THE AUSTRALIAN NATIONAL UNIVERSITY
Center for Resource and Environmental Studies
Ecological Economics Programme

Working Papers in Ecological Economics

Number 9702 **March 1997**

TIME SERIES PROPERTIES OF GLOBAL CLIMATE VARIABLES: DETECTION AND ATTRIBUTION OF CLIMATE CHANGE

by

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Fire as an Economic Disincentive to Smallholder Rubber Planting in *Imperata* Areas

Ken Menz and Katie Ellis

Introduction

Land infested with *Imperata cylindrica* has traditionally been regarded as being of low productivity. Recent research has shown tree growing to be an option for the *Imperata* areas of Southeast Asia (Grist and Menz 1995, Gunawan et al. 1996, Turvey 1995, Pasicolan and Tracey 1996). In this context, fire is seen as a major constraint (Turvey 1994, Wibowo et al. 1997).

Rubber is one tree that is successfully grown in *Imperata* areas by many smallholders. In this paper, the physical impacts and private economic costs of fire associated with rubber planting are examined. Also, an aspect of the *social* costs of fire control are examined - in particular, the costs associated with the risk of fire spreading from one farm to another. These social benefits are not usually factored into private decisions regarding fire control, and thus may result in fire control, and tree plantings, being below the desirable level.

A simple conceptual model of fire in *Imperata* areas is presented. This 'fire model' is then incorporated within an existing bioeconomic model of a smallholder rubber agroforestry system involving *Imperata* (Menz and Grist 1996). In the latter model, rice is initially the understorey to rubber followed after two years, by *Imperata*. The geographical focus of the study is South Sumatra, Indonesia. Much of the empirical data which was used to calibrate the model is from the Palembang region.

Fire in Smallholder Rubber Plantations in *Imperata* Areas

Imperata is a fire climax vegetation type. The subsoil rhizomes of *Imperata* are stimulated by fire to grow rapidly, so fires perpetuate *Imperata*. Mature *Imperata* has been found to burn in the dry season, if there is no rain for a week (Wibowo et al. 1997), and so is extremely hazardous in dry periods. *Imperata* may be cleared from a rubber plantation, but this is a very labour intensive (and therefore costly) process, and the weed will quickly re-establish (Gunawan et al. 1997). Gunawan et al. (1997) also found that some farmers consider the fire hazard posed by *Imperata* to be as serious a threat to their immature rubber as the direct competitive effect of *Imperata* on rubber growth. This dual impact of *Imperata* on tree growth is shown in Figure 1. The circularity of competition between *Imperata* and rubber is also shown there - increased *Imperata* groundcover provides more competition for the tree, which reduces the tree's shading capacity with consequences for the level of *Imperata* groundcover.

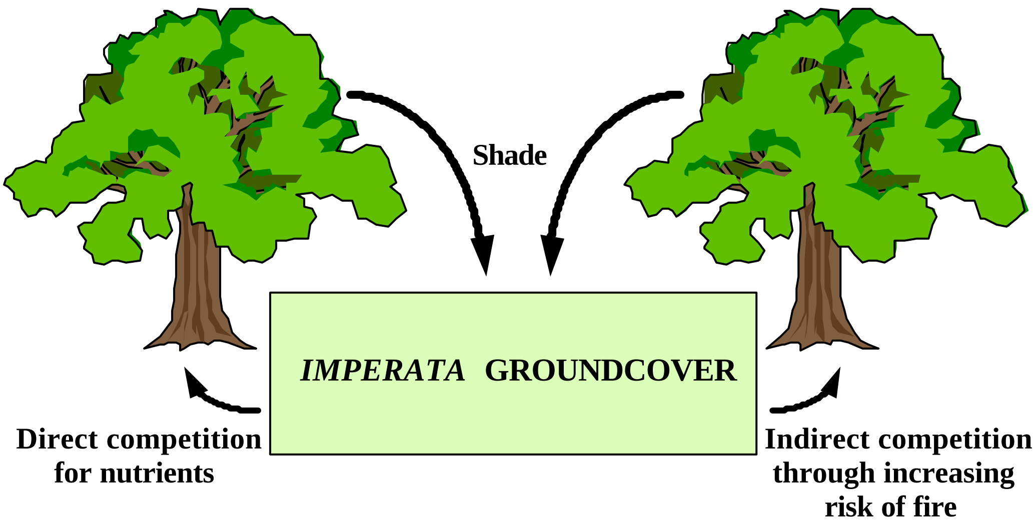

Figure 1. The dual competitive effect of *Imperata* and the circularity of competition between *Imperata* and rubber.

