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and *Guazuma crinita*, two fast-growing timber species of
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Manuscripts

1 **Efficiency of early selection in *Calycophyllum spruceanum* and *Guazuma***
2 ***crinita*, two fast-growing timber species of the Peruvian Amazon**

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Abstract

'Bolaina' (*Guazuma crinita*, Malvaceae) and 'capirona' (*Calycophyllum spruceanum*, Rubiaceae) are fast-growing Amazonian timber trees. In Peru, they are increasingly being used in agroforestry systems and plantations, and interest in developing improved germplasm is growing. However, tree improvement incurs both direct costs and interest costs on investments; because of this, early selection is of interest. We examine the efficiency of early selection at 13 or 17 months after field trial establishment. These are compared with selection after 49 or 53 months using two efficiency metrics: one based on discounted response to selection per unit of present value of cost, the second on net discounted revenues, using discount rates of 5%, 10% and 15%. Our metrics differed from those used in previous studies by taking into account direct costs as well as costs of capital. We found that in most scenarios early selection was attractive, partly due to direct cost savings. We conclude that, in evaluating the efficiency of early selection, lack of consideration of direct costs may produce erroneous results. We also explore some general implications of the results.

Keywords

progeny-test, tree improvement, age-age correlation, financial analysis, breeding strategies

Introduction

'Bolaina' (*Guazuma crinita*, Malvaceae) and 'capirona' (*Calycophyllum spruceanum*, Rubiaceae) are fast-growing timber trees of the Peruvian Amazon. They are increasingly being used in agroforestry systems and plantations in Peru (Sears et al. 2014; Cornelius pers. obs.¹). Saw-timber rotations of bolaina in plantations are 6-10 years (Wightman et al. 2006), producing a relatively low density, versatile timber used in interiors, furniture and pallets in the Amazon, and for social and emergency housing in the desert conditions of Lima (Putzel et al. 2013). The strong, dense timber of capirona (Sotelo Montes et al., 2006) is one of the most traded on the Peruvian domestic market. The species also has multiple on-farm, non-traded uses, including medicinal applications (Reynel et al., 2003). Expected sawtimber rotations of capirona in plantations are from 15-20 years (Wightman et al. 2006).

Both species grow throughout the Amazon basin (Grandtner and Chevrette 2014). Bolaina is a pioneer species found in riparian and non-riparian locations up to 1500 m a.s.l. (Reynel et al. 2003). Capirona is a longer-lived pioneer found in open or disturbed situations in riparian, floodplain, and other types of forest up to 1200m a.s.l. (Reynel et al., 2003; Sotelo Montes et al., 2003).

In Peru, there is increasing interest in genetic improvement of both species. Interest charges are a key factor in determining profitability of tree improvement research, and these depend on the time between investment and return. Here we explore the feasibility of reducing this interval in the two species using early selection, which we define as selection at an age a on a given trait, intended to bring about a response to selection in

¹ June 2013, Pachitea River, Huánuco, Peru.

the 'same' trait at age b , such that $a < b$. Early selection reduces costs directly, because it reduces costs of maintaining and monitoring field tests.

Lambeth (1980) summed up early thinking on this theme: 'the question has been: how much gain per generation can be sacrificed in the interest of saving time?', and formulated the following efficiency metric:

$$E = \frac{h_j r_{j,m} T_m}{h_m T_j}$$

where h_j is the square root of the heritability at the younger selection age, h_m is the square root of the heritability at the older selection age, $r_{j,m}$ is the phenotypic correlation between measurements at the two ages (assuming that the phenotypic correlation approximates the genetic correlation), T_m is the length (years) of a breeding cycle based on later selection, and T_j is the length (years) of a breeding cycle based on early selection.

The formulation in terms of gain per unit time is not consistent with mainstream approaches to financial analysis, as it implicitly assumes discount rates of zero.

Accordingly, McKeand (1988), White and Hodge (1992), Balocchi et al. (1994), and Osorio et al. (2003) used efficiency metrics based on discounted selection responses.

However, studies to date did not consider costs of alternative selection strategies (i.e. early v. later selection), other than the cost of capital represented by the discount rate.

