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On-farm evaluation of the establishment of clonal rubber in multistrata agroforests in Jambi, Indonesia

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Abstract

Perennial tree crops are often grown in complex multistrata systems that incorporate natural vegetation. These systems contribute simultaneously to sustaining rural livelihoods and to the conservation of biodiversity, but their productivity is usually low. Introduction of high yielding germplasm, usually selected in monocultural plantations, is a potential way to increase productivity, but a critical requirement is that such plants can be established in a competitive multispecies environment. The establishment of clonal planting stock in the jungle rubber agroforests of Indonesia was explored through participatory on-farm research. The trial involved four farmers who grew clonal rubber trees in a total of 20 plots, constituting five replicate experimental blocks spread across four farms. Unexpectedly, vertebrate pest damage by monkeys (*Presbytis melalophos nobilis*) and wild pigs (*Sus scrofa*) was the most important influence on establishment, explaining almost 70% of the variation in rubber tree growth. The amount of labour invested in weeding was also positively correlated with rubber tree growth. Farmers generally decided to completely cut back vegetation between rows of rubber trees, including potentially valuable trees, rather than weeding within the rows and selectively pruning trees in the inter-row. Farmers thought that the inter-row vegetation would harbour vertebrate pests and compete with the clonal rubber, and they had access to fruits, firewood and other non-timber forest products from other land. Thus, contrary to expectations, when offered clonal germplasm, farmers opted to use plantation monoculture methods to protect what they considered a valuable asset, rather than maintain the traditional multispecies strategy they use with local germplasm.

Introduction

Perennial tree crops are often grown as part of complex multistrata systems that incorporate natural vegetation, either through enrichment planting in thinned forest, as in the miang tea gardens in northern Thailand (Preechapanya, 1996), or in rotational systems involving natural regeneration of secondary forest together with a planted tree-crop component, as in the jungle rubber agroforests in Indonesia (Gouyon et al., 1993). Both of these ways of using natural vegetation also occur simultaneously in the cacao (*Theobroma cacao*) agroforests of West and Central Africa, traditionally established on partially cleared forest land (Gockowski and Dury, 1999). There is a lot of interest in these systems because of their potential to contribute to sustainable rural livelihoods while conserving biodiversity, but there is also a critical need to increase their productivity, in order to enhance the living standards of people who depend on them for a large proportion of their household income. Introduction of high yielding germplasm is one way of improving productivity, but this generally involves using genotypes selected for use in intensively cultivated monocultures, which may not thrive in competition with natural vegetation in complex multistrata systems (de Foresta and Michon, 1996; Michon and de Foresta, 1997). This research evaluates strategies for establishing high yielding germplasm that can survive and grow in the competitive environment that prevails in agroforests.

Jungle rubber is a traditional multistrata agroforestry system in Indonesia, that extends over an area of more than 2.6 Mha, mostly in the forest margins of Sumatra and Kalimantan, providing the main source of income for around five million people (Gouyon et al., 1993). It is a rotational system, where plots of secondary forest or old unproductive jungle rubber are cleared using slash and burn techniques, rubber trees (*Hevea brasiliensis*) are planted (sometimes with upland rice (*Oryza sativa*), and subsequently secondary forest species are allowed to regenerate. The resulting system, rich in timber and fruit tree species (either deliberately planted, or derived from natural regeneration) provides a diverse range of timber and non-timber forest products, as well as environmental benefits arising from its forest-like structure. However, rubber production per hectare is low.

A network of on-farm trials was set up to investigate the potential for intensification of the traditional jungle rubber system (Penot et al., 1994).[1] The trials involved substitution of the older unimproved rubber seedling varieties currently used by farmers, with new high-yielding grafted clones. These clones have been selected and grown under monoculture plantation conditions where their production is up to three times that of the farmers' existing trees. The objective of the experiment reported here was to test a range of low input management practices that were designed to ensure survival and growth of the clones in a highly competitive multi-species environment. Clonal rubber was planted in rows which were weeded, and secondary forest was allowed to regenerate between rows. This study was designed to: a) assess the effect of four weeding management regimes on the growth of clonal rubber in a competitive multi-species environment like that of the jungle rubber system; and b) identify and quantify constraints to, and factors affecting, clonal rubber growth under on-farm conditions.

