Evaluation of economic weights for selection and breeding in macadamia

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ABSTRACT

The identification of economically sensitive traits is a critical step in the breeding process as it defines the direction of the breeding program. Quantifying how each trait affects the profitability of the production system further increases the efficiency of a breeding program. Production activities are ultimately aimed at maximising the level of consumer satisfaction with the product concerned which is, in turn, relfected by the profitability of the growing and processing stages of the production process. In that regard, breeding objectives need to be consistent with maximising the profitability of the farm production sector by producing genotypes with improved performance. By assigning economic weights to different traits, genotypes with differing performance it will be possible to predict objectively how they contribute to profitability. In this paper, the derivation of economic weights for different traits in Macadamia is described. A financial model of a large-scale commercial macadamia orchard typical of those in Northern New South Wales was developed. Important parameters for the model including yields, prices, farm costs and various management options, were determined in consultation with industry representatives. Discounted cash flow analysis was used with a 20-year planning horizon. Economic weights for different traits were then determined by observing the change in the Net Present Value of the income stream generated by the model as a result of independently increasing the level of each trait by one unit. The use of economic weights in a breeding program will be illustrated with a simple example.

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INTRODUCTION

Macadamias are an important and expanding perennial tree crop industry of Australia (Mason and McConachie 1994). Establishment of macadamia orchards requires a large investment of capital which, after several years of zero of low yields, is expected to provide a high return on investment as the orchard matures (Rielly and Bevan 1995, Hinton 1996). Assuming that managerial practices are adequate, the profitability of the enterprise can be raised by the selection of varieties that are superior in economically important traits for orchard establishment. In 1996 a breeding program was initiated by CSIRO Division of Plant Industry, in collaboration with the Queensland Department of Primary Industries and New South Wales Department of Agriculture for the production of superior macadamia cultivars.

The aim of this paper is to develop a model of macadamia production which be used to calculate the economic value (or weight) of important traits. The economic weight of a trait is defined as the effect on the profitability of a production system of a one-unit change in the level of a trait, independent of the change in other traits (Weller 1994). Knowledge of the economic weight of a trait is important for the evaluation of genotypes which differ in performance across several traits. Once determined, the economic weight for different traits can be used to calculate a selection index (Cotterill and Dean 1989). A selection index is a linear function of coefficients that weight a genotype's observed level of performance for a trait by the degree of genetic control of the trait (i.e. how easily the level of performance can be captured by selection) and the value of a change in the trait. This allows genotypes that differ in performance to be evaluated objectively with respect to their impact on the profitability of the production system.

The macadamias industry can be broken into three sectors: orchard production; processing of nut-in-shell (NIS); and marketing. Orchards may vary in size from small part-time enterprises of less than 20 hectares to large commercial operations more than 100 hectares. After site preparation, orchards are planted with elite cultivars that have been vegetatively propagated, usually by grafting onto seedling rootstock. Densities may range 200 to 300 trees per hectare. Fertiliser, herbicide, and slashing and mulching operations commence in year one followed by an insect pest and disease management program that begins in year four. In general, trees start producing around year 5, with yields increasing as the orchard ages. Nut-in-husk (NIH) is mechanically harvested from the ground after which the husk is removed and dried to approximately 10% moisture content to give nut-in-shell (NIS). Skirting and hedging is required at later ages to manage the canopy and maintain orchard productivity.

NIS is sold to processors at prices paid on the basis of NIS with a premium for consignments with high kernel recovery. Kernel recovery is the proportion of nut mass that is kernel. Processors dry the NIS to 1.5 % moisture content and crack the nut to extract the raw kernel. This may either be sold to distributors or roasted to produce a higher grade product. Processors sell product in different styles or grades with a premium paid for styles containing a high proportion of whole kernels of intermediate size (approx. 13-18mm in diameter). Macadamias are commonly consumed as either snack foods, as an ingredient in confectionery of bakery products, or as cooking oil.

The model presented in this paper has been developed to examine the impact of 5 important traits: nut-in-shell (NIS) yield per tree; kernel recovery; tree size as determined by projected canopy diameter; and percentage whole kernel. Previous economic models of macadamia production have been developed by Reilly and Bevan (1995) and Hinton (1996), however, they were primarily developed to evaluate the profitability of macadamia production were insufficiently flexible to enable economic weights to be calculated. In this study, the effect on plantation income from changes of yield of NIS per tree and kernel recovery were directly modeled through the development of a unique price formula to transmit processor income into payments to growers. In particular, this price formula was extended to accommodate variation in proportion of whole kernels on processor income. Projected tree canopy diameter was also allowed to affect income through its affect on planting density. In addition, variations in planting density affected production costs for inputs that were applied on a per tree basis. Several inputs were applied in proportion to canopy volume which was expressed as a function of projected canopy diameter.

