Modified BEAM Rubber Agroforestry Models: RRYIELD and RRECON

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Preface

The modified BEAM model can be run using Quattro Pro (Version 4 or later) on an IBM-compatible computer. While the Quattro Pro software is required, a working knowledge of Quattro Pro is not. This report outlines the functions of the model and gives details of the modifications made to the original model. The modifications to the BEAM models were carried out progressively, as documented in a series of five papers (*Imperata* Project Papers 1995/3, 1995/4, 1995/ 5 1995/6 and 1997/6). Here we summarise all in a single volume. Tutorials, included as an appendix to this report, were designed to enable a novice to use and understand the basic functions of the model. Further information on the modified version of the models, and additional copies of this report and computer program, can be obtained from the Australian Centre for International Agricultural Research (ACIAR), GPO Box 1571, Canberra, ACT 2601, Australia. They are also obtainable electronically at the *Imperata* Project website:

http://cres.anu.edu.au/imperata/imperat1.htm

For a more detailed understanding of the BEAM models (i.e. of the research which forms the basis for the functions used in the model) and the mechanics (the Macro functions) which drive the model, the documentation of the original BEAM rubber models (RRYIELD and RRECON) should be consulted. It can be obtained from the Bioeconomic Agroforestry Modelling (BEAM) Project, School of Agricultural and Forest Sciences, University of Wales, Bangor, Gwynedd, LL57 2 UW, United Kingdom.

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P. Grist*, K. Menz* and Thomas†

Introduction

This paper details changes to the BEAM models, RRYIELD and RRECON, which are two of a series of bioeconomic models developed by the Bioeconomic Agroforestry Modelling (BEAM) project, which is based at the School of Agricultural and Forestry Sciences at the University of Wales. The RRYIELD model deals with the biophysical components of a rubber-based agroforestry system. It focuses on the changes in output (latex, wood and intercropped annual and perennial crops) in response to a number of bioclimatic, topographic and silvicultural variables (Thomas et al. 1993). Outputs are measured annually over the life of the plantation. The RRYIELD model is linked to an economic model RRECON (Willis et al. 1993), which is used to determine the economic returns from a rubber plantation. The two models are designed to be used in combination as an extension and research tool to supply farmers or researchers with information on the viability of alternative rubber intercropping systems.

The work reported here was carried out as part of a project entitled 'Improving smallholder farming systems in *Imperata* areas of Southeast Asia—a bioeconomic approach'. The project was based at the Australian National University and involved collaboration with the Indonesian Rubber Research Institute at Palembang, South Sumatra, and other institutions.

The original model was developed for large estates and government plantations, and thus embodied high levels of management including weed control, fertilizer application and use of clonal planting material. The changes outlined in this report aimed to make the model more applicable to smallholders in *Imperata* infested areas of Southeast Asia,

*Centre for Resource and Environmental Studies, Australian National University, Canberra, ACT 0200, Australia.
†Sembawa Research Station, Rubber Research Institute of Indonesia, PO Box 1127, Palembang 30001, Indonesia.

particularly Indonesia. The changes made involved: modifications to existing components of the model (such as the girth and latex yield functions); replacing existing components of the model (such as the site index); and adding new factors (such as girth loss due to tapping and ground cover, clonal and fertilizer indexes, weed ground cover, weed control and fire risk). These modifications were made progressively and were documented in a series of five papers (*Imperata* Project Papers 1995/3, 1995/4, 1995/5 1995/6 and 1997/6). They are now presented here together in a single paper.

For details on the basic set-up of the model and background into the unchanged parameters, the original RRYIELD and RRECON models, and associated documentation (Thomas et al. 1993), should be consulted.

Summary of Changes

The changes made to the models were in five main areas:

- girth function (page 9);
- latex yield function (page 15);
- fire damage calculation (page 18);
- site index function (page 19); and
- changes to RRECON (page 28).

The changes to the girth function involved making it incremental rather than cumulative, the addition of 'girth loss' features to account for early tapping or competition with ground cover, and the inclusion of indices for fertilizer and clones (i.e. indices which change the girth function).