Materials and methods

Study site

The trial was implemented in the villages of Muara Buat and Rantau Pandan, Sub-district Rantau Pandan, Jambi Province, Sumatra, Indonesia (1°39′ S, 101°53′ E and 1°41′ S, 101°56′ E respectively, at 250 m a.s.l.). The study site is located in the foothills of the Barisan mountains, adjacent to the buffer-zone of Kerinci-Seblat National Park. Mean annual rainfall is 2,900 mm (average of six years), with a wet season occurring between November and April. The driest months are June to August, with monthly averages ranging from 120 to 145 mm. Temperatures are relatively constant throughout the year (average daily range 26–33 °C).

Soil samples were taken from experimental fields at 0 to 5 and 5 to 20 cm depths, and analysed for pH, total N, P, K, Ca, Mg, Na and Al, cation exchange capacity (CEC) and organic carbon at the Centre for Soils and Agro-Climatic Research, Bogor, Indonesia. No major differences were found between the various fields used for the experiment (Williams, 2000). They were all found to be very low in nutrients, with low CEC (9.61 meq/100 g), low pH (4.07) and high Al concentration (3.53 mg/100 g), and were classified locally as 'red-yellow podsolics' (equivalent to acrisols (FAO)). The experimental fields were on slopes ranging from 20 to 30°.

Weeding trial

Experimental design

The aim was to compare four weeding management regimes (Table 1). Rubber trees were to be strip-weeded (1 m on either side of the trees, with weeds cut back to ground level), with a range of weeding frequencies chosen to represent the low level of management in jungle rubber (B), intensive management in monoculture plantations (D), and an intermediate level (C). Treatment A was a control, comprising the standard management recommendations of a national monoculture rubber project for smallholders (TCSDP/World Bank), and included a legume cover crop. Each treatment was replicated five times, once in each of five experimental blocks, located on four farms. Each block was sub-divided into four plots of area 0.125 ha, and treatments A to D were allocated randomly to these.

Implementation

Farmer motivation was the first criterion in the farmer selection process (Beer, 1991). The participating farmers were selected from those who showed a strong interest in joining the experiment, who had already planned to clear an old jungle rubber or secondary forest plot to plant rubber that year, and whose fields were easily accessible, and at least 0.5 ha in size. These farmers received free grafted rubber clones, fertiliser, fungicide and technical advice. They were responsible for clearing the field, building a fence, planting and fertilising the trees, implementing the weeding treatments, selectively pruning regenerated trees in the inter-row that were overtopping the rubber, and managing the legume cover crop in Treatment A. The latter (*Calopogonium* sp.) was sown at a rate of 10 kg ha^{-1}, into three drills per inter-row area, not less than 1.5 m from the rubber trees.

Fields were cleared in July 1995, and burned two months later. Farmers were advised to follow TCSDP recommendations for smallholders with respect to contour staking, holing and planting (Delabarre and Benigno, 1994). The clonal rubber trees (clones GT1 and PB260, with only one clone used on each farm) were planted in rows along the slope contours in January 1996 (3×6 m; 550 trees ha^{-1}). A minimal fertilisation regime, that had been designed to be affordable by smallholders, was applied (113 g triple super phosphate $tree^{-1}$ at planting (equivalent to 13 kg P ha^{-1}), followed by 50 g urea $tree^{-1}$ (equivalent to 55 kg N ha^{-1}) every three months, for the first two years of growth). Treatment plots were marked out from top to bottom of the slope after the rubber was planted, and included border rows at the upper and lower boundaries, but not between adjacent plots. Measurements were made on thirty core trees per plot (excluding borders), selected from similar topographic positions across treatments.

Table 1. Planned weeding-frequency treatments (agreed upon by farmers and researchers), for the 21 month study period, in a rubber agroforestry trial in Jambi province, Indonesia.