METHODS

Base values for biological traits

Site averages from the Clunes macadamia regional variety trial in northern NSW (Stephenson *et al*. 1996) for annual NIS; percentage kernel recovery; percentage wholes kernel; projected tree canopy diameter; and tree height, were used as the base values in the economic model. Values for annual NIS yield per tree are presented in Table 1. It was assumed that with regular skirting and hedging operations at later ages, the yield of an individual tree attained in year 10 could be maintained to year 20 (McConchie *et al*. 1998).

Table 1. Base values for annual yield of nut-in-shell per tree (NIS) by orchardage.

Age	0	1	2	3	4	5	6	7	8	9	10+
NIS (kg)	0	0	0	0	0.4	1.6	6.6	5.9	10.9	13.4	19.9

Kernel recovery (kr) and the proportion of whole kernels (w) were set to 0.33 and 0.45 respectively. A constant value for kernel recovery and percentage wholes was used across all years, as these traits do not exhibit a trend with age (Hardner *et al.* 1999a). Projected tree canopy diameter at planting (d_0) was set to zero and to 5 m at 10 years of age (d_{10}). A linear growth rate in canopy diameter was assumed between planting and year 10 with no change after year 10 because of regular skirting and hedging operations. Tree height at planting (h_0) was set at 1.2m with height at 10 years (h_{10}) equal to 6.4m. To model height growth it was assumed that annual height growth rate between planting and 5 years was four times that between 5 and 15 years after planting. Annual growth rates after 15 years were assumed to be zero.

Farm characteristics

The economic model was developed for a farm with and an orchard of 100 hectares (T_a = 100) with and additional 10 hectares for farm infrastructure (roads fences sheds). The capital cost of land was determined on actual farm area, while the cost of orchard management practices was based on actual orchard area. The model assumed all the 100 hectares is established in the one year. The farm was assumed to be located in northern New South Wales and therefore irrigation was a required management input (Trocoulias and Johns 1992). The planning horizon for the model was 20 years.

Planting density (PD, trees per hectare) was determined by the diameter of the tree canopy reached at year 10 (d_{10}) and an allowance for tractor clearance (c):

$$PD = \frac{10000}{\left[d_{10} * \left(d_{10} + c\right)\right]}$$

Tractor clearance was set to 2m in this study giving a planting density of 286 plants per hectare (5x7m) for the base value of 5m for d_{10}.

Cost of variable inputs

Variable inputs are defined in this study as those that are directly influenced by the biological traits of interest. Inputs included were: (i) planting and tree replacement; (ii) fertiliser operations; (iii) foliar spray operation; (iv) insecticide operations; (v) disease control; (vi) herbicide operation; (vii) slashing and mulching operations; (viii) skirting and hedging; and (ix) harvesting. Costs for these inputs were expressed per tree with total farm values determined by multiplying by planting density and orchard area. This enabled costs to change with planting density.

In general, the annual variable cost per tree of the i^{th} input in year t was modelled as:

$$Vc_{it} = Mc_{it} + Ac_{it}$$

where Mc_{it} is the annual cost of the material required for the input in the t^{th} year, and Ac_{it} is the annual cost of applying the input in year t. The cost per tree of the material for the i^{th} input was modelled as:

$$Mc_{it} = \left(R_{it} * Uc_i\right) * Nm_{it}$$

where R_{it} is the application rate per tree (units/tree) of the input in year t, Uc_i is the unit cost ($/units), and Nm_{it} is the number of applications in the t^{th} year. The cost per tree in year tof applying the i^{th} input was modelled as:

$$Ac_{it} = \left(X_{it} * \frac{d_{10}}{1000} * \frac{Tc_{it}}{Ts_{it}}\right) * Na_{it}$$

where X_{it} is the number of times a the machinery must pass up a planting row each application in year t, Tc_{it} is cost per hour of the tractor used to apply the input ($ per hour) in the t^{th} year, Ts_{it} is the tractor speed for the operation (km per hour) in the t^{th} year and Na_{it} is the number of times the application cost is incurred in the t^{th} year.