Metrics that do not take costs into account are valid only if differences in costs of different options are negligible; this seems unlikely, as cost savings (other than interest charges) are a key potential advantage of early selection. The present study differs from earlier ones, in that costs are taken into account in the metrics used.

Materials and methods

84 ***General approach***

85 We examine the feasibility of early selection based on its efficiency in financial terms,
86 using two measures of efficiency. The first is based on discounted response to selection
87 per unit of present value of costs. The second is based on net present values. Below, we
88 first describe the progeny tests on which we based the estimates of response to selection,
89 then the selection options examined, and finally our approach to calculation of selection
90 efficiencies.

91 ***Progeny tests***

92 In 1995, World Agroforestry Centre (ICRAF) scientists surveyed preferences of
93 smallholder farmers in the Peruvian Amazon. They found that farmers considered
94 capirona and bolaina to be among the species of highest priority for participatory
95 domestication (Sotelo Montes and Weber, 1997). In response, ICRAF began a
96 participatory domestication programme (Leakey et al. 2012). Farmers selected 200
97 mother-trees of each of bolaina and capirona in seven provenances within the Aguaytía
98 watershed, Ucayali Region. ICRAF then collected open-pollinated seed from these trees
99 (see respectively Rochon et al. (2007) and Weber et al. (2009) for provenance locations
100 of capirona and bolaina).

101 The procedure and experimental design were the same for both species. Seedlings of the
102 200 families of each species were grown in a randomized block experimental design in
103 the nursery for 15 months before being outplanted in a provenance-progeny test (bolaina:
104 January to April 2001; capirona: February to April 2000). These were located in the
105 lower, middle and upper parts of the Aguaytía watershed (see Weber et al. (2009)). The
106 field experimental design was also a randomized complete block with 15 replications.
107 Each of the 15 nursery blocks corresponded to one of the provenance/progeny test blocks.

Maintenance practices are detailed in Weber et al. (2009). The blocks were established on 15 different farms: four in the lower, five in the middle and six in the upper parts of the watershed. The tests were not replicated within farms. In each block, the 200 families were randomly assigned to 200 experimental plots, each plot containing two trees, for a total of 400 trees per block. Spacing was 2.5 by 2.5 meters within and between rows, and two rows of border trees completely surrounded each block. Dead trees were replaced during the first year, but data collected on replacement trees were not included in the analyses.

Thinning practice differed between the species and between blocks of each experiment. For capirona, 11 of the blocks were thinned between 38 and 40 months. For bolaina, eight of the 15 blocks were thinned between 30 and 32 months. In each case, one tree per plot was removed (the smallest tree, unless the larger tree was a replacement or affected by pests, diseases or mechanical damage).

Selection options

The selection options are summarized in Table 1 and detailed in Appendix 1.

In Option 1 (early selection), selection is based on progeny test results for total height at 13 months (bolaina) and 17 months (capirona). In Option 2, selection is based on results for height at 49 months (bolaina) and 53 months (capirona). These ages correspond to actual measurement ages. In each case, the source of improved germplasm in our model is a seed orchard consisting of the 20 families with the highest height means at the selection age in question, selected from the 200 families included in the field trials. We assume no within-family selection. Seed production is assumed to begin at two (bolaina)

and five (capirona) years after planting. We set orchard life at 10 years; we assume that, subsequently, improved sources of higher quality will supersede the orchards.

The target (older) trait is growth rate over the first 48 to 53 months. Selection at these ages would itself be expected to generate a correlated response of <100% of the gain at the harvest age (because we would not expect perfect genetic correlations between age 4 to 4.5 and final harvest time), but we do not examine this aspect here.

In our analysis, we consider Option 2, i.e. deferral of selection, as a decision to make additional investments (prolongation of field-testing) aimed at achieving additional genetic gain. In evaluating this decision, which is the usual or default one, the relevant costs are those future costs that are either unique to one of the two options (i.e. thinning or trial maintenance subsequent to month 13 or 17), or that are timed differently in the two options. Past costs are relevant to the overall return on investment, but not to the evaluation of future investment decisions, and therefore are not relevant to our analysis.