Treatment	Inter-row vegetation	Number of weedings
A	Legume cover crop	10
B	Secondary forest regrowth	4
C	Secondary forest regrowth	7
D	Secondary forest regrowth	10

Data collection and analysis

Measurements of rubber trees (survival, height and stem diameter at 10 cm above the basal graft), and vertebrate pest damage were made every three months on the core 30 trees $plot^{-1}$, for the first 21 months after planting. An index of pest damage was calculated for each plot: the cumulative number of times each tree's main stem was completely severed over 21 months was totalled for all trees in the plot, then divided by the total number of trees. Only trees surviving at 21 months after planting were included in the calculation.

The frequency of weeding actually implemented by the farmers was recorded, along with the time and labour expended on this. Socio-economic data were collected by a questionnaire survey (Kelfoun et al., in press), and regular informal discussions were held with the farmers in the field regarding experimental management, problems encountered and their opinions. Statistical analyses of the effects of farmer weeding frequency, weeding effort and pest damage on rubber growth were conducted using ANOVA and multiple regression in Genstat 5.32.

Results

Influence of individual farmer decisions

Rubber tree growth and survival

Twenty-one months after planting, there were highly significant differences in both rubber tree stem diameter and height amongst farms ($P < 0.001$), but no significant difference in tree size between the four weeding treatments (as implemented: see below and Figure 1; only stem diameters shown as diameter and height were strongly correlated ($r = 0.99$) over all experimental plots). This was partly because three of the farmers did not implement the weeding frequency treatments as agreed when defining the protocol (compare Table 1 and Figure 1). In addition, although farmers planted the legume cover crop in treatment A plots, this failed in all farms due to inadequate weeding and fertilisation. Tree survival (% of original trees planted) showed the same trend across farms as tree growth, being highest for Farmer 1 (100%) and Farmer 2 (97%), decreasing to 87 and 75% for R2 and R1 in Farmer 3's field, and being lowest in the case of Farmer 4 (31%).

Treatment implementation and farmers' socioeconomic status

Treatment implementation (management intensity of the clonal rubber field) depended on the farmers' socioeconomic situation (Table 2) and strategy in allocating labour and/or cash resources to farming or other activities. Farmer 4, who weeded least frequently and whose rubber grew the least and had the highest mortality, had no regular salary. His priorities were tapping rubber for cash income and production of irrigated rice for subsistence. He already owned a large area of immature rubber, so intensive management of his experimental field was not a priority. The inter-row vegetation was not managed and grew unchecked, heavily shading many rubber plants.

The other three farmers had regular incomes from government salaries, which provided for their subsistence needs, and so they were able to invest more cash and labour in their plots. However their resources were still limited, and Farmers 1 and 3 restricted weeding frequency to what they perceived as economically justified, which was less than the protocol stipulated. Only Farmer 2 implemented the agreed number of weedings but generally behind schedule as he worked alone, did not hire extra labour and had little available time because of his off-farm employment.

Contrary to the experimental protocol of selective pruning, the three salaried farmers managed the inter-row vegetation (the regenerating secondary forest 'multistrata' component) by slashing it back severely. Cutting the inter-row was a higher priority for them than weeding within the rubber row, because they perceived that weed regrowth was slow in the rubber row and did not justify the weeding frequencies in the protocol, whereas the woody species in the inter-row (up to 3 m in height) were a more significant problem. Their