A summary schedule of the values of variables used to calculate the per tree costs of different inputs is presented in Table 2. The operating cost per hour for the tractors used on the model farm were assumed to be $ 15 for a 100HP tractor, $ 12 for a 70HP tractor, and $ 10 for a small second hand tractor.

Insert table here

The cost of tree planting was set at $ 20 per tree. This included costs of land preparation (i.e. clearing, stick raking, contour drain construction, marking rows, deep ripping, and row cultivation), planting and purchase of the tree. A cost for the replacement of dead trees of 2 % of the initial planting costs was included in the first 4 years.

A complete fertiliser was used for all the orchards nutrient requirements. Fertiliser application rates increased with the annual increase in tree size (Table 3). Essential micro-nutrients and trace elements were applied as foliar sprays (Table 2). The cost of foliar spray application was negligible as they are combined with insecticide operations.

Table 3. Annual fertiliser application rates by orchard age.

Age	1	2	3	4	5	6	7+
Rate (kg/tree/ application)	0.1	0.2	0.4	0.5	0.7	0.9	1.2

Insecticide operations commenced in year four. Endosulfan was used to control of flower caterpillar and fruit spotting bug while beta-cyfluthrin was used for macadamia nutborer (O'Hare *et al*. 1996). Both chemicals were assumed to be applied twice a year. The application rate per tree of these chemicals was determined by the canopy volume of the tree:

$$Canopy\ volume = \frac{\pi * d_t^2 * H_t}{12}$$

where, d_t is the projected canopy diameter at year t, and H_t is the tree height at year t.
The major fungal diseases of macadamia include blossom blight, husk spot and trunk canker (O'Hare *et al*. 1996). The fungicide carbendazim, was used for the control of blossom blight, while copper oxychloride was used for the control of husk spot. Again, the application of carbendazim and copper oxychloride did not incur additional tractor operating cost because they can be applied with either of the two insecticide sprays (ie $Ac_i = 0$).

The herbicide glyphosate is used to control the growth of weeds under the tree canopy. The application rate per tree was determined assuming 1/3 of the orchard would be sprayed each application. The total number of herbicide applications decreases with orchard age to compensate for a decrease in weed growth as the orchards canopy develops (Table 4).

Table 4. Number of herbicide applications per year (*Na*) by orchard age.

Age	1	2	3	4	5	6	7	8	9	10+
Na	8	8	8	7	7	7	6	6	6	5

Slashing was applied to control grass and weeds within the inter-row area. The number of slashing applications per year and the number of passes per row varied with orchard age (Table 5) to compensate for the additional growth of weeds when the orchard was young. The speed of tractor operation was also varied (Table 5), with slower speeds in the earlier years as it was assumed that the large volume of weeds would increase tractor work rate.

Table 5. Number of applications per year (*Na*), passes per row and tractor speed for slashing by orchard age.

Age	*Na*	Passes per row	Tractor speed (km/hr)
1	6	3	2.5
2	6	3	2.5
3	6	3	2.5
4	6	3	2.5
5	6	2	3.5
6	5	2	3.5
7	4	1	3.5
8+	3	1	3.5

Mulching redistributes grass slashings, leaf drop and nut husks from the inter-row area under the tree canopy and is used to control of weeds, maintain a more even soil temperature, improve the soil surface structure, and reduce soil erosion (O'Hare *et al*. 1996). It is assumed that mulching operations do not commence until the orchard begins to produce NIS at year 5.

Branch thinning by skirting and hedging were applied at later ages to maintain orchard productivity by increasing light and spray penetration and reducing conditions conducive to fungal diseases, and to maintain machinery access (O'Hare *et al*. 1996). Outside contractors were used for skirting and hedging operations. It was assumed that costs for skirting and hedging were the same, with the cost per tree of undertaking skirting and hedging determined as:

$$Ac_{skirting+hedging,t} = \left(\left[X_{skirting+hedging,t} * \frac{d_{10}}{1000} * \frac{Rate_{skirting+hedging,t}}{Ts_{skirting+hedging,t}} \right] + \$removal \right) * Na_{skriting+hedging,t}$$

where $Rate_{skirting+hedging,t}$ is the hourly rate of contract skirting and hedging, *$removal* is the additional machinery cost per tree of removing the debris, and the other variables are as defined above. A contract rate of $ 100 per hour was used and *$removal* was set to $ 0.30 per tree. Operations did not start until year 6 with skirting and hedging alternating between years. Tractor speed decreased as the orchard aged (Table 6).