The risk of fire is deemed to be most significant following the period of intercropping rice (usually the first two years after planting). This risk remains, but diminishes up to the time of canopy closure. For smallholders, this is usually between years 8-10 after planting (Hugh Bagnall-Oakeley 1996, pers. comm.), as portrayed in Figure 2. Susceptibility in this period of immature rubber relates to the presence of highly flammable *Imperata* growing as the understorey (Pickford et al. 1992).

A more economically meaningful interpretation of Figure 2 was constructed after consultation with staff at the Indonesian Rubber Research Institute (IRRI) at Sembawa, near Palembang, South Sumatra. This interpretation is portrayed in Figure 3, as a '**fire damage function**', showing damage caused by a fire *within a rubber plantation* for various levels of *Imperata* groundcover *within the plantation*. The function is based upon the accumulated experience and perceptions of IRRI staff.

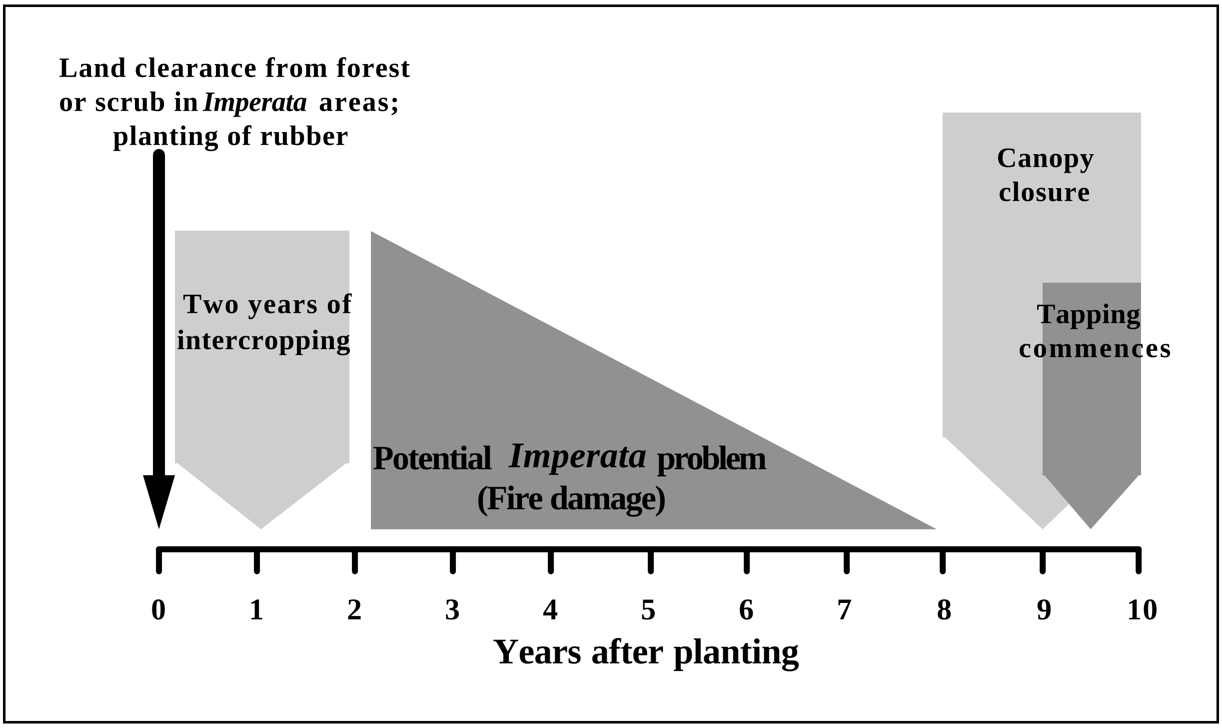

Figure 2. Period between planting seedling rubber and canopy closure, when *Imperata* is likely to be a fire hazard