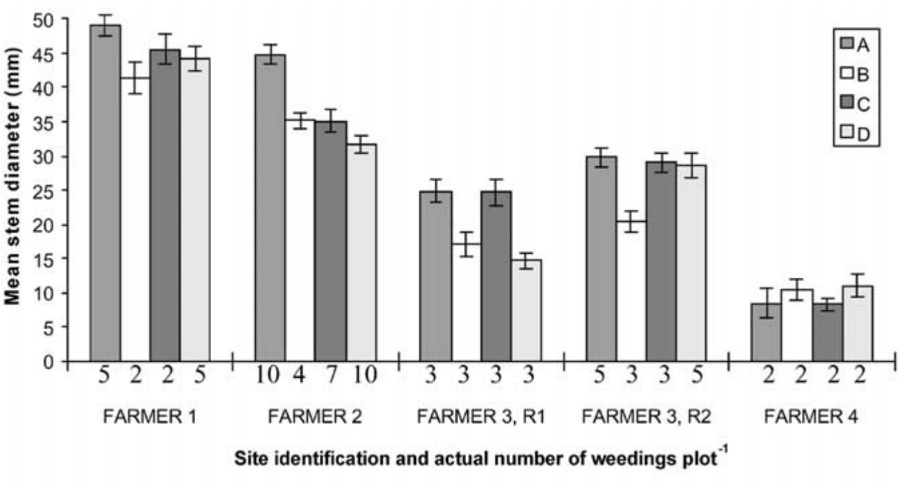

Figure 1. Mean (and standard error) of rubber tree stem diameters (at 10 cm above the graft) after 21 months growth in the field, and the actual number of weedings plot^{-1}, in an agroforestry trial in Jambi province, Indonesia. (Note that the actual weeding frequencies (treatments A, B, C and D; Table 1) differed from those originally planned and the cover crops were not effectively established in treatment A.)

Table 2. Socioeconomic characterization of farmers participating in a rubber agroforestry trial in Jambi province, Indonesia.

Farmer	1	2	3	4
Local/immigrant	Local	Local	Immigrant	Local
Occupation	Teacher	Teacher	Soldier	Village head
Monthly salary (US $)[a]	168	381	174	–
Monthly income from rubber (US $)	49	–	–	78
Other business[b]	None	Shop	Timber trade	Rattan trade
Total annual income (US $), excluding other businesses	2598	4576	2087	934
Total land area (ha)	3.5	2.5	1.5	10.5
Productive rubber (ha)	1.5	–	–	2.0
Immature[c] rubber (ha)	–	1.0	–	4.5
Experimental plot (ha)	0.5	0.5	1.0	0.5
Irrigated rice (ha)	–	–	–	0.5

[a] 1 US $ = 2300 Rp, July 1997.
[b] No financial information available.
[c] Rubber trees have not attained sufficient girth for tapping.

perception was that clonal rubber performs best in monoculture, and they were unwilling to allow secondary forest regrowth to compete with such a valuable asset. Furthermore, these three farmers all thought that the inter-row vegetation could provide cover for destructive pests such as wild pigs (bearded pig, *Sus scrofa*) and so should be cut down.

Influence of weeding (at plot level)

Weeding frequency

Variation in tree growth was not explained by the actual frequency of weeding carried out by the farmers; there were major inter-farm differences independent of the number of weedings (Figure 1). For example, comparing plots that were weeded twice, trees in Farmer 1's field had diameters four times larger than those in Farmer 4's. In the case of Farmer 3's first replicate block (R1), weeding frequency was the same in all plots, but mean diameters in plots A and C were significantly higher ($P < 0.05$, LSD test) than in plots B and D. Similarly, in his second replicate block (R2), the two plots that were weeded three times also differed significantly ($P < 0.05$, LSD test). The lack of a significant relationship between weeding frequency and rubber stem diameter or height was confirmed by simple linear regression analyses on these variables over all 20 experimental plots: adjusted r^2 values were 0.204 for stem diameter and 0.258 for height. Therefore, the effect on growth of another weeding-related variable, namely the total number of person-days spent weeding a plot ('weeding effort') was investigated, as this would reflect farmers' thoroughness in weeding each plot, and be a rough measure of weeding intensity.

Weeding effort

The relationship between weeding effort and frequency was not significant ($P = 0.15$, linear regression on the 20 plot values). There were significant differences between blocks for weeding effort ($P < 0.001$, one-way ANOVA). Weeding effort was positively correlated ($P < 0.001$) with rubber tree stem diameter and height and explained 57.8 and 48.7% of the variation in rubber stem diameter and height, respectively (Figure 2a, for stem diameter).