Table 6. Tractor speeds for skirting and hedging operations by orchard age.

Age	6	7	8	9	10	11	12+
Speed (km/hour)	3.5	3.5	3.0	3.0	2.5	2.5	2.0

Two different harvesters were used the small "nut naber" and the larger "macmaster". The "nut naber" was not required during the first harvest of the season, although it followed the "macmaster" for the remaining harvests. Harvesting operations commenced at year 5 with nuts were harvested every four weeks. The number of harvested a year increased with increasing production to year 7 after which the number remained constant (Table 7). Tractor speed was assumed to be unrelated to yield per tree (Table 2).

Table 7. Number of harvests per year for two different harvesters by orchard age.

Age	Applications/year (Na)	
	Nut naber	Macmaster
4	0	0
5	2	3
6	3	4
7	4	5

Fixed costs

Fixed costs for the model include: (i) land expense; (ii) labour (iii) repairs and maintenance; (vi) fuel and oil (sundry); (v) electricity; (vi) administration; and (vii) rat control.

An annual land expense was estimated as an annuity. The capital value of land was set at $ 10 108/ha which was typical of the present value of unimproved sloping land, suitable for macadamia production in northern NSW (LJ Hooker, Ballina pers. comm.). This gives an an annual land expense (opportunity cost of the investment) for the entire farm of $ 113 347 using a discount rate of 8 percent over 20 years.

The labour requirement of a commercial macadamia orchard is considerable. Labour requirements for this model were a manager; full-time employees and casual labour during harvest (Table 8). It was assumed that the orchard manager is not involved with the direct labour requirement for the orchard management practices. Casual labour was used to meet the requirement of de-husking, sorting and transport of NIS from the orchard to the shed during the harvest period each year. Annual wages for the manager and full-time were set at $40 000 and $30 000 respectively. It is assumed that casual employees work a 30hr per week at a rate of $15 per hr (see harvesting operation for duration of harvest period). Indirect costs such as insurance and superannuation are included in the hourly rate for casual employees.

Table 8. Labour requirements for the model orchard by orchard age.

Age	0	1	2	3	4	5	6	7	8+
Full-time	3	3	3	3	2	2	2	3	3
Casual	0	0	0	0	0	0	2	2	3

The cost of repairs and maintenance to farm machinery (excluding the tractors), buildings and related capital infrastructure was estimated to be $7 000 per year. An allowance of $5 000/year was used to operate the farm utility and other miscellaneous farm machinery. An electricity expense of $7 000 per year was assumed for the operation of dryers, de-husker, elevators and other miscellaneous workshop equipment. Administration costs of $10 000 per year include rates, professional fees, insurance, registrations, office expenses, and licenses. The cost of rat poison was assumed to be $1 000 per year but was not introduced into the farm managerial program until year three.

Capital costs

It is assumed that the model farm will require the capital equipment outlined in Table 9. Items such as mulcher, harvesters, and de-husking equipment were not required until later years. Some items are assumed to have a life span less than 20 years and therefore purchased on more than one occasion during the life of the project.

Table 9. Capital requirements

Capital Item	**Cost ($)**	**life (years)**
Year 0		
Shed	25 000	20
Workshop equipment	6 000	20
Sundry tools	5 000	5
100HP cab tractor	65 000	15
70HP 4x4 tractor	45 000	15
Small orchard tractor (2nd hand)	8 000	15

Utility	15 000	10
Slasher (3.6m)	12 000	20
Tipping trailer (2 @ $5000ea)	10 000	10
Herbicide application	4 000	20
Air blast sprayer	20 000	15
Fertiliser spreader	10 000	20
Land est/preparation @ $20/tree	571 429	
Total Year 0	**796 429**	
Year 4		
Machinery:		
70HP orchard tractor	45 000	15
Mulcher	9 000	20
Small nut-naber	25 000	20
Macmaster finger wheel	100 000	20
Dehusking plant:		*20*
Dehusking machine	10 000	
Sorting tables (2)	9 000	
Water sorters (2)	4 000	
Hopper	3 000	
Elevators (3 @ $1500ea)	4 500	
Tromel	4 000	
Power (phase 3)	20 000	
Silos 40t (6 @ $25000ea)		
Incl.: fan, elevator etc	150 000	
Installation	30 675	
Total Year 4	**414 175**	

It is assumed that the shed, large enough to contain idle machinery and the de-husking plant, is built in year four. Workshop equipment includes items such as compressor, welder, tools and other miscellaneous workshop equipment with a five-year maintenance requirement. The large 100 HP cab tractor was required for heavy machinery operations including spray operations with the air blast sprayer and harvesting with the large macmaster. The smaller 70HP orchard tractor is used to operate the slasher, fertiliser spreader, small nut-naber and the mulcher. An additional 70HP orchard tractor was purchased in year four to meet the increasing machinery requirements of the orchard and operation of a tipping trailer during harvest. The small second-hand tractor is required for herbicide applications, using the small under tree boom, and for operating a tipping trailer during harvest.