Criteria of selection efficiency

Our first efficiency metric (E1) is the ratio of the present value of gain per unit cost for the two options, i.e. the quotient of two benefit : cost ratios, corresponding to the two selection ages:

$$[1] \quad E1 = \frac{DR_1}{PC_1} / \frac{DR_2}{PC_2}$$

where: DR_1 = discounted response to selection in Option 1 (see below for estimation methods), PC_1 = present value of costs of Option 1; DR_2 = discounted response to selection in Option 2; PC_2 = present value of costs of Option 2.

Our second efficiency metric is the difference between the net present values (i.e. net discounted revenues) of the two options:

$$E2 = NPV_1 - NPV_2$$

where:

$$NPV_1 = PR_1 - PC_1$$

and PR_1 = discounted revenue from Option 1.

For a given discount rate, calculation of the 'benefit' components of the metric E1 requires only estimates of response to selection, whereas metric E2 requires also estimates of the monetary value of the response.

The response to selection at the older age was predicted using standard formulae (Falconer and Mackay 1996) as:

$$R_o = i_o h_o^2 \sigma_o.$$

Response to early selection was predicted as:

$$CR_o = i_y r_{y,o} h_y h_o \sigma_o$$

where: i = selection intensity, r = genetic correlation, h^2 = family mean heritability, σ = phenotypic standard deviation of family means, and subscripts are as defined for Equation 1.

We ignore genetic gain from mother-tree selection, as it is likely to be minimal in the case of selection for growth in wild stands (Cornelius 1996; Cornelius et al. 2011).

Family heritability was estimated as:

$$h_f^2 = \frac{\sigma_f^2}{\sigma_f^2 + \sigma_e^2/b}$$

168 where σ_f^2 = variance component due to families, σ_e^2 = variance component due to block
 169 by family interaction (error), b=number of blocks).

170 Variance components were estimated using the SPSS General Linear Model variance
 171 components routine (restricted maximum likelihood method) under the following linear
 172 model:

$$\bar{Y}_{ij} = \beta_i + \alpha_j + \beta\alpha_{ij},$$

173 where

174 $\bar{Y}_{ij}$ = mean of family j in block i , β_i = random effect of block i , α_j = random effect of
 175 family j , $\beta\alpha_{ij}$ = block by family interaction (error).

176 Standard errors were calculated for the heritabilities with Dickerson's approach (Dieters
 177 et al. 1995), using the asymptotic variance-covariance matrix generated by SPSS.

178 The model confounds provenance and family effects. Previous analyses indicated
 179 significant provenance effects on growth in both bolaina and capirona (Sotelo et al 2006;
 180 Weber et al. 2011), but in both cases of much smaller magnitude than the family-in-
 181 provenance effect. We pool them here because we consider that the most likely
 182 application of our results is in selecting superior families independent of the respective
 183 contributions of the different sources of variation in the genetic hierarchy. All analyses
 184 were carried out on observed values standardized by the phenotypic standard deviation of
 185 each block, as in Osorio et al. (2003).

186 Genetic correlations cannot be estimated accurately without large amounts of data
 187 (Falconer and Mackay 1996). An alternative approach is to use estimates of phenotypic

correlation coefficients as surrogates (Cheverud 1988), as there is strong empirical support for “Cheverud’s conjecture” (Roff 1995) that phenotypic correlations are good surrogates for genetic correlations (Cheverud 1988; Waitt and Levin 1998). In the present study, we use phenotypic correlations between family marginal means (i.e. least squares means). We expect these correlations to be closer in value to genetic correlations than individual phenotypic correlations would be, because of their expected high correlation with breeding values. Confidence limits (95%) were calculated for the estimates, using the z-transformation method (Sokal and Rohlf, 1995).

We calculate the annual undiscounted revenue from selection as:

$$R_s = (\Delta G)(Rha^{-1})(A)$$

where ΔG = percentage response to selection, Rha^{-1} = gross revenue ha^{-1} from unimproved plantations, A = area (ha) of improved plantations harvested $year^{-1}$.

The percentage genetic gain for Option 2 was calculated as:

$$\Delta G = (R_o/\bar{x}_u)100$$

where $\bar{x}_u$ = unimproved mean at 49 or 53 months (and analogously for Option 1).