This relationship is largely explained by the variation amongst, rather than within farms, indicating that weeding effort is strongly influenced by the farmer, probably because of the different weeding methods employed by different farmers, which varied in intensity, effectiveness and labour requirements. For example, slashing with a machete (Farmers 2, 3 and 4) was quick, but subsequent weed regrowth was fast, whereas hoeing (Farmer 1) was much more labour-intensive but also much more effective. The greater weeding effort expended by Farmer 1 than by

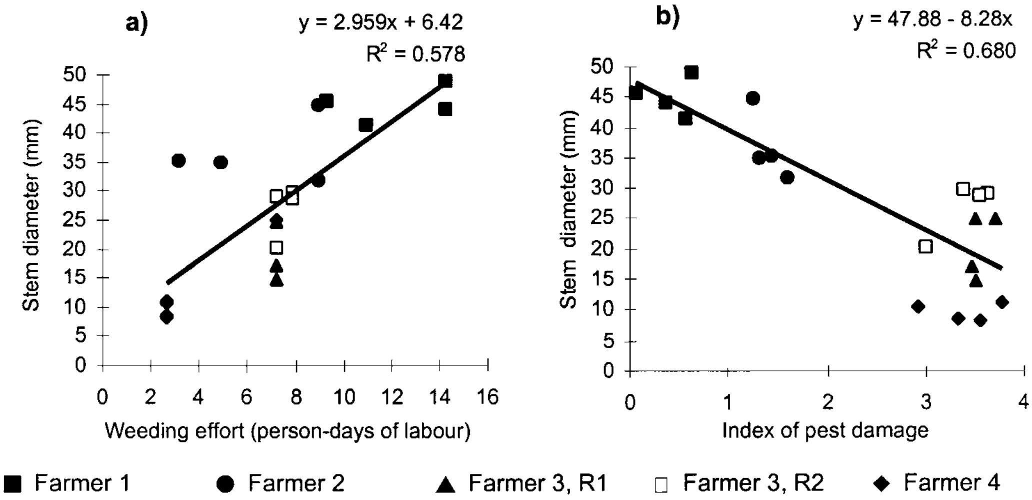

Figure 2. Linear regressions of: a) mean rubber tree stem diameter per plot after 21 months on weeding effort (person-days/plot); and b) mean rubber tree stem diameter per plot after 21 months on pest damage index*, for 20 plot means in an agroforestry study in Jambi province, Indonesia.

* The cumulative number of stem breaks of each tree, sustained over 21 months, totalled for all trees in the plot, divided by the total number of trees.

Farmer 4, for the same weeding frequency (two weedings in 21 months) would thus partly explain the difference in tree size between their fields.

Influence of vertebrate pest damage

Breakage of rubber tree stems by vertebrate pests (banded leaf monkeys, *Presbytis melalophos nobilis* and wild pigs) was a very important factor at the landscape level, the potential severity of which had not been sufficiently recognised by the researchers or the farmers before implementation of the on-farm trial. As for weeding, there were large differences amongst farmers in the amount of effort invested in guarding and fencing their fields against these pests, although they had all agreed to build fences at the start of the experiment. This was reflected in the index of pest damage: that is, the mean number of stem-breaks per tree for each plot.

One-way analysis of variance on the index of pest damage showed that the difference amongst experimental blocks was significant ($P < 0.001$). Pest damage in Farmer 1's field was significantly lower than in any other of the research fields, whereas in Farmer 4's field, damage was significantly higher than in the other trial sites (LSD test). The low incidence of pest damage in Farmer 1's field can be explained by its proximity to a road, good fencing and regular guarding by the farmer (who had his own transport, and therefore had easy access to the field). In contrast, Farmer 4's field was difficult to access, very isolated, and family members would not go there to guard as they were afraid of being attacked by the pigs themselves. Trees in this field only rarely grew above 1 m before being broken again. Farmer 2's field was similar to Farmer 1's, but less well guarded. It was close to the village, so monkeys were less of a problem; however there was an increased risk of goats getting into the field. The higher damage in Farmer 3's field (blocks R1 and R2) was due to its remoteness, lack of fencing and irregular guarding.

Simple linear models of pest damage explained 68 and 69% of the variation in rubber stem diameter and height, respectively (Figure 2b, for tree diameter). Again, this was strongly associated with variation amongst farms and clear groupings were found: fields where pest damage was low showed correspondingly high rubber growth. New leading shoots of damaged trees were usually produced within the first month after stem breakage, and if no further damage was sustained, trees recovered quickly. However, successive damage was observed to have an additive negative effect on tree growth, and also the probability of damage reoccurring was higher, as the new shoots were easily accessible from the ground.