It is assumed that the de-husking plant has adequate drying and storage capacity and the required number of elevators, to constitute a return-line system which can store nut-in-husk (NIH) and conduct secondary de-husking of NIS. It is anticipated that the requirement for secondary de-husking will eventuate during peak harvest periods.

Income

To allow the value of a change in the percentage whole kernel to be included in the model, a price formula for the model farm was developed to express price of 1 kg NIS as a function of kernel recovery and the proportion of whole kernels:

$$P_{NIS(kr,w)} = PI_{kr,w} - PM$$

where $PI_{kr,w}$ is the price received by the processor for 1 kg of NIS with a particular kernel recovery (*kr*) and proportion of whole kernel (*w*) and *PM* is the processor margin. This assumes that any premium that the processor receives for different proportions of wholes kernel is transferred completed back to the grower. In addition, it was assumed that the processor margin was unaffected by kernel recovery or proportion of whole kernel. The processor income for 1 kg NIS was modeled as:

$$PI_{kr,w} = kr * TKV_{whpd}$$

where:

$$TKV_{whpd} = (w * P_w) + (h * P_h) + (p * P_p) + (d * P_d)$$

which is the total value to the processor of 1 kg of kernel with proportions of wholes, halves, pieces and dust, *w, h, p* and *d* and where P_w , P_h , P_p and P_d are the price per kg of these respective kernel styles. Industry average values for P_w, P_h, P_p and P_d were obtained from a large Australian macadamia processor ($14, $12, $12, and $1, Darren Burton, Agrimac pers. comm.).

Pieces and dust are a by-product of factory processes and were assumed to remain constant at 3% each irrespective of the distribution of wholes and halves. This allowed TKV_{whpd} to be expressed in terms of *w* and P_w, P_h, P_p and P_d. The processor margin was estimated as $1.65/kg NIS by substituting industry values for the price of 1 kg NIS ($2.50), kernel recovery (0.33), and the proportion of wholes (0.45) were substituted into the price formula. This allows the price of 1 kg NIS with kernel recovery (kr) and proportion of wholes (w) to be expressed as:

$$P_{NIS} = kr[(w * 14.0) + (0.94 - w) + 0.39] - 1.65$$

Discounted Cash Flow Analysis

A characteristic of tree crops such as macadamia is that there is a large initial cost to establish the plantation while production costs and benefits are spread over time. A discounted cash flow analysis was undertaken to reduce the stream of benefits and cost to a present value or present day equivalent. A project life of 20 years and a discount rate of 8 percent were assumed to calculate the net present value (NPV). The NPV of the model farm was calculated as the difference between the present value of income and the present value of costs.

Total operating costs was calculated as the sum of variable and fixed costs, but excluding capital and land costs. Total costs are the sum of total operating costs, the cost of capital and an annual land expense. Net cash flow was calculated as the difference between total farm revenue and total costs.

Derivation of economic weights

The economic weight was calculated for cumulative NIS yield per tree to 10 years (cNIS10), kernel recovery, projected tree canopy diameter, and the proportion of whole kernels as the change in NPV of the model resulting from an independent unit change in the level of the trait, i.e.:

$$w = NPV_{new} - NPV_{base}$$

where, NPV_{base} is the base NPV of the model farm, given the input values for biological traits and NPV_{new} is the NPV of the model following a unit change in the respective biological trait. To allow annual NIS yield at different ages to be adjusted for a change in cNIS10, a change in cNIS10 was distributed across ages proportional to the size of the annual NIS yield.