The latex function was adjusted to account for the poorer management practices associated with smallholder systems, and a factor linking the latex function to the girth function was included, so that improvement in the growth (girth) characteristics are also represented in the latex yield.

The inclusion of a fire damage element in the model required changes to the tree stand density calculation. Stand density is reduced relative to the level of fire risk and the intensity of the fire (based on the density of the weed undergrowth). The reduction in stand density translates into a reduced total latex yield (fewer trees tapped) and reduced wood yield. However, the latex yield per tree is potentially higher, because of reduced inter-tree competition.

The site index was fully replaced with a new site index which was seen to be more representative of Indonesian rubber-growing conditions.

Relatively minor changes were made to RRECON to align its variables with some of the major changes made to RRYIELD.

Tree girth

The girth function is the building block for many of the other functions in the model: equations for height, canopy width, wood volumes, etc., all include girth as a variable. The modified version of the model also calculates latex

yield as a function of girth. In the original BEAM model, girth is a function of tree age, planting density and site index. Tree age and planting density provide the general shape of the function, while the site index shifts the function up and down the vertical axis (Thomas et al. 1993).

The girth function was compatible with graphs of girth increment produced by DeJonge (1961) and Westgarth and Buttery (1965). The equation in the original BEAM model was seen to be acceptable for calculating the girth of an estate-grown tree. However, with the following changes, it was made more dynamic and applicable to smallholders.

Girth calculated on a cumulative basis

The girth equation in the initial version of the BEAM model was unsuitable when factors that shift the equation vary in the short term (e.g. annually). These factors are then more appropriately related to changes in girth *increment*—measured with respect to the same time interval as the change in factor input levels. A change was needed because the calculation of total girth must be referenced to the girth in previous years. It cannot simply be calculated on the basis of variable input levels in the current time period.[1]

Consequently, the girth equation was changed to calculate the annual girth increment. The girth increments were then added to give the cumulative girth at time t. This results in consistency of total girth across years, such that annual changes in environmental factors can flow through to the girth function.

Only a small change to the model was required to achieve this. A function for annual girth increment was created by subtracting the previous year's girth from the current year's girth (i.e. $G_t - G_{t-1}$). Although this change is superficially simple, the practical ramifications are substantial. G_t and G_{t-1} were calculated using the original girth equation.

The new tree girth increment equation is:

$$\Delta G_t = \frac{2.37 \times \text{age} \times \text{site index}}{22 + \left\{\left[(\text{age}/20)^2 \times \text{density}\right]\Big/\left[0.2 + (5 \times \text{age})\right]\right\}^{1.35} + \text{age}} -$$

$$\frac{2.37 \times (\text{age}-1) \times \text{site index}}{22 + \left\{\left[((\text{age}-1)/20)^2 \times \text{density}\right]\Big/\left[0.2 + (5 \times (\text{age}-1))\right]\right\}^{1.35} + (\text{age}-1)}$$

where Total Girth$_t = \displaystyle\sum_{n=1} \Delta G_n$.

[1] A simple example of problems that otherwise arise is demonstrated using the graphs in the BEAM manual (Thomas et al. 1993). If a change in the climatic parameters occurs, causing a reduction in the site index (growing conditions) from 100 in year 5 to 50 in year 6, the model will move to a lower *total* girth function, as shown in the graphs on pages 20 and 21 of the manual. Assuming constant density at 400 stems per ha, total girth will appear to fall from 48 cm to 28 cm.

This girth equation was then modified further to include a 'reduction in girth increment due to tapping' factor, and a 'reduction in girth increment due to ground cover' factor. The first factor enables the girth of an untapped tree, or the effect of delayed tapping, to be calculated. The rationale for this is outlined below. The second factor incorporates in the model, the interaction between the ground cover and the tree. It enables calculation of the effect on tree growth of crop or weed competition. The reasoning behind this is also outlined below.