Combined model

A combined model of rubber tree growth was developed using stepwise multiple regression, correcting for auto-correlation. Greater weeding effort necessarily involved farmers spending more time in the field, which in turn may have decreased the incidence of pest damage. To estimate the relative contribution of weeding frequency (X_1), pest damage (X_2) and weeding effort (X_3) to rubber tree stem diameter (21 months after planting), model simplification was conducted using the analysis of deviance procedure (Crawley, 1993). Removal of the variables weeding effort and pest damage from the maximal model caused significant increases in deviance (Table 3). Therefore the minimum adequate models for both stem diameter and height contain only the latter two variables (X_2 and X_3), and not weeding frequency.

The estimated regression line of rubber tree stem diameter (mm, measured at 10 cm above the graft 21 months after planting (R)), on weeding effort in person-days of labour per plot (W) and pest damage in terms of the mean number of stem-breaks per tree (P), over the 20 experimental plots is $R = 29.81 + 1.653W - 5.75P$ (1), with adjusted $r^2 = 0.798$, $P < 0.001$ and standard errors for the three constants of 6.03, 0.488 and 1.27, respectively.

This combined model explains 80% of the variation in rubber tree stem diameter observed in the trial. In addition, the model shows that, in terms of tree stem diameter, the effect of reducing pest damage by an average of one stem-break per tree is equivalent to 3.5 person-days of weeding per 0.125 ha plot, over the first 21 months after planting (5.75/1.653). However, as we have no specific data on the amount of time required to guard the fields to reduce damage, we cannot quantify the effectiveness of spending time on guarding rather than on guarding plus weeding.

Discussion

Clonal rubber growth in relation to weeding regimes

The planned comparison of the effect on clonal rubber growth of three different strip-weeding frequencies was not possible because of the irregular implementation of experimental treatments by the farmers. In the case of the only farmer (Farmer 2) who implemented the agreed weeding frequencies, there were no significant differences in stem diameter growth of the rubber trees amongst the three treatments within his farm (LSD test). This indicates that the lowest weeding level was sufficient for successful establishment of clonal rubber (if adequately protected from pests). The same result was found in a similar trial established the following year (Wibawa et al., in press).

Clonal rubber growth in a competitive multi-species environment, like that of the jungle rubber system, was satisfactory for Farmers 1 and 2, although the diameter increment over the first 21 months after planting was about half that expected of clones grown in well-weeded and well-fertilised plantation conditions on flat land (G. Wibawa, pers. comm., 1999). However the very low management input in terms of weeding, pest control

Table 3. Results of multiple regression using the analysis of deviance procedure on mean rubber tree stem diameter and height per plot (with step-wise elimination of non-significant terms, starting from the maximal model; data from an agroforestry trial in Jambi province, Indonesia).

Explanatory variable	Symbol	Stem diameter	
		Deviance	Significance
Weeding frequency	X_1	79.3	$F = 2.42$, n.s.
Pest damage	X_2	2327	$F = 41.44$, $P < 0.001$
Weeding effort	X_3	408	$F = 11.50$, $P < 0.01$

and lack of pruning of the inter-row vegetation by Farmer 4 was clearly inadequate for clonal rubber growth in this environment (40% mortality and growth increment of only 5 mm in 21 months).

Factors affecting clonal rubber growth

Pest damage
Damage by vertebrate pests was found to be the most significant factor which affected rubber growth in the trial. The extent of the pest damage problem was not expected by either the researchers or the farmers, and would not have been detected if the experiments had been carried out on-station. This research exemplifies Monteith's (1997) argument, that agroforestry modelling is too narrowly focused on parameterising the competition between crop components for light, water and nutrients in ideal conditions, whereas in farmers' fields, significant reductions in growth caused by pests and diseases are common, and since such factors affect competition, they need to be taken into account if the performance of agroforestry systems is to be realistically predicted.