During the first two years after planting rubber, both fire and *Imperata* control are usually effected through intercropping. Therefore high levels of *Imperata* groundcover would not normally be observed in practice during this period. After canopy closure, with *Imperata* groundcover at 25% or less, fire is not expected to result in significant damage to rubber trees, since fires in mature rubber are relatively uncommon (Gunawan et al. 1997) Thus, it is in the intervening years, between the conclusion of intercropping and canopy closure that the fire risk from *Imperata* is a major concern, when the 'probability of having immature rubber damaged or destroyed by fire is worryingly high' (Gunawan et al. 1997). In terms of Figure 2, this is between the end of year 2 and canopy closure. In Figure 3, it is at *Imperata* groundcover levels above 25%. All trees are assumed to be destroyed by fire at levels of *Imperata* groundcover greater than 75%. For *Imperata* groundcover levels less than 75%, there is a proportionate reduction in stem damage as *Imperata* groundcover falls (Figure 3). This assumption is supported by data from smallholder farm interviews carried out in South Sumatra. Fires there did not necessarily destroy *whole* parcels of immature rubber, but trees that were burnt were completely destroyed (Gunawan et al. 1997).

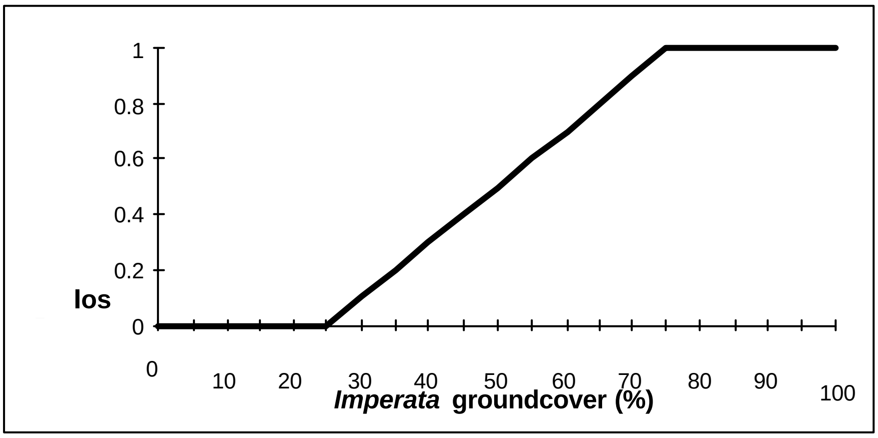

Figure 3. Fire damage function: proportion of rubber stems lost in a dry season fire, in relation to the level of *Imperata* groundcover *within* the plantation.

The nature of the surrounding vegetation will influence the risk of fire entering a plantation. In this paper, the risk of fire entering a plantation ('**fire risk**') is taken to be the product of the probability of fire ignition and proportion of *Imperata* groundcover *in the surrounding areas*. Smallholders often use firebreaks to reduce this risk (Gunawan et al. 1997), so the fire risk should be regarded as being measured in the light of such ameliorating actions.

Probability of fire entering a plantation (fire risk) = (probability of fire ignition) x (proportion *Imperata* groundcover in areas surrounding the plantation)

..................................Equation 1

An average annual probability of fire ignition was used for the expository purposes of this paper. The probability of ignition was set at 0.1 (10%) per year, or once every 10 years. So, with an *Imperata* groundcover of one (100%) surrounding a plantation, fire risk would be 0.1 x 1 = 0.1, or 10% per year. This average-year approach avoids the complexities involved with a stochastic model and in South Sumatra, regular small fires appear to be more common than occasional large fires (Gunawan et al. 1997).

The number of rubber stems lost to fire per year is thus the risk of fire entering a plantation (from Equation 1) times the prevailing *Imperata* groundcover *within* the plantation (from Figure 3).

The *Imperata* groundcover *within* the plantation is derived from the shading function in a rubber plantation simulation model. That model is also used to trace through the long run consequences of fire damage on the plantation.

The Rubber Plantation Model and Key Assumptions in the Analysis

The bioeconomic rubber agroforestry model, RRYIELD, is described in Grist and Menz (1995) and Menz and Grist (1996). The focus of the model is on smallholders, rather than estates. The RRYIELD model includes a section dealing with the competitive effect of *Imperata* on rubber tree growth (Grist et al. 1995).