Because economic weights for different traits are expressed on unrelated scales, an attempt to examine the effect of equivalent changes in different traits by calculating the value of a one- percent and a one standard deviation change in each trait. Standard deviations for the biological traits were determined from a macadamia regional variety trial (Hardner *et al.* 1999a, 1999b). However, all these measures do not for differences in the degree of genetic control (i.e. how easily traits can be change through genetic selection) among traits. To examine the value of the different traits for selection of cultivars from a regional variety, the response to selection (*R*) for each trait independent of other traits was calculated as (Wricke and Weber 1986):

$$R = iH^2_{\overline{cv}}\sigma_{\overline{cv}}w$$

where *i* is the intensity of selection (i=1.755 for selection of the top 10% of cultivars for a particular trait, Falconer 1989), $H^2_{\overline{cv}}$ is the heritability (or the repeatability) of clonal means (the selection unit), and $\sigma_{\overline{cv}}$ is the standard deviation of family means. Values for these parameters were obtained from (Hardner et al 1999a, 1999b).

<u>RESULTS</u>

Economic model

A summary of the cash flows for the model farm over a twenty-year planning horizon is presented in Table 10. The model farm experiences a six-year period of negative cash flows before the orchard begins to produce increasing amounts of NIS. The orchards steady-state before tax annual profit in year 16 is $ 985 102.

(Insert Table 10 near here)

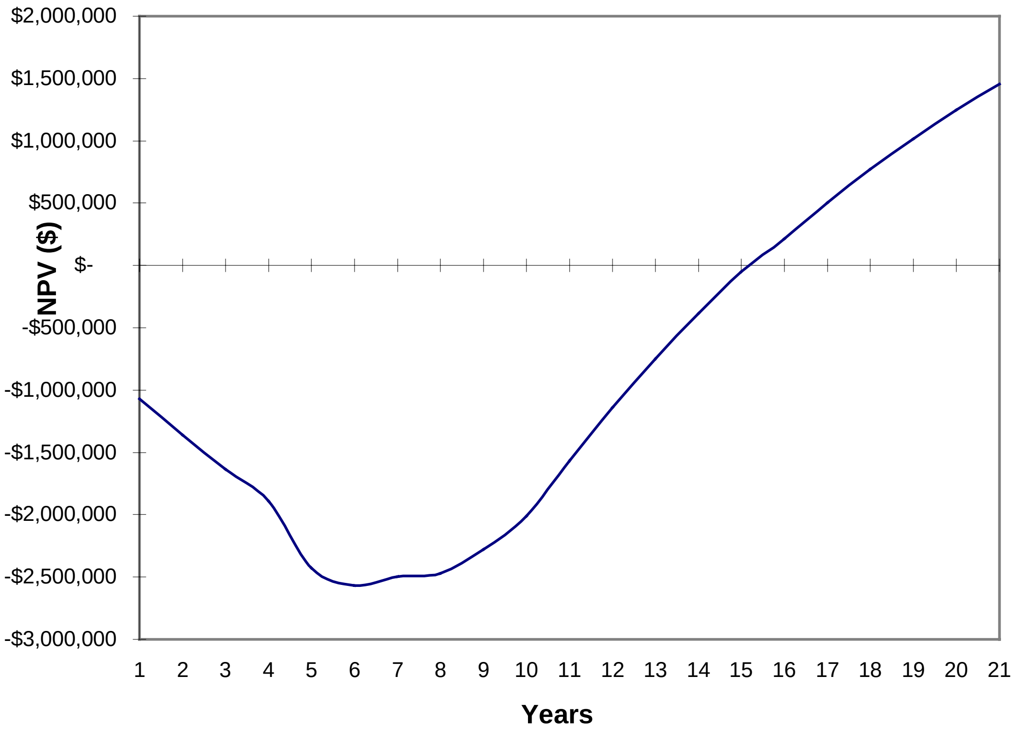

Figure 1. NPV Profile of 100 ha commercial macadamia orchard – Northern NSW.

The NPV_{base} of the model farm was $1 456 703. The high capital requirement for machinery and capital expense of land results in a significant period of negative project balances with a maximum debt of $2 565 860 in year five. The timing of capital purchase are evident, specifically the purchase of de-husking plant and equipment in year four. The secondary purchase of machinery in year 15 reduces the gradient of the profile. The most distinctive feature of the NPV profile is its steep positive gradient as the orchard begins to produce increasing amounts of NIS, indicating a high rate of return on capital.

A summary of the total discounted revenue and costs over 20 years for the different inputs is expressed per kilogram, per tree per year, and per farm per year is presented in Table 11. The present value of total farm revenue expressed per kilogram of NIS is $0.90. Alternatively this value can be regarded as the discounted price per kilogram of NIS. The major costs incurred by the model farm can be ranked as labour, land and capital with component costs per kilogram of NIS of $0.20, $0.17 and $0.16 respectively. Fertiliser and foliar operations and fixed operating expenses were the next highest of the component costs with a value of $0.05 per kilogram of NIS produced. The present value of total before tax farm profit over the 20 year planning horizon is $0.20 per kilogram of NIS produced.