Here we assume that the percentage improvement is applicable to harvest age; in practice, as stated above, correlations of age 49 or 53 months with rotation age would be <1 , as Option 2 is itself early selection with regard to final rotation. Application of the same proportional decrease in genetic gain for Option 1 and Option 2 (i.e. to reflect this non-perfect correlation with final rotation age) would leave E1 unchanged and would slightly reduce E2 (i.e. slightly reducing efficiency of early selection).

207 The income at harvest time from both species depends not solely on productivity and tree
208 quality but also on the degree of transformation carried out. For example, a typical price
209 for standing timber of bolaina is around US\$2.00 tree⁻¹ (with around 200 trees ha⁻¹),
210 around US\$3.00 tree⁻¹ if felled and cut into logs, and around US\$11.00 tree⁻¹ once
211 transformed into sawntimber (Sears and Pinedo 2014). Here we based our calculations for
212 bolaina on the foregoing price for logs ("tucos"), i.e. $R \text{ ha}^{-1} = \$600$; for capirona we
213 assume sale price of double that for bolaina, i.e. $\$1200 \text{ ha}^{-1}$; we refer to these later as the
214 'base timber values.' These assumptions on transformation reflect the orientation towards
215 smallholders of the tree improvement activities executed by ICRAF and partners, as
216 smallholders are less likely to engage in production of sawtimber or other more highly
217 transformed products. Congruent with this, we also assume that the seed orchards will
218 support relatively modest plantations programs, i.e. we assume $A = 500 \text{ ha yr}^{-1}$.
219 In order to examine the implications of a higher degree of value-adding, we also test an
220 alternative returns scenario under which sale price is four times that indicated above (i.e.
221 $\$2400 \text{ ha}^{-1}$ for bolaina and $\$4800 \text{ ha}^{-1}$ for capirona) We refer to these later as 'high timber
222 values'.

223 We assume constant future real timber prices.

224 We calculated the discounted responses (metric E1) and net present values (E2) as the
225 product of the response to selection itself (E1) or annual undiscounted revenue (E2) and
226 the discounting multiplier (see next section).

227 ***Discounting multipliers***

228 Recurrent annual seed collections from the orchards lead to a series of n marginal yields
229 (i.e. yield increases resulting from genetic gain in height or diameter), where n = number

of years during which seed is harvested from the seed source in question (set to 10 years for both species). Additionally, the flow of returns cannot begin until time t , y years after establishment of plantations derived from the first year of seed production, where y = rotation length (set to 16 for capirona and 8 for bolaina).

Under our analytical framework, the decision of whether to proceed with early selection is taken following analysis of the data at 13 (bolaina) or 17 (capirona) months, i.e. at 3.17 years after program commencement for capirona and 2.83 years for bolaina (Table A1). Time t is then respectively 24.67-3.17 and 27.66-3.17 for capirona (Option 1 and Option 2) and 13.33-2.83 and 16.33-2.83 for bolaina (that is: for capirona, 21.5 (Option 1) and 24.5 (Option 2) after the decision point and discounting base year and 10.5 and 13.5 years for bolaina (Table A1)). Consequently, the flow of annual returns will initiate at a time $d = t - 3.17$ for capirona and $d = t - 2.83$ for bolaina. The multiplier for the present value of a series of n constant annual returns starting at time d is:

$$D = \frac{((1+r)^n - 1)1+r}{r(1+r)^n(1+r)^d}$$

where r = discount rate in decimals (e.g. 5% = 0.05) (Cornelius and Morgenstern 1986).

For bolaina, the respective present value multipliers were therefore:

$$D_{13} = \frac{((1+r)^{10} - 1)1+r}{r(1+r)^{10}(1+r)^{10.5}}$$

$$D_{49} = \frac{((1+r)^{10} - 1)1+r}{r(1+r)^{10}(1+r)^{13.5}}$$

In the case of capirona, the respective present value multipliers were therefore:

$$D_{17} = \frac{((1+r)^{10} - 1)1+r}{r(1+r)^{10}(1+r)^{21.5}}$$

246

$$D_{53} = \frac{((1 + r)^{10} - 1)1 + r}{r(1 + r)^{10}(1 + r)^{24.5}}$$

247 We used three different discount rates (5%, 10% and 15%). As we assume zero inflation
248 in timber prices, these can be considered as real interest rates. The higher rate would be
249 appropriate for private investment (e.g. for example, Peru's Agricultural Bank
250 (Agrobanco) is currently offering credit for timber tree planting in coffee agroforestry
251 systems at 16.5%-17.0%, while annual inflation is at around 3%-4%). The lower value
252 can be considered as a social discount rate, applicable, for example, to development
253 projects.