Imperata groundcover is the key variable in both the fire risk and fire damage calculations. In the work to be reported in this paper, 'fire damage' and 'fire risk' parameters were calculated and incorporated within the RRYIELD model, based upon the logic outlined in the previous section. For determining the risk of fire entering a plantation ('fire risk'), the relevant *Imperata* groundcover is that on *surrounding* farms or plantations. For determining 'fire damage', it is the *Imperata* groundcover *within* the plantation being examined.

Wibowo et al. (1997) specified fire risk to be a function of various factors, including fuel load and ignition probability. The latter two factors are considered to be incorporated into the average 'fire risk' used in the model. The probability of ignition (0.1 per year in the example to follow) is input directly into the model by the user. *Imperata* groundcover *within* the plantation is calculated in the model annually, based upon light intensity passing through the rubber canopy (see Figure 3). The *Imperata* groundcover *surrounding* the plantation can either be specified by the user, or it can be simulated by RRYIELD. The latter method is the appropriate one to use where the *surrounding* areas also contain rubber plantations.

All RRYIELD model output is determined on an annual basis. For this analysis, the rubber seedlings are planted at a density of 750 stems per hectare. This was the average planting density found by Gouyon and Nancy (1989) in a survey of smallholders. It also coincides with the economically optimal tree planting density (in *Imperata*) found by Menz and Grist (1997).

Fire damage has been assumed to be evenly distributed throughout the rubber plot. Trees destroyed by fire are deemed not to be replaced within the model. *Imperata* groundcover is not to affected by fire for a significant length of time, since the rhizomes ensure fast recovery of *Imperata* after fire (Pickford et al. 1992). Therefore fire does not *directly* alter the competitive effect of *Imperata* on rubber tree growth. However it does so *indirectly* by killing rubber trees, which allows more light to reach the *Imperata* understorey (aiding subsequent *Imperata* growth).

After the two-year period of intercropping with rice, no further *Imperata* control is specified, other than that which occurs through shading by rubber trees. *Imperata* groundcover becomes a function of light penetration through the rubber tree canopy. There is competition between rice and rubber trees, in terms of the mutual effects on growth during the two years of intercropping. However, this competition is less than that between *Imperata* and rubber (Grist and Menz 1995).

The planting material most commonly used by smallholders is unselected seedlings (wildlings). The model parameters are based upon this planting material. Seedlings are usually transplanted from seed dispersed from nearby trees (Grist and Menz 1995), and the material is often of relatively poor quality.

The physical outputs obtained from the RRYIELD model are translated into economic terms via a companion economic model, RRECON, which calculates net present value (NPV) from the annual cash flows of alternative scenarios. A (real) discount rate of 10 per cent is used. Price and cost data were obtained for the Palembang region in South Sumatra (Grist et al. 1995). Where fire reduces the number of trees available to be tapped, a corresponding reduction in tapping cost is made within the model. This corresponding reduction is also applied to other tree-related costs such as harvesting and processing.

The model was initially run three times (with unselected seedlings as the planting material):

1) with the probability of fire ignition set at 10% per year and the surrounding *Imperata* at 100% **(the 'fire$_{100}$' scenario)**
2) with the probability of fire ignition set at 10% per year and the surrounding *Imperata* at 50% **(the 'fire$_{50}$' scenario)**
3) with the probability of fire ignition set at 0% per year **(the 'no fire' scenario)**

The first two situations represent an individual planting rubber in a plantation surrounded by high and moderately *Imperata* infested areas.

The Economic Costs of Fire in Rubber

The results of the modelling exercise, in terms of net present value (NPV, as determined using a 10% discount rate) and total latex production, are shown in Table 1. Inclusion of fire risk in the 100% surrounding *Imperata* situation of the model caused a reduction in latex yield over the life of the plantation of 2.6 tonnes/ha which led to a reduction in NPV of Rp 224 000/ha. These figures are indicative of the cost of fire for this type of circumstance, or alternatively, of the value of eliminating the risk of fire. NPV is calculated after allowing for payment to labour (ie. NPV is net of labour costs). So a small proportional change in latex revenue can give a large change in NPV.