Changes in girth increment due to tapping

The girth at which tapping begins is a key element affecting the output of a rubber plantation. In the girth equation in the original version of the BEAM RRYIELD model (Thomas et al. 1993), it was assumed that tapping begins in the seventh year after establishment (this corresponds to a girth of approximately 45 cm). However, for smallholders, who comprise a significant portion of rubber production in Indonesia (80% of all producers and 73% of production [Gouyon and Nancy 1989a]), tapping often begins at girths of less than 45 cm. The slower rate of tree growth, which leads smallholders to begin tapping at a smaller girth, is due mainly to poor rubber genetic material, and competition with weeds such as *Imperata*.

The option to choose when tapping commences was added to the model. This enables the user to assess the effects of commencing tapping at different ages or girths. To evaluate the effects of beginning tapping at girths other than the 45 cm specified in the original BEAM model, the difference in the rate of growth between a tapped and an untapped tree was needed. This also allows the simulation of tree growth entirely for timber should such an option become relevant.[2]

A relationship between the rate of growth of tapped and untapped trees was provided by Templeton (1969). For a small sample of RRIM 600 and 500 series clones, Templeton calculated the girth increment of a tapped tree as a percentage of the girth increment of an untapped tree. The percentage difference varied over clones, and as we are considering a non-clonal case, the mean percentage was taken as being most appropriate. The mean percentage difference between the tapped and untapped girth increment was 58.7%. The magnitude of this difference is supported by research conducted by Simmonds (1981) and Shorrocks et al. (1965). (Grist et al. (1995) give details of these relationships.)

The Templeton relationship was used for calculating changes in the girth increment as a result of commencing tapping at girths other than 45 cm.

For trees that are not tapped even after reaching a girth of 45 cm, an addition is made to the girth increment calculated by the BEAM model. Inverting the Templeton relationship, the girth of an untapped tree is 170% of the girth of a tapped tree ($1.7 = \frac{1}{0.587}$). Therefore, the percentage addition to

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[2]For example if timber becomes a predominant objective of rubber tree cultivation.

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be made to the girth increment obtained in the original BEAM model is 70%. This calculation will apply in any year the tree is not tapped after it reaches a girth of 45 cm.

A similar calculation is made to obtain the girth increment of a tree that is tapped before it reaches a girth of 45 cm. Again using the Templeton equations, the girth increment of a tree tapped before it reaches a girth of 45 cm will be 58.7% of the girth calculated in the model. The reduction in girth increment for a tree that is tapped before it reaches a girth of 45 cm is 41.3% (i.e. 1–0.587=0.413) of the girth increment derived in the original BEAM model. This 41.3% of the girth increment is subtracted from the girth increment calculated in the original BEAM model for every year the tree is tapped before it reaches a girth of 45 cm. These changes are made in the ARBOR loop[3] of the BEAM model.

Within the model, rather than have the 'begin tapping' time fixed at year five, the Macro function was altered to enable the time and method of tapping commencement to be chosen by the user in the input section of the model. This involved the introduction of two new variables in the input section:

- a 'begin tapping' calculation method, enabling the user to decide whether tapping would begin at a specified girth or a specified age; and
- the age or girth minimum at which tapping would begin.

Also, the first few lines of the GOMA loop[3] in the model had to be changed to read these options.

Loss of girth increment due to ground cover: *Imperata*-tree interaction

Smallholder rubber trees often encounter a high level of competition from weeds. The main weed competition for smallholders in Indonesia (and most of Southeast Asia) comes from *Imperata*. *Imperata* competes strongly for soil moisture and nutrients. In the early stages of tree development it can reduce growth of the tree by up to 50% (Menz and Wibawa 1995).

The original BEAM model captures only the shading influence of the tree on the intercrop, reducing the crop yield as the tree develops and shades the crop, and not the effect of the ground cover (be it an intercrop or weed species) on the. However, it is known that the ground cover will affect tree growth through competition for soil moisture and nutrients. The magnitude of these effects will vary according to the type of ground cover, and with the density of the cover. A legume cover crop is likely to have less impact on tree growth than a rice crop (Menz and Wibawa 1995). Woody weeds are likely to have less impact than *Imperata* (Gouyon and Nancy 1989b).