Table 11. Total discounted revenue and costs over 20 years for different inputs per kilogram NIS, per tree per year, and per farm per year.

Component Revenue and Costs	$/kg NIS	$/tree/year	$/farm
Farm Revenue	**0.90**	**231.44**	**6,612,469**
Costs			
Variable Costs			
Herbicide	0.01	2.42	69 190
Insecticide	0.02	5.61	160 225
Fertiliser & folior	0.05	13.01	371 847
Slashing	0.01	2.00	57 031
Mulching	0.01	1.73	49 554
Skirting & hedging	0.02	4.14	118 219
Harvesting	0.01	2.99	85 311
Labour	0.20	52.28	1 493 627
Fixed costs			
Fixed (operating)	0.05	12.68	362 397
Land expense	0.17	42.88	1 225 127
Capital	0.16	40.71	1 163 238
Total cost	**0.70**	**180.45**	**5 155 767**
Farm Profit (NPV - before tax)	**0.20**	**50.98**	**1 456 703**

Economic weights

The value of a one-unit, one-percentage and one-standard deviation change in per tee cumulative yield to 10 years, kernel recovery, projected canopy diameter, and proportion of whole kernel for a 100 ha orchard over 20 years are presented in Table 12. The value of a unit change in each trait is equivalent to the economic weight of the trait (w). This is the first study to present economic weights for traits in macadamia. The biological traits can be ranked in terms of their impact on orchard profitability of a one-unit change in kernel recovery, tree canopy diameter, per tree cumulative NIS yield to 10 years, and proportion of whole kernels. A change of 0.01 kernel recovery has almost a three-fold effect on orchard profitability compared to a change of 1 kg in per tree cumulative yield to 10 years. In addition, a unit change in tree canopy diameter has almost a two-fold effect on orchard profitability when compared with a unit change in per tree cumulative yield to 10 years. The impact of a unit change in the proportion of whole kernels is of little value compared with kernel recovery, tree canopy diameter, and cumulative NIS to 10 years.

Table 12. The discounted economic value for a 100 ha farm over 20 years of a change in one unit (*w*), one percent and 1 standard deviation (σ) in the level of cumulative yield per tree to 10 years (cNIS10), kernel recovery, tree canopy diameter at 10 years and the proportion of whole kernels. Also shown is the standard deviation in clonal means ($\sigma_{\overline{CV}}$), clonal mean heritability ($H^2_{\overline{C}}$) (Hardner et al. 1999a, 1999b) and the response from selecting the top 10 genotypes for each trait.

Trait	cNIS10 (kg)	Kernel recovery	Tree diameter (dm)	Whole kernel
unit Δ (*w*)	$ 112 649	$ 332 728	$ 193 141	$ 17 470
percentage Δ	$ 66 125	$ 109 800	$ 95 292	$ 7 861
σ	17 kg	0.04	7 dm	0.14
σ Δ	$ 1 915 033	$ 1 330 912	$ 1 605 259	$ 244 580
$\sigma_{\overline{C}}$	9 kg	0.3	4 dm	0.8
$H^2_{\overline{C}}$	0.69	0.95	0.81	0.90
Response	$ 1 277 683	$ 1 659 481	$ 1 095 110	$ 220 122

The small economic weight for proportions of whole kernels is attributed to the comparatively small impact with which changes to the trait effect the price/kg of NIS. The price formula developed for the model farm indicates that a 0.1 increase in the proportion of whole kernels increases the price/kg of NIS by just 0.66 of a cent. In contrast, a change in kernel recovery by 0.01 increases the price/kg of NIS by 12.6 cents. The impact on orchard profitability from a unit change in tree canopy diameter is not surprising as this increases the planting density from 286 to 296 trees/ha. In addition, it appears that the increase in revenue from increasing the number of trees per hectare is much greater than the increased cost of applying input to these trees. Compared to the rank of traits when the value of a unit change was calculated, there was no difference when the value of a percentage change in the traits was calculated (Table 12).