Table 1. NPV and total latex production per hectare over 30 year life of a smallholder rubber plantation for the one 'no fire' and two 'fire' scenarios, using unselected rubber seedlings as planting material.

	Net Present Value (Rp '000)	difference due to fire	**Latex Production** (tonnes)	difference due to fire
No fire	471	-	17.8	-
Fire$_{50}$	401	70	16.9	0.9
Fire$_{100}$	247	224	15.2	2.6

Net present value was determined using a 10% discount rate.

The underlying reasons for these differences in net present value and in latex production can be seen in Table 2. Fire in a plantation surrounded by sheet *Imperata* reduces the number of tappable trees in the plantation by 22 per cent. *Imperata* groundcover within the plantation is higher under the $fire_{100}$ scenario than the no fire scenario (Figure 4). The shaded area provides an indication of the competition from *Imperata* as a result of fire. This is due to the increased light penetration through the canopy, as the density of trees is reduced by fire. The extra *Imperata* groundcover reduces tree growth rate for a given tree planting density. It also increases fire risk in subsequent years. There is an economic cost associated with both of these effects.

Table 2. *Imperata* groundcover and the number of tappable trees per hectare, at the time of tapping commencement.

	No fire	$Fire_{100}$
Number of trees reaching tappable size	750	586
Reduction in number of trees reaching tappable size, due to fire	-	22%
Year of tapping commencement	10	10

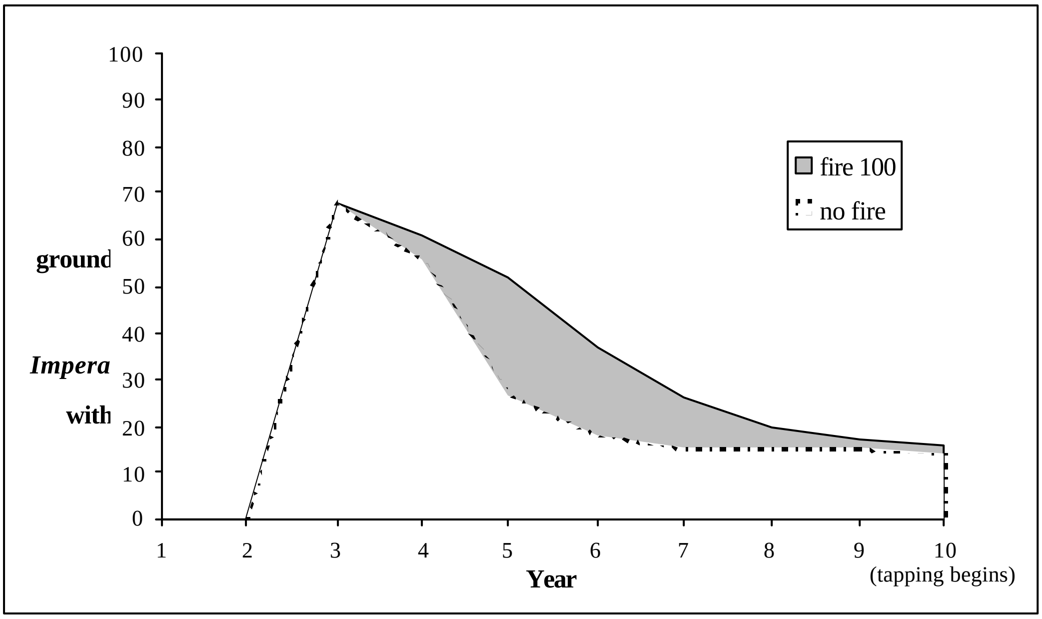

Figure 4. *Imperata* groundcover within the plantation up to the time of tapping commencement.

Individual trees in the $fire_{100}$ scenario grew at a slightly faster rate than the trees unaffected by fire (Figure 5) due to the reduced tree density as a result of fire. The additional competition from a higher *Imperata* groundcover was approximately equal to the competitive effect of the trees in the no fire scenario. As a result, tapping commencement time was approximately the same in the $fire_{100}$ and no fire scenarios. Since fire did not reduce tree girth increment or tapping commencement time, the net negative effect of fire was to reduce tree numbers. The difference in total latex production was largely due to the greater number of stems in the no fire scenario. Since costs were approximately equal in all scenarios, (with the exception of lower tapping and harvesting costs per hectare following fire), NPV is lower with $fire_{100}$ by 224 000 Rp (48%). Up to 224 000 Rp could be profitably be spent in achieving fire control where a smallholder is planting rubber in an area surrounded by 100% *Imperata.* With surrounding *Imperata* groundcover at 50%, up to 70 000 Rp could be spent (see Table 1).