Vertebrate pests were identified as a major constraint to clonal rubber establishment in the study area. This is especially true if farmers' priorities are for extensive (low input, non-intensive) systems (e.g., for Farmer 4), where they may only spend a small amount of time in their fields, or if the fields are remote. In the extensive jungle rubber system, planting material has virtually no cost, as it is collected from existing agroforests; this means that farmers can plant trees at high densities to offset losses from pest damage. Dupraz (1999) proposed a terminology for farmer strategies based on the ratio of tree density planted and the intended final density ('6–8 = conservative, 4 = prudent, 2 = risky and 1 = daring'). Conventional management of monocultural rubber plantations follows a 'daring' or 'risky' strategy, suitable only with near complete control over pests, diseases and weeds and high-cost planting material. Typical management of rubber agroforest regeneration, based on locally obtained seedlings, is in the 'prudent' category, appropriate for incomplete control of pests and low-cost planting material. This issue is integral to the intensification of agriculture, as farmers' tolerance of pest damage decreases when their investments increase; e.g., in improved planting material and fertiliser. As a result, vertebrate pest control has tended to become a higher priority for farmers, because pests are now perceived as having a greater economic impact on their livelihood (Balson et al., 1997).

Greater system biodiversity is often perceived as offering greater protection against invertebrate pests (e.g., through providing a better habitat for natural predators of the pests), though the empirical evidence to support this is still weak (e.g., Risch et al., 1983; Andow, 1991; Watt, 1992; Vandermeer et al., 1998). However, in the case of large vertebrate pests, this may not be the case. In this study, most farmers perceived that the greater cover provided by a more complex, high-biodiversity multistrata agroforestry system increases problems of vertebrate pest damage to the most valuable crop species.

Farmer management
The variation in growth of clonal rubber in this trial was primarily caused by differences in the way individual farmers managed their plots (frequency and effectiveness of weeding), and managed their fields (pest control). It is not possible to say how representative these particular farmers' management is for smallholders in Indonesia. However, the close contact with these four farmers led to a detailed understanding of how their differing socioeconomic situations and priorities affected their farming practice and hence the performance of different intensification options for their agroforests. Farmers 1, 2 and 3 could be considered 'progressive' or 'innovative' farmers, and with their safety-net of a regular income from off-farm employment, they might be expected to be the least risk-averse and thus most likely to adopt high yielding rubber clones in the absence of development projects or government incentives. The conversion of their experimental fields to monocultures occurred because they sought to protect their valuable asset of clonal plants from the risk of pest damage and from potential competition from woody weeds. Their behaviour was strongly influenced by their perception that the monocultural plantation system would be most suitable for clonal rubber. This perception had probably arisen because they were relatively well educated, had spent considerable

time outside the study area, and had been exposed to cultivation systems other than jungle rubber. In addition, their lack of confidence in agroforestry practices involving clonal rubber could also have stemmed from the official extension services. These generally consider agroforestry a backward technology, and are responsible for promoting a single technological package, based on intensive monoculture, and involving high levels of inputs.

Researcher expectations that farmers would be more likely to adopt a new cropping system that was an incremental improvement on the traditional one were not borne out. Researchers thought that they had allowed for the possibility of farmers wishing to manage their clones intensively, by including a high frequency strip-weeding treatment. However, farmers found that this form of weeding was not justified by the sparse weed regeneration, and preferred to slash the whole field less frequently. In their opinion, even once-yearly removal of the woody inter-row vegetation, which they perceived to be a major competitor, was far more efficient in alleviating effects of 'weed' competition on the rubber trees, and this does correspond with standard practice in the establishment phase of plantation forestry. It is reasonable to assume that this outcome would have been even more likely if farmers had purchased the clonal planting stock themselves (cost approximately US$145 for a 0.5 ha field), especially if they had taken out a loan or taken part in a credit scheme, because their investment in the clonal germplasm would then have been greater. The pressure to repay their debts would probably result in farmers trying to maximise their returns, as quickly as possible, which would entail more intensive management of their clonal rubber. A similar outcome was found in Togo when CIRAD introduced high yielding hybrid cocoa seedlings to farmers, with the aim of improving the traditional 'jungle-cacao' agroforestry system (Vaast, 1988). The farmers perceived the new planting material to be so valuable that they weeded it very intensively, and changed their traditional system to a monoculture. Van Noordwijk and Ong (1999) link the negative perceptions of 'competition' to the difference in value (per unit resource capture) between competing components; rubber is already the most valuable component in the systems based on local seedlings and use of clonal rubber clearly increases this difference in value. The notion that higher value components can be successfully integrated into a domesticated forest (Michon and de Foresta, 1997) may indeed need revision.