254 **Costs**

255 We estimated the cost of each option based on ICRAF records and our experience of
256 carrying out the different component activities (Table 2: estimations were made in 2015
257 PEN (Peruvian new soles), converted to USA dollars at PEN3.00 \$US⁻¹). We then
258 calculated the discounted costs for each option, based on the specifications in Table 1 and
259 Appendix 1 (see Results), excluding costs common to and incurred at the same time in
260 both options. Salary costs were assumed to be equal to the non-salary cost of each option.
261 Although not exact, we considered this approach to be preferable to attempting to
262 attribute fractions of scientist and technician time to specific activities. It corresponds to
263 typical ‘project’ budget ratios of 1:1 (salaries:operations).

264 **Results**

265 Mean height at months 53 (*C. spruceanum*) and 49 (*G. crinita*) were respectively 7.8 m
266 (s.e. = 0.06 m) and 11.7 m (s.e. = 0.08 m). Estimates of genetic and phenotypic
267 parameters are presented in Table 3. Family heritabilities were around 0.70 for capirona

and around 0.45 for bolaina; standard errors were around 0.1 in all cases, indicating relatively precise estimates. Age-age correlations were 0.88 (95% C.L. 0.84-0.91) for capirona and 0.72 (95% C.L. 0.65-0.78) for bolaina (Table 3).

Discounted Costs

The present values of non-salary costs are summarized in Table 4. They were inversely proportional to the discount rate for both selection options (this is axiomatic, as all costs were discounted, not compounded). Over both species and options, total costs at the 5% discount rate were ~22-26% higher than those at 15% discount rate. At each discount rate, Option 2 was roughly three times as expensive as Option 1, which is in accordance with the basic rationale for early selection (i.e. it is cheaper). The higher cost of Option 2 is due principally to the prolongation of test maintenance and to the need for thinning.

Response to selection, efficiencies

Results with respect to selection response and efficiencies are summarized below and detailed in Tables 5 and 6.

Response to selection

The predicted response to selection in capirona was notably higher than in bolaina (>3 times larger for Option 1 and >2 as large for Option 2). However, in bolaina the marginal gain due to deferral of selection (i.e. Option 2) was proportionally larger than in capirona (about 10% more v. about 43% more).

As is axiomatic, discounted response to selection was inversely proportional to the discount rate: for capirona, about nine times greater at 5% than at 15% for Option 1 and about 12 times greater at 5% than at 15% for Option 2. For bolaina, it was about three

times greater for Option 1 and about four times greater for Option 2 (5% v. 15%). Discounted response in capirona was lower than discounted response in bolaina except at 5% discount rate. For capirona, discounted response was higher for Option 1, whereas for bolaina it was higher for Option 2, except at 15% discount rate.

Selection efficiency (E1)

For both species, as is axiomatic, discounted genetic gain per unit of present value of costs was inversely proportional to the discount rate for Option 1 and Option 2. For both species, efficiency metric E1 was always >1 (that is, early selection was always more efficient) and was higher at higher discount rates. As measured by E1, Option 1 was more efficient in capirona than in bolaina at all discount rates; in both species, E1 at 15% discount rate was about 40% higher than at 5% discount rate.

Gross and net present values and selection efficiencies (E2)

Gross present values from selection, axiomatically higher at lower discount rates, were notably higher in capirona than bolaina. The difference in values at higher and lower discount rates was notably greater in capirona than bolaina (>10 times v. four to five times). In capirona, gross present values were always higher for Option 1, whereas for bolaina they were higher for Option 2, except at 15%. Net present values were also notably higher in capirona than bolaina and were higher at lower discount rates. For both species, selection efficiency as measured by metric E2 was higher for Option 1, with broadly similar values for the two species. For capirona, E2 was higher at lower discount rates, whereas for bolaina E2 was lowest at 5%. Under the high timber value scenarios, Option 1 was still more efficient, except for bolaina at 5%.