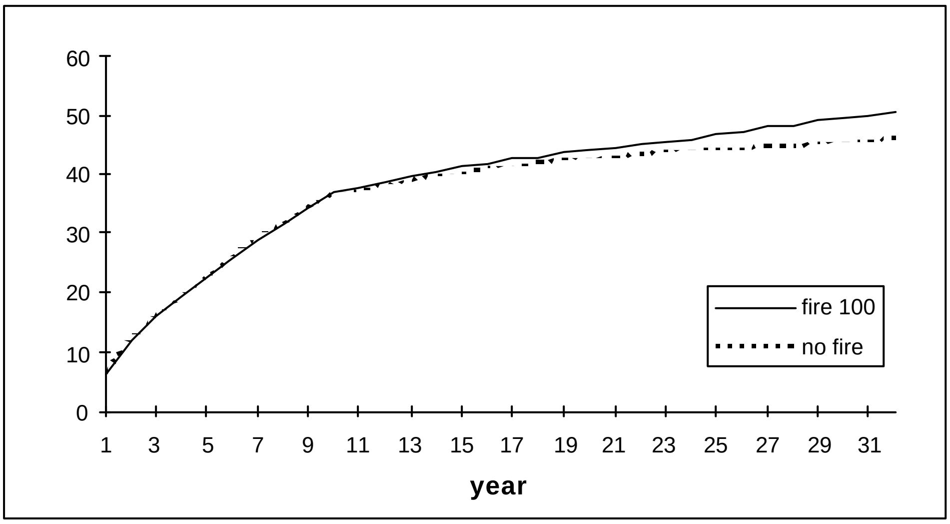

Figure 5. Effect of fire on tree growth.

Sensitivity Analysis

A higher probability of fire risk

The effect of fire risk levels greater than 10% per annum were assessed. Fire risk is calculated as the product of ignition probability and surrounding *Imperata* density, so for this analysis it was not important which of the latter two factors was manipulated. Only the product (fire risk) was altered. The 'break-even' point, where NPV approaches zero, was found to be where fire risk was 13% per annum. For fire risk values above 25% per annum, fire damage in seedling rubber was extensive. Canopy closure was not achieved, and tree establishment costs were not recouped. Under these conditions, rubber growing is not economically viable.

Fire Control via a Co-ordinated Approach to Tree Planting

Complete elimination of fire may well be impractical in the early stages of *Imperata* grassland transformation, where the prevailing fire risk conditions are inherently high. However, a relatively simple and low cost method for reducing fire risk exists - this is for groups of smallholders on *Imperata* to *simultaneously* undertake rubber planting.

Tree planting is a form of fire control (refer Figures 1 and 2). The risk of fire entering a farm is conditioned by the fuel load conditions on neighbouring farms.

Fire spreading across farm boundaries can be regarded as an 'economic externality' in a similar manner to herbicide drift, or a weed spreading, from farm to farm (Menz et al. 1984). The value of fire control consists not only of the private benefits from control (Table 1) but also of the 'social' benefits stemming from a reduction in fire risk to neighbouring farmers, through a reduction in *Imperata* groundcover. If one farmer reduces fuel load (eg. via tree planting), then the fire risk is reduced *for all neighbouring farmers*.

This phenomenon was examined with the aid of the models. The previous results for the $fire_{100}$ and the $fire_{50}$ scenarios (shown in Table 1), showed latex yield and net present value on the assumption that no *Imperata* control was undertaken on surrounding farms.