Specification of the type of ground cover present is made in the inputs section of the model. At this stage only *Imperata* is considered, although there

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[3]See Figure 2.1 in the original BEAM manual (Thomas et al. 1993) for a description of the loop sequence in the Program Flow Diagram.

is scope to expand the number of ground cover variables if information on their competitive relationships with the tree is known.

The modelled net effect of *Imperata* ground cover on tree girth was developed using two relationships. The first is a relationship between light intensity and *Imperata* density. The second is a relationship between *Imperata* density and tree girth. A full description of these relationships can be found in Menz and Wibawa (1995).

The two equations used to derive the light intensity–*Imperata* density relationship are:

$$\text{Percentage weed ground cover} = 0.50 \times \exp^{(\text{light}/1.445)} \qquad (0.20 \leq \text{light} \leq 1.00)$$

and

$$\text{Percentage weed ground cover} = 2.88 \times \text{light} \qquad (0.00 \leq \text{light} \leq 0.20)$$

The *light* variable used was established in the original version of the BEAM model, as the percentage of light penetrating the rubber tree canopy. Once the weed ground cover is established, it can be used to determine consequent reduction in tree girth increment (or girth loss due to ground cover, 'girth loss$_{gc}$'):

$$\text{girth loss}_{gc} = \text{girth increment} \times \left[0.05 \times \sqrt{(\%\text{weed ground cover})} \right]$$

where girth loss$_{gc}$' is the reduction in girth increment due to ground cover (in this case *Imperata*); 'girth increment' is the girth increment with no *Imperata*; and, 'weed ground cover' is measured on a scale of zero to one.

Weed ground cover was included as a new column in the input/output section of the model. The corresponding loss of tree girth increment was also included in a new column in that section. The loss of girth increment because of ground cover was then subtracted from the total girth for the given year. As the *Imperata* (or other ground cover) density increases, tree girth increment will decline.[4]

A further model option allows for calculation of the impact of keeping the plantation weed-free for a number of years. If a smallholder removes *Imperata* from a plantation, the model can calculate the gains from weeding. This is done by simply holding the loss of girth increment due to ground cover at zero in the years specified as having no ground cover. The specification of the number of years the smallholder clears the site is made in the inputs section of the model.

The weed ground cover variable was originally used solely to calculate girth loss due to ground cover, and was integrated into this calculation. Now, as it is being used in other functions, the weed ground cover calculation has been altered so that it stands alone. In its original form, weed ground cover was calculated every year. If clearing or a rice crop occurred in a given year,

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[4]The base situation in the model with regard to ground cover is where the ground is clear. So increases in weed ground cover cause *reductions* in the base level of girth increment. In contrast, with the tapping/no tapping situation, the base is tapping. Girth increment is increased in the no tapping case.

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the girth loss variable was altered and not the weed ground cover variable. Now, if clearing of weeds or a rice crop occurs, the weed ground cover is set to zero so that fire risk is calculated correctly. The result of calculating girth loss due to ground cover remains the same, but now it is the independent variable (weed ground cover) which is set to zero and not the dependent variable (girth loss due to ground cover). If no clearing occurs or no rice crop is planted, the weed ground cover will be calculated as before, i.e. as a function of the light reaching the plantation floor.

Partial *Imperata* control

Smallholders often do not have the capital to optimally control *Imperata* (i.e. zero competition between *Imperata* and tree), and therefore will only partially control *Imperata*. For example, 5 L/ha may be the prescribed dosage of herbicide for the optimal control of *Imperata*, but financial constraints may lead the smallholder to apply only 2 L/ha. With this amount of herbicide the smallholder gains some benefits, in terms of improved tree growth rate resulting from control of *Imperata*, but there will still be some competition between the *Imperata* and the tree. To account for this, weed ground cover is calculated such that it allows for partial control of *Imperata*.

There is little empirical information available on the relationship between the volume of herbicide used and the level of *Imperata* control. In the absence of specific information, a straight-line relationship is assumed. That is, the amount of herbicide used (2 L), as a proportion of the amount required for complete (100%) *Imperata* control (5 L), defines the amount (percentage) of *Imperata* controlled (40%) and thus the density of *Imperata* remaining (60%).