Discussion

We found that for both species, in general, early selection (Option 1) is more attractive than deferred selection. For capirona, an analysis based on discounted returns alone (but not on gain year⁻¹) would have reached this same conclusion. However, for bolaina, Option 2 would have appeared to be more attractive had costs not been considered. We therefore conclude that, in evaluating the efficient of early selection, analyses that fail to consider direct costs (and not just the cost of capital) may produce erroneous results.

At the base timber values, efficiency as measured by E2 shows the same trends as for E1. Under the higher timber value assumption, the same result holds for capirona – early selection remains more efficient, due to the small difference in response between Option 1 and Option 2 and the strong discounting effect produced by the longer discounting period (a consequence of the longer rotation). In the case of bolaina, however, the doubling of the timber price, coupled with the larger difference in gain between Option 1 and Option 2, is enough to offset the higher cost of Option 2—but only at the lowest discount rate. This merely underscores the point that results of such an analysis will depend on the specifics of each situation. The same applies to other possible scenarios regarding the magnitude of genetic parameters, as these affect revenues in the same way as do changes in price assumptions.

In spite of this specificity, some general points—in addition to the importance of taking costs into account—may be made.

First, the time of decision is clearly fundamental, as this has a major effect on the cost of deferring selection. In the present case, early selection avoids substantial trial maintenance and thinning costs. It is possible to envisage other situations in which costs of earlier and later selection will be more similar: for example, a comparison between

selection following first thinning and 'site capture' versus later selection closer to final rotation age. Under such circumstances, future costs would be more similar and the returns component of the efficiency metrics E1 and E2 may exert a stronger influence than the costs component. However, this would depend also on the relative values of the genetic parameters at the two ages.

Second, early selection is likely to be more attractive in the private sector, where higher, market rates of interest apply, rather than in development-oriented activities where lower, social discount rates may apply. For both sectors, other things being equal, early selection will be more attractive for higher-value precious timber than for 'fastwood', because of the longer rotations. As seen in the case of the higher-value timber price scenario with bolaina, higher prices, value-adding, or larger-scale planting programs may all act to make deferral of selection the preferred option, particularly at lower interest rates applicable to development-oriented activities. However, higher degrees of value-adding and larger-scale planting may be less common in the case of such activities.

Finally, such point-in-time analyses should not be confused with an overall financial analysis of a given breeding program. However, the parameters that affect relative advantages of different selection strategies, including values of genetic correlations (Lambeth et al. 1980; Matheson et al. 1994) and costs, can be estimated or modeled and taken into account in the initial design phase. This is important as the design, and therefore the costs, of short-term genetic tests aimed at informing juvenile selection may not be the same as the design of longer-term tests.

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Table 1. Selection options analyzed in the present study (see Appendix, Table 1A for details)

Option and description		
OPTION 1. EARLY SELECTION	<i>Calycophyllum spruceanum</i>	<i>Guazuma crinita</i>
Number of families in tests:	200	
Selection criterion:	Best 20 families in field trial after 13 months (selection intensity = 1.7422)	Best 20 families in field trial after 17 months (selection intensity = 1.7422)
Source of improved seed:	Seed orchard of the 20 families, established following field test analysis in Year 3	
Start of seed production:	Year 8	Year 5
First harvest of plantations from improved seed:	Year 24	Year 12
Seed orchard life:	10 years	
OPTION 2. LATER FIELD SELECTION		
Number of families in tests	200	
Selection criterion	Best 20 families in field trial after 49 months (selection intensity = 1.7422)	Best 20 families in field trial after 53 months (selection intensity = 1.7422)
Source of improved seed	Seed orchard of the 20 families, established in Year 6 following test analysis	
Start of seed production	Year 11	Year 8
First harvest of plantations from improved seed	= Commencement of seed production + rotation length (16 years) = 27.41 years after first seed collections from founding mother-trees (see Appendix 1)	= Commencement of seed production + rotation length (8 years) = 16.08 years after first seed collections from founding mother-trees (see Appendix 1)
Seed orchard life	10 years	10 years