When the value of a standard deviation change in traits was calculated (Table 12) there was a change in ranking, with per tree cumulative yield to 10 years of greatest value followed by tree canopy diameter, kernel recovery, and proportion of whole kernels. The value of a one-standard deviation change in a standard deviation change of cumulative yield is similar to that of an equivalent change in tree canopy diameter and kernel recovery are similar. The relatively low value attained for proportion of whole kernels this trait has a comparatively small impact on profitability, with a change in kernel recovery of much greater value to processors than the proportion of whole kernels. It is therefore unlikely that in reality the premium processors gain for a whole kernel is unlikely to be passed on to growers. However, this analysis only indicates the value a change in one phenotypic standard deviation. The degree of change that can actually be achieved depends on the degree of genetic control and the effect of management practices within the production system.

A measure of the change in profitability that can be achieved by adoption of superior cultivars is the response from selecting the top 10 % of genotypes for different traits (Table 12). This depends on the variability of a trait, the extent to which the variability can be captured by selection of superior genotypes (i.e. the heritability of a trait) and the value of a change in the trait (*w*). From this analysis, the most valuable trait for selection is kernel recovery, because there is sufficient variability in the trait, the heritability of the trait is high, and the value of changing the trait is high. The response from selection of the top 10% of genotypes for yield is similar to the response for selecting the 10 % smallest genotypes. Similar to the above analyses, there is little value in selecting for proportion of whole kernel.

Sensitivity Analysis

Sensitivity analysis was conducted to test the model for changes in important parameters of income and cost. The change in NPV was observed from an independent 10 percent increase or decrease to the income parameters of per tree cumulative NIS yield to 10 years and price/kg NIS (Table 13). Similarly, the change in NPV was observed from a 10 percent increase or decrease in the cost of capital items and operating cost (Table 14). Capital costs includ the collective sum of the annual land expense and purchase cost of capital machinery, equipment and farm infrastructure, while operating costs included both variable and fixed costs associated with the managerial plan.

Table 13. Change in NPV for 10% change in price of NIS and cumulative yield

NPV ($)		Yield/tree NIS (kg) % Δ		
		-10	0	+10
Price/kg	-10	$ 200 333	$ 795 455	$ 1 390 578
NIS	0	$ 795 455	$ 1 456 703	$ 2 117 950
% Δ	+10	$ 1 390 578	$ 2 117 950	$ 2 845 321

Table 14. Change in NPV for a 10% change in capital and operating costs

NPV ($)		Capital Cost % Δ		
		-10	0	+10
Operating	-10	$ 1 936 040	$ 1 697 203	$ 1 458 367
Cost	0	$ 1 695 539	$ 1 456 703	$ 1 217 866
% Δ	+10	$ 1 455 039	$ 1 216 202	$ 977 365

The results of the analysis indicate that a similar percentage change in cumulative NIS yield per tree and price/kg NIS have an equal and linear effect on orchard profitability. A change in NPV of $ 661 248 was observed from a 10 percent variation in each parameter of income. Operating costs were ranked third with a $ 240 501change in NPV from a 10 percent change. The effect of a 10 percent change to Capital costs was similar to that of operating costs with a $ 238 836 change in orchard profitability.

Sensitivity analysis indicated that a simultaneous 10 percent increase or decrease in NIS yield per tree and price/kg NIS had considerable impact on orchard profitability. A 10 percent decrease in these two income parameters caused NPV to decrease to $ 200 333. In addition, a combined 15 percent decrease in NIS yield per tree and price/kg NIS results in a negative NPV after 20 years, -$378 258 (results not presented). In contrast, the model is not as sensitive to a combined 10 percent increase in capital and operation costs, with a reduction in the NPV to $977 365.

CONCLUSION

An economic model of a typical commercial macadamia orchard of Northern New South Wales was used to calculate economic weights for biological traits of macadamia. The economic model developed for this research has extended the scope of previous models in two ways. Firstly, the model includes the capacity to simulate the effect of changes in biological traits on income and production costs. In doing so, the model has accounted for additional complexity that might otherwise not have been encountered had the primary objective been that of a study of orchard profitably. In addition, the detail of this model allows changes to assumptions and evaluation of other traits to be easily incorporated. Secondly, the scope of previous models has been extended to develop a price formula that expresses price/kg NIS as a function of kernel recovery and the proportion of whole kernels.

This is also the first study to calculate economic weights for any trait in macadamia. This has enabled the economic importance of changes in biological traits to be quantified. Economic weights for these traits will provide plant breeders with valuable information that can be combined with genetic information to calculate a selection index for maximising selection efficiency.

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