In the user inputs section of the RRYIELD model, an option to determine the level of weed control is included. This can be observed in the third section of inputs, below the option for ground cover and number of years cleared. A value between 0 and 1 is chosen by the user to represent the proportion of herbicide used relative to the amount required for full *Imperata* control. This input parameter is labelled to enable it to be linked to calculations in the Macro functions of the model.

If clearing occurs in a given year, the weed growth calculations are modified within the Macro section of the model to compute a proportion of the expected weed growth. The proportion of expected weed growth is calculated using the relationship between the amount of herbicide used and the amount needed for complete control. Thus, the model calculates weed growth in a clearing or weeding year as the expected weed growth (given the level of shading) multiplied by the proportion of weed remaining (one minus the level of weed control). For example, if there is 60% light and 40% *Imperata* control in a year of clearing, then the model will calculate weed ground cover to be $0.5(e^{0.6/1.445}) \times (1 - 0.4)$, or 48.4%.

Loss of girth increment due to ground cover: rice/tree interaction

A ground cover of intercropped rice is a feature of the original BEAM model (Thomas et al. 1993). However, that formulation allowed only for the impact of rubber on rice, not for the reciprocal impact of rice on rubber growth. The ground cover index now incorporates such a feature. Field trials at the Indonesian Rubber Research Institute at Sembawa indicated that the growth rate of rubber with a rice intercrop is 80 percent that for a clean-weeded plot (Menz and Wibawa 1995). Thus, the tree girth increment is reduced by 20% in years in which the tree is intercropped with rice.

Information on the type of ground cover is selected by the model user and specified in the inputs section of the model. The information then passes to the Macro section, where ground cover becomes a function of light, and tree girth a function of ground cover. Light levels under rubber change as trees develop and provide shade. The effect of the light reduction flows through the equations, reducing *Imperata* density (or rice yield) and increasing tree girth. Tree girth is the dominant factor influencing the economic value of the rubber tree in terms of latex yield and wood volume. These latter impacts can be seen in the outputs section of the model.

Clonal index

A clonal index is included as part of the rubber tree girth-increment function. This index allows the effect of improved planting material to be manifest in tree girth. Research has shown that improved genetic material is directly related to tree girth (Barlow and Murharminto 1982). At this stage only a GT1 clone has been included in the model. GT1 is a relatively common clone used by smallholders in Indonesia, who would expect a 30% improvement in its growth (girth increment) compared with wildlings (Gouyon 1992; Barlow and Murharminto 1982). Thus, the girth increment is multiplied by a factor of 1.3 to capture this improvement in growth rate. Other clones can be included in the model in a similar way if the improvement in growth relative to wildlings is known.

The clonal index is included in the model by first specifying choice of clone, under 'Site Factors' in the inputs section in Part 2c of the model. This is linked to the corresponding 'clonal index' in Section 2d. Finally tree girth increment is multiplied by the clonal index to adjust girth increment to the appropriate level.

Fertilizer effect

A fertilizer effect was added to the model to recognise the potential for improved tree growth from using fertilizers, though it should not be assumed that smallholders will add fertilizer. Few smallholders will have the cash to purchase fertilizer at tree establishment, so fertilizer application will be the exception rather than the rule. The impact of fertilizer will vary, depending on the quantity and type of fertilizer used. Thus, it is left for the user to

determine—via the site index—the potential improvement the fertilizer will have on the growth rate and latex yield of the tree. It is expected that fertilizer application will lead to a vertical movement of the girth and latex yield functions, relative to the magnitude of their improvement. Thus, the fertilizer index is linked to the site index variable, which shifts both the girth and latex yield functions up and down along a vertical plane.

The fertilizer index is included in the model by first specifying if fertilizer is used, then defining the impact of fertilizer use (e.g. a 20% increase in tree growth rate). These options are included under 'Tree Management Criteria' in the inputs section of Part 1b of the model. The effect of fertilizer is linked to the site index calculation, improving the value of the site index relative to the fertilizer improvement (e.g. if the fertilizer effect is 20% and the site index is 80 then the adjusted site index would become 96 [1.2×80]). The adjusted site index then leads to improvements in tree girth and latex yield.

