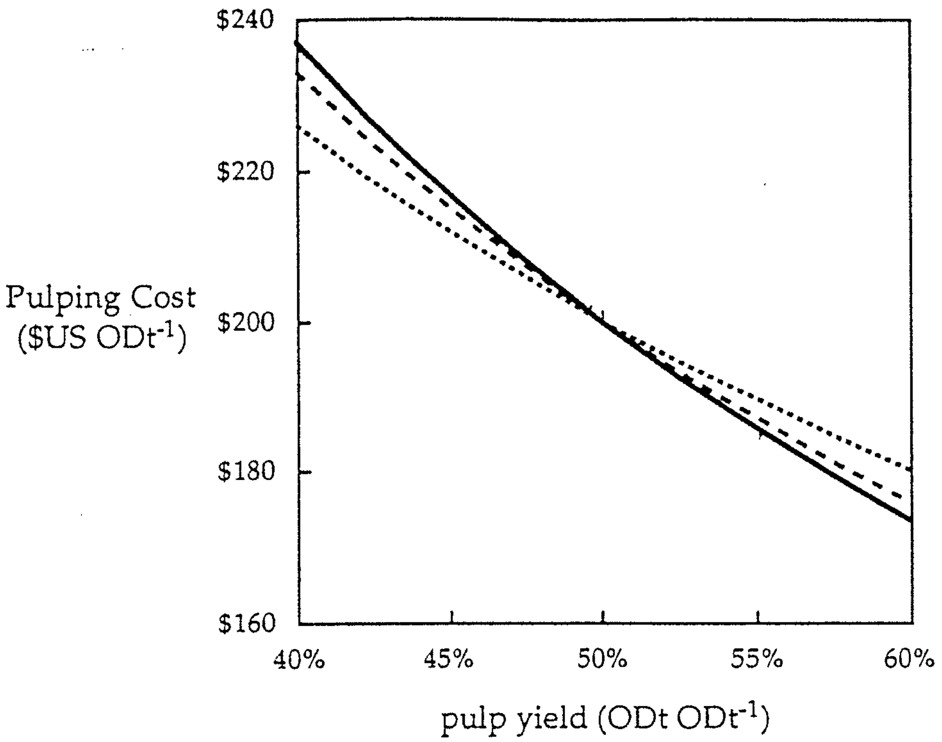

Figure 3: Total pulping cost (US dollars per oven-dry tonne of unbleached kraft pulp - US\$ ODt^{-1}) versus pulp yield, for three pulp-mill cost structures: high digester costs (———); high recovery returns (..........); and intermediate costs (- - - - -).

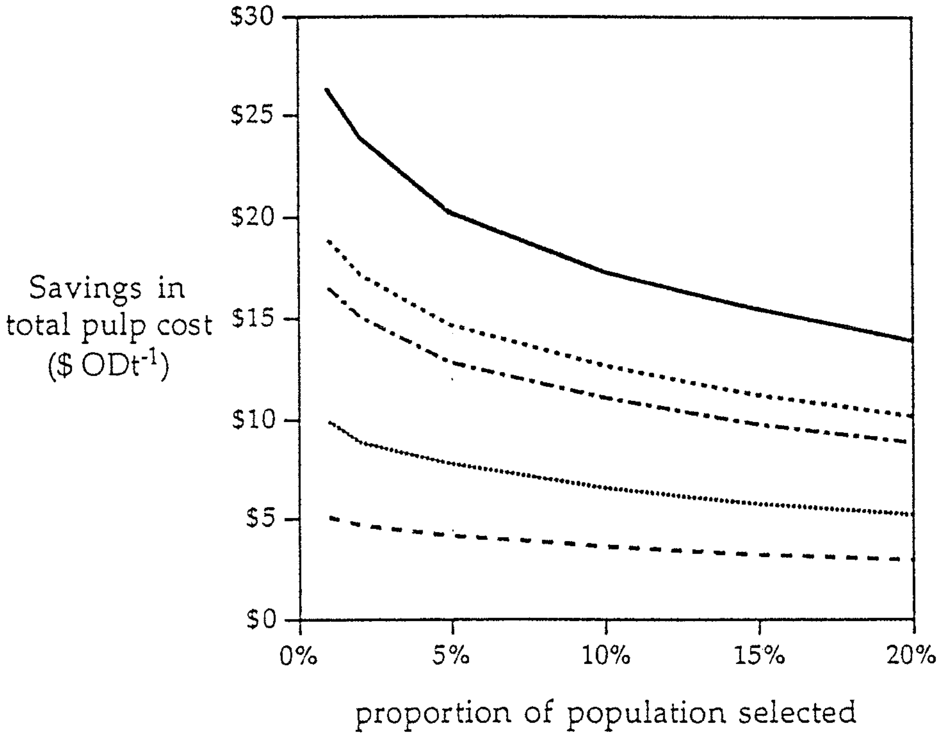

Figure 4.: Savings in total pulp cost due to selection (discounted to the time of plantation establishment) versus proportion of the population selected, for multi-trait selection (———); and single-trait selection on: density (.......); standing volume (-.-.-.); pulp yield (..............); and stem form (- - - -). The presented responses are the simple mean of the observed responses to selection individually applied to 50 simulated data-sets.