Table 2. Unit costs of field and nursery activities (excluding salary costs)

Activity	Unit cost ^{a,b}
Mother-tree location and collection	\$104 tree ⁻¹
Plant production	\$0.33 seedling ⁻¹
Measurement in nursery	\$0.03 seedling ⁻¹
Selection and transportation of plants	\$73 test ⁻¹ or orchard ⁻¹
Site preparation and planting	\$656 test ⁻¹ or orchard ⁻¹
Seed collection in orchards	\$500 collection ⁻¹
Test and orchard weeding	\$114 test ⁻¹ occasion ⁻¹
Test thinning	\$192 test ⁻¹
Measurement in field	\$200 test ⁻¹

^a2015 Peruvian new soles (PEN), converted to United States dollars (USD) at PEN 3.00 USD⁻¹; ^bRounded to nearest USD

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Table 3. Family heritabilities for height and correlations between least-squares means in progeny tests of *Calycophyllum spruceanum* and *Guazuma crinita* in the Peruvian Amazon used for estimations of response to selection

Parameter	<i>Calycophyllum spruceanum</i>		<i>Guazuma crinita</i>	
	H17 ^a	H53	H13	H49
σ_f^2 (family variance component)	0.110	0.119	0.042	0.054
σ_e^2 (error variance component)	0.662	0.825	0.827	0.899
h_f^2 (family heritability) ^b (S.E.)	0.71 (0.101)	0.67 (0.102)	0.43 (0.103)	0.46 (0.112)
σ_o (standard deviation of family means)		0.42		0.34
Correlation with H17 or H13 (95% C.L.)		0.88 (0.84-0.91)		0.72 (0.65-0.78)

^aHeight at 17months; ^b $\sigma_f^2 / (\sigma_f^2 + \sigma_e^2 / b)$, where b = number of blocks

Table 4. Present value of costs (thousands of US\$) of the two selection options, excluding salary costs.

Source of costs	Option 1: (Selection at 13/17 months)			Option 2: (Selection at 49/53 months)		
	Discount rate					
	5%	10%	15%	5%	10%	15%
<i>Calycophyllum spruceanum</i>						
Plant production	0.30	0.30	0.30	0.38	0.33	0.29
Test thinning	n.a.	n.a.	n.a.	2.87	2.86	2.86
Test measurement	3.00	3.00	3.00	2.59	2.26	1.98
Site preparation and planting (orchards and tests)	0.72	0.71	0.71	0.62	0.54	0.46
Seed collection (orchard)	3.14	2.04	1.38	2.71	1.54	0.91
Maintenance (orchards and tests)	1.26	1.18	1.10	14.1	13.24	12.53
Totals	8.42	7.24	6.49	23.25	20.76	19.02
<i>Guazuma crinita</i>						
Plant production	0.30	0.29	0.29	0.26	0.22	0.19
Test thinning	n.a.	n.a.	n.a.	2.82	2.77	2.71
Test measurement	3.00	3.00	3.00	3.89	3.38	2.96
Site preparation and planting (orchards and tests)	0.72	0.71	0.70	0.62	0.54	0.46
Seed collection (orchard)	3.63	2.73	2.11	3.14	2.04	1.38
Maintenance (orchards and tests)	1.24	1.15	1.06	13.71	12.95	12.29
Totals	8.90	7.88	7.16	24.43	21.90	20.00

Table 5. Predicted responses to selection and early selection efficiencies in *Calycophyllum spruceanum* in Ucayali, Peru.

Rate ^a	DC ^b (K\$US)	R ^c	DR ^d	DR / DC	E1 ^e	PV Gross revenue (base ^h) (K\$US)	NPV ^f (base ^h) (K\$US)	E2 ^g (base ^h)	PV Gross revenue (high ^h)	NPV ^f (high ^h)	E2 (high ^h)
Option 1											
5%	16,840	0.44	1.26	(7.5)(10 ⁻⁵)	2.90	172.0	155.2	38.0	688.1	671.3	1.1
10%	14,480	10.1%	0.39	(2.7)(10 ⁻⁵)	3.47	52.9	38.4	36.2	211.4	197.0	1.5
15%	13,000		0.13	(9.8)(10 ⁻⁶)	4.07	17.4	4.4	29.9	69.6	56.6	4.7
Option 2											
5%	46,500	0.49	1.20	(2.6)(10 ⁻⁵)	1	163.6	117.1	1	654.6	608.1	1
10%	41,500	11.1%	0.32	(7.7)(10 ⁻⁶)	1	43.6	2.1	1	174.6	133.0	1
15%	38,000		0.09	(7.7)(10 ⁻⁶)	1	12.5	-25.4	1	50.1	12.1	1