Latex Yield

The original BEAM latex yield equation sets an annual latex yield expectation of 2000 kg/ha. A series of indexes then allows this expectation to be modified. The first is an age index, reflecting the relatively lower latex yields achieved in the early years of tapping. By the fifth year of tapping this age index approaches unity, and the latex function approaches its maximum value. The second index represents the growing conditions at the site. It is similar to the growth index in the girth equation, but has an additional factor to account for the number of tapping days lost because of bad weather.

The next adjustment index in the BEAM model is for the rubber clone planted. This alters the yield relative to the clone RRIM 600. The clonal index for trees used by smallholders will be significantly lower (less than a third) than the clonal index for the trees used by estates. This conclusion is supported by Barlow and Murharminto (1982), who suggest an average rubber yield of approximately 600 kg/ha/year for smallholder producers in Indonesia. This is less than a third of the yield calculated for an average site (site index 75) by the BEAM model for the RRIM 600 clone. Thus, in calibrating the model to better represent smallholder growing conditions, the clonal index has been reduced (from 2.00 to 0.6).

The final adjustment index included in the BEAM latex yield equation is a density index. An increase in the density of the rubber plantation will increase the number of tappable trees per hectare and increase competition between trees. The net effect is expected to be an overall increase in latex yield per hectare, but a decrease in yield per tree.

Research by Gouyon (1992) indicates that latex yield will rise over the first few years after tapping, then plateau, then begin to decline. The BEAM model specifies the a plateau interval of approximately five years; this is not unreasonable for smallholders.

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The BEAM model, by including an additional equation in the Macro function, calculates a 'natural' decline in latex yield after the ninth year of tapping. This is done on an absolute function basis. (The decrement is independent of all the individual characteristics of the tree [size, site, clone, etc.] and is dependent solely on the number of years since tapping began.)The general shape of the decline function is close to that provided by Gouyon (1992), and is seen as an acceptable representation of the yield decline over time.

The overall shape of the original BEAM latex yield equation seems sound, but the equation does not explicitly represent yield as a function of girth. Many studies have shown that there is a close relationship between the latex yield and the girth of a tree (Narayanan and Ho 1973; Narayanan et al. 1973; Huat 1981; Nga and Subramaniam 1974; Westgarth and Buttery 1965; Dijkman 1951). Because this relationship is not captured in the BEAM equation for latex yield, it will be unable to fully trace improvements made in the tree growth through better management practices.

Several other authors allude to a relationship between girth and yield. Ho (1975) attempted to establish the relationship between latex yield (Y) and girth (G), but he also included several other variables. The relationships that he found included:

$$Y = 1.92G - 2.02P - 16.18$$

where P is the plugging index, and

$$Y = 0.9G + 1.46N - 19.49$$

where N is the number of latex vessel rings

Ho also established a correlation coefficient of 0.62 between girth and yield, but did not provide a regression equation. Gomez et al. (1989) suggested a strong relationship between yield and dry matter increment, which can be regarded as a proxy for increase in girth. They found correlation coefficients of 0.7492 ($P < 0.001$) for dry matter increment, but again provided no yield/girth regression equation. Narayanan and Ho (1973) suggest that a linear relationship is most appropriate for describing the girth/yield relationship. They provide graphs of the relationship but no data or equation.

As a direct relationship between latex yield and girth, represented by an equation, was not readily discernible, the original BEAM equation was modified to capture the relationship with girth. The new equation is:

$$\text{latex yield} = \text{girth} \times 30 \times \frac{\exp(\text{tapping year} / 0.5)}{1 + \exp(\text{tapping year} / 0.5)} \times \left(\frac{\text{index}}{100}\right)$$
$$\times \text{inadj} \times \left(\frac{\text{density}}{400}\right)^{0.7} \times (\text{tap})$$

where 'tap' is the switch variable (see pages 10–11) and 'inadj' is the clonal index adjustment factor (page 14).

There is no significant change to the predictive capacity, compared with the original BEAM equation, and it is felt that it closely fits the 'age to latex yield' relationship established in Gouyon (1992). The main aim of the modification is to explicitly include a girth factor in the equation, while retaining the shape of the BEAM function.