Before implementing the trial, researchers perceived that the regenerating secondary species in the inter-row were valuable to farmers, providing fruits, firewood and other NTFPs, and also preventing *Imperata cylindrica* from invading the field, as this weed is notoriously difficult to eradicate once established (Bagnall-Oakley et al., 1997). However, farmers did not consider any tree species to be more valuable than clonal rubber and thus tolerable as potential competitors during the establishment phase. They all owned other gardens which provided them with NTFPs, and they were quite prepared to use glyphosate-based herbicide to control the *I. cylindrica* that had invaded parts of their plots.

Although farmers had followed the plantation model in slashing the inter-row, they were not interested in planting legume cover crops, as they said this involved too much labour and cash for little obvious gain. Uptake of legume cover crops by smallholders outside official projects in Malaysia was similarly low (Blencowe, 1989). Farmers' preferences may be better met through applications of the kind of taungya system often used in establishing timber trees in a farmed landscape. Intercropping of herbaceous crops with intensive weeding may be appropriate in the establishment phase of rubber trees. Then development of a more diverse multistrata rubber agroforest would depend on the capacity of other species to regenerate after closure of the canopy of the rubber trees.

Critique of experimental design, and recommendations for future on-farm trials

The four management interventions tested were designed to be suitable for farmers with different socioeconomic circumstances (e.g., availability of household labour). Therefore, as only one treatment was likely to be relevant to the situation of each participating farmer, there was no incentive for them to implement every one of the four treatments in their field. To ensure treatment implementation, the project could have made regular cash payments to farmers on satisfactory completion of weeding, but this would have prevented any information being obtained about farmer decision-making and the likelihood of the techniques being taken up in the farming community after the end of the project. One treatment per farm may have been more appropriate since each farmer has socioeconomic circumstances that determine what technology is appropriate. Replicate farmers from each of a series of socioeconomic profiles could be identified using a brief questionnaire covering socioeconomic variables and farmers' attitudes to the technological intervention proposed.

The design of treatments for on-farm trials, that aim to explore biophysical interactions in multistrata systems or develop new technological interventions, should be based on farmers' actual practices and preferences; these could be elicited beforehand using PRA techniques with farmer groups (Cornwall et al., 1994). The single phase of on-farm trials carried out in this study should then be split into discrete sequential phases. The first set of trials should be on farmers' land to ensure relevant conditions, but be researcher-managed. From these experiments, relationships amongst components (such as high yielding clones), management interventions (such as weeding method and frequency) and outcomes (productivity, sustainability and/or environmental impacts) would be identified, and feedback obtained from farmers visiting the plots. Then, in the second phase, suitable combinations can be tested by a sample of farmers, as described above, in a fully participatory manner. Researchers can then observe how farmers adapt the combinations, relate this to their socioeconomic situation, and thus identify the constraints and opportunities for adoption of particular technological interventions from the farmers' perspective and define their extrapolation domains.

Conclusions

Clonal rubber technically can be established in a multistrata environment, with a minimum level of weeding management; e.g., three person-days per 1/8 ha plot in the first 21 months after planting. However, two hitherto unrecognised constraints to the adoption of high-cost genetically-improved planting material in multistrata systems have been identified through on-farm research: damage by vertebrate pests and farmers' perceptions of the necessity for intensive management of these valuable clones. The interaction of these two factors led farmers to adopt what they perceived as a risk-reduction strategy: the monoculture model. Although researchers assumed that farmers would prefer to retain their traditional management practices, the reality in this trial was that when farmers obtained valuable germplasm, they were prepared to move to monoculture to protect their asset, and in doing so to abandon their traditional multistrata system. The conclusions obtained here may only apply to the farmers participating in this trial and further exploration of techniques for establishing more productive rubber germplasm in a rubber agroforest context, by farmers of different resource access and motivation, remains a priority.

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Note

1. The Smallholder Rubber Agroforestry Project (SRAP) is a network of on-farm trials, established in three Indonesian provinces and working with 98 farmers from four different ethnic groups. Given the geographic and ethnic diversity covered by the project, the results from the single study presented in this paper should not be considered representative of the whole network.

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