^aDiscount rate; ^bDiscounted costs; ^cResponse to selection; ^dDiscounted response to selection; ^eEfficiency Metric 1 (see text); ^fNet present value;

^gEfficiency Metric 2 (see text); ^hRefers to timber value assumptions; see text.

Table 5. Predicted responses to selection and early selection efficiencies in *Guazuma crinita* in Ucayali, Peru.

Rate ^a	DC ^b (K\$US)	R ^c	DR ^d	DR / DC	E1 ^e	PV Gross revenue (base ^h) (K\$US)	NPV ^f (base ^h) (K\$US)	E2 ^g (base ^h)	PV Gross revenue (high ^h)	NPV ^f (high ^h)	E2 (high ^h)
Option 1											
5%	17.8	0.19	0.92	(5.2)(10 ⁻⁵)	2.2	42.8	25.0	20.7	171.4	153.6	-102.4
10%	15.8	2.94%	0.47	(3.0)(10 ⁻⁵)	2.6	21.9	6.2	26.3	87.7	71.9	21.1
15%	14.3		0.25	(1.8)(10 ⁻⁵)	3.0	11.7	-2.5	26.3	47.0	32.6	4.7
Option 2											
5%	48.9	0.27	1.1	(2.3)(10 ⁻⁵)	1	53.2	4.3	1	212.7	163.8	1
10%	43.8	4.22%	0.51	(1.2)(10 ⁻⁶)	1	23.7	-20.1	1	94.6	50.8	1
15%	40.0		0.24	(5.9)(10 ⁻⁶)	1	11.1	-28.9	1	44.3	4.3	1

^aDiscount rate; ^bDiscounted costs; ^cResponse to selection; ^dDiscounted response to selection; ^eEfficiency Metric 1 (see text); ^fNet present value;

^gEfficiency Metric 2 (see text); ^hRefers to timber value assumptions; see text.

Table A1. Timing of program activities for the two selection options, by species

Event	Timing (years after discounting baseline of 0.0 years)
Common to both options and species	
Mother-tree selection, seed collection start	0.0 years
Seed collection completed	1.25 years
<i>Calycophyllum spruceanum</i>, option 1	
Trial site preparation completed	1.75 years
Trial establishment completed	1.75 years
Measurement and analysis completed	3.17 years
Seedling seed orchard established	3.42 years
Annual seed harvests	8.42 years to 17.42 years
Improved plantations established	8.67 years to 17.67 years
Improved plantations harvested	24.67 years to 34.67 years
<i>Calycophyllum spruceanum</i>, option 2	
Trial site preparation completed	1.75 years
Trial establishment completed	1.75 years
Trial thinning completed	3.25 years
Measurement and analysis completed	6.16 years
Seedling seed orchard established	6.41 years
Annual seed harvests	11.41 years to 20.41 years
Improved plantations established	11.66 years to 20.66 years
Improved plantations harvested	27.66 years to 34.66 years
<i>Guazuma crinita</i>, option 1	
Trial site preparation completed	1.75 years
Trial establishment completed	1.75 years
Measurement, analysis completed	2.83 years
Seedling seed orchard established	3.08 years
Annual seed harvests	6.08 years to 14.08 years
Improved plantations established	6.33 years to 14.33 years
Improved plantations harvested	13.33 years to 20.33 years
<i>Guazuma crinita</i>, option 2	
Trial site preparation completed	1.75 years
Trial establishment completed	1.75 years
Trial thinning completed	3.25 years
Measurement and analysis completed	5.83 years
Seedling seed orchard established	6.08 years
Annual seed harvests	8.08 years to 17.08 years
Improved plantations established	8.33 years to 17.33 years