The Effect of Fire

In smallholder rubber plantations, *Imperata cylindrica* creates a major weed control problem. However, the level of competition between weed and tree should not be the only consideration when deciding on *Imperata* control measures. *Imperata* also creates a high fire risk. Thus, *Imperata* control measures should also take into consideration the potential losses due to fire.

Fire risk is especially important for perennial crops such as rubber. The high initial cost and the long-term exposure to the fire risk for a single tree crop, add further weight to the importance of considering fire when establishing rubber plantations.

In adjusting the BEAM RRYIELD model to include the effects of fire, two main assumptions were made:

- that the risk of fire reaching a plantation is dependent on the density of the *Imperata* present; and
- that the effect of fire will be observed via a reduction in the proportion of stems present on a site, this reduction being calculated according to the amount of *Imperata* present.

As the dynamics of fire are extremely difficult to fully capture, in this 'first run' attempt a straight-line probability of fire was assumed rather than a random effect. The straight-line effect is an approximation to the dynamic effect, such that if *Imperata* is a blanket cover (i.e. 100% *Imperata*), there is a probability of a fire event every 5 years, then the probability of fire in each year is 0.2.

The probability of fire within a region will vary widely, depending on a range of factors including topography, attitude of the local people to fire, land use by neighbours, etc. There is no readily available formula for calculating the probability of fire within a region. Because of this, the probability of fire is provided in the model as an exogenous variable. Thus, the user inserts the expected probability of fire, based on local knowledge of the region.

Within upland areas, inherent *Imperata* density is a significant factor in determining the risk of fire at a given site. There are two options available in the determination of fire risk within the model. It can be assumed that the plantation being modelled is surrounded by other rubber plantations of the same age and thus that the *Imperata* density of the region is uniform. In this case the *Imperata* density, calculated by the model as a function of shading, is used in determining the fire risk. Alternatively, it can be assumed by the user

that a given average density of *Imperata* surrounds the plantation. Fire risk is then calculated as a function of the average *Imperata* density bordering the plantation.

Fire risk is calculated using the following equation:

fire risk = probability of fire × *Imperata* density surrounding plantation.

Fire damage

Once the risk of fire reaching the plantation is determined, the effect of fire within the plantation can be calculated. As an approximation of the expected losses due to a fire, the model calculates a reduction in the stems per hectare. Thus, the occurrence of a fire will reduce the number of trees available to tapping and will thin the canopy. This will increase the weed ground cover in later years and will increase the growth rate of the remaining trees, other things being equal. The function used to calculate the reduction of stems due to fire is shown in Figure 1.
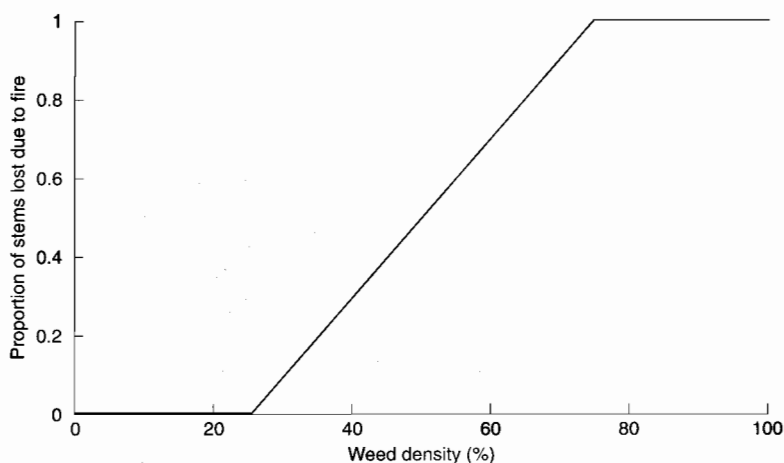
Figure 1. Proportion of stems lost due to fire, as a function of weed ground cover.