Where a farmer and his/her neighbours undertake simultaneous, or co-ordinated, rubber planting, fire risk is lowered *for all farmers* because the *Imperata* density of surrounding farms is reduced. Such co-ordinated planting has been noted in farm interviews in South Sumatra (Gunawan et al. 1997). Table 3 shows the economic effect of co-ordinated planting of smallholder rubber. The benefit from a co-ordinated approach to planting was 133 000 Rp (per hectare in NPV terms) for the $fire_{100}$ scenario and 29 000 Rp for the $fire_{50}$ scenario (this compares with a saving of 224 000 Rp per hectare achieved by the complete elimination of fire in the $fire_{100}$ scenario). There were corresponding increases in latex yield of 1.4 tonnes and 0.4 tonnes per hectare, respectively, over the life of the plantation. There was less tree loss and less competition from *Imperata* with the co-ordinated approaches to tree planting compared to unilateral planting.

Table 3. NPV and total latex production per hectare over the 30 year life of a smallholder rubber plantation, unilateral vs co-ordinated tree planting.

	NPV (Rp '000)	**Latex Prod^n** (tonnes)
Unilateral planting: $fire_{100}$	247	15.2
Co-ordinated planting: $fire_{100}$	380	16.6
Benefit gained	133 (54 %)	1.4 (9 %)
Unilateral planting: $fire_{50}$	401	16.9
Co-ordinated planting: $fire_{50}$	430	17.3
Benefit gained	29 (7 %)	0.4 (2 %)

These incremental benefits from a co-ordinated approach to planting (via a reduction in fire risk) are necessarily less than the benefits of total fire control (for the latter see Tables 1 and 2). The benefits for co-ordinated planting may be obtained at lower costs than the benefits from more conventional fire-fighting techniques. The only cost is that of the co-ordination itself.

A co-ordinated approach to planting rubber would have added advantages in terms of the cost of constructing fire breaks. Firebreaks in South Sumatra are generally made by slashing the vegetation and then turning over the land with a *cangkul* (a mattock-like agricultural implement) and are 3m wide or greater (Gunawan et al. 1997). This, therefore presents a cost in terms of labour usage. When farmers plant their immature rubber plots adjacent to each other in one area, the cost of surrounding all of the plots with a fire break, and maintaining such a structure, would be shared by the farmers involved, thereby reducing costs per farm due to the reduction in perimeter size per unit area planted. The fire breaks would benefit all the farmers involved by reducing the risk of fire approaching their rubber.

Conclusions

The risk of fire was demonstrated to be an economic disincentive to tree growing. Even a modest fire risk of 10% per year was shown to considerably reduce expected profit from rubber growing. A fire risk greater than 13% resulted in economic non-viability of rubber growing under the specified conditions. Total control of fire, in a plantation surrounded by 100% *Imperata*, would return an additional 224 000 Rp in terms of NPV. A simple, low cost, fire risk reduction technique in *Imperata* areas, would be for all smallholders to *simultaneously* plant rubber. This policy would provide approximately one half of the benefits obtained by complete elimination of fire. Other forms of fire risk reduction such as fire breaks and care with lighting fires in windy conditions are feasible.

In addition to the direct economic impact of fire risk on the profitability of neighbouring farms, there are other external costs associated with fire (land degradation, smoke haze, reduction in carbon sequestration) which were not examined in this paper. For example, in Indonesia in 1994, smoke haze from fires caused airline flight disruptions in the area, and the pollution which spread to Singapore and Malaysia became a diplomatic issue with these neighbouring countries (Gunawan et al. 1997).

In general fire risk becomes less as grassland areas become more developed (Magcale-Macandog and Galinada 1996). The issue of fire risk is most pertinent in the less densely populated, *Imperata* dominated areas. The calculations here were for non-clonal planting material. The benefits from fire control would presumably be less with clones.

The fire damage function used in the empirical models is admittedly somewhat speculative. Yet it is in accordance with observed general relationships between fire and *Imperata* groundcover, and with tree losses over time. The fire ignition probability is genuinely speculative, but at 0.1 per year is thought to be conservative.

Precision in estimation was not the objective. Rather it was to demonstrate a framework for conceptualising fire risk and damage in relation to tree growing in *Imperata* areas, to demonstrate that the social costs of fire may be substantial, in terms of the economic disincentive to neighbouring farms, and to demonstrate the promise of a co-ordinated community approach to fire control. Smoke haze, global warming (through emissions of carbon and reductions in tree planting) and land degradation are other social costs emanating from fire. If account were taken of the impacts of fire control with respect to these issues, total social benefits would be higher than indicated here.

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