The equations used in the RRYIELD model, derived from this function are:

$$\text{stems lost} = FR \times SD \qquad\qquad (WD \geq 0.75)$$

$$\text{stems lost} = \frac{(WD - 0.25)}{(0.5)} \times FR \times SD \qquad (0.25 \leq WD \leq 0.75)$$

$$\text{stems lost} = 0 \qquad\qquad (WD < 0.25)$$

where FR = fire risk; SD = stand density; and WD = weed ground cover.

As mentioned earlier the effect of fire is calculated on a straight-line basis. This averages the effect of fire over the life of the plantation, rather than treating plantation destruction by fire as a random event. This is an acceptable

approach if the average effect of fire is required. If the random event approach is applied over a large sample it is expected that average losses will approximate the losses provided by this straight-line approach.

Stand density

Previously, the tree stand density was calculated once only, at the beginning of the model, and was held constant over all years the model was run. The introduction of fire makes the stand density calculation more dynamic. The stand density per hectare is reduced annually, as a result of fire, by a 'stems lost' factor. Stand density is now calculated as:

$$\text{stand density}_t = \text{stand density}_{t-1} - \text{stems lost}_t$$

The calculation of stand density for each year becomes a new column in the outputs section of the model, and is applicable to all variables that are computed as a function of stand density, such as girth increment and latex yield.

Site Index

The site index forms the base on which tree girth, latex yield and ground cover (rice and *Imperata*) productivity are calculated. In the original BEAM model the site index is a multiplicative function of fourteen (14) climatic and soil variables. The climatic variables considered are: rainfall, dry season period, water deficit, tapping days lost, vapour pressure deficit, temperature and windspeed. The soil variables considered are: slope, drainage, duration of flooding, texture, soil depth, organic matter, CEC and base saturation. Each of these variables is assigned a value between 0 and 1, relative to the optimal conditions for the variable. The variables are then multiplied to provide the site index.

As the product of fourteen fractions is invariably a very small number, the site index in the original model was relatively weak, and probably not a particularly good representation of the true site index. This problem can be overcome by using a site index override function. This was designed for circumstances in which the user had insufficient information or confidence in the variables employed to calculate the site index. To override, the user puts in a number between 0 and 100 to represent the quality of the site. In general, 100 represents a high quality site, 75 an average quality site and less than 50 a poor site. The site index override function enables the user to take advantage of the power of the BEAM models in other areas, such as calculating tree growth, even when lacking confidence in the site index calculation.

The new site index is considered to be more appropriate for smallholder rubber growers in Indonesia. It represents a significant improvement on site index in the original model, but requires further development. It is suggested that where the user lacks confidence in the results obtained from the new site

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index, or cannot obtain information on the component parameters of the site index, that the override function be used to approximate the growth conditions that prevail at the site of interest.

In the site index of the modified version of the BEAM model, three climatic factors (i.e. rainfall, air temperature and light intensity) are used to create moisture, thermal and light indices. These indices are then combined to form an overall climatic index, similar to the GROWEST approach developed by Fitzpatrick and Nix (1970), and tailored specifically to rubber in Indonesia. Each of the three indices ranges from 0 to 1, where an index of 1 means that there is no constraint to growth. The indices are then multiplied to form the climatic index. This will again be between 0 to 1.

The soil index developed here is based on the soil index derived by Sugianto (1987). It relies on seven soil parameters (soil depth, slope, texture, drainage, percentage of rock, soil nutrient levels and pH), and rates them as good, moderate or bad. Each rating is then assigned a value which is weighted so that, when added, the values provide a soil index between 0 and 100.

The soil index is multiplied by the climate index to provide the site index. The site index is calculated as a number between 0 and 100.

Moisture index

Tree production and latex yield are affected in different ways by soil moisture. Soil moisture has a larger bearing on latex yield than on tree growth, as turgor pressure in latex vessels is required to facilitate the flow of latex. Thus, two different moisture indices were derived: moisture index [tree] and moisture index [latex]). Consequently, there will be two separate climate indices and two site indices.

Using the input data:

(P)	monthly rainfall
(Ep)	potential evapotranspiration
$(ST \text{ max})$	soil water content at field capacity
(WP)	wilting point

and by calculating the variables:

$(APWL)$	accumulated potential water loss
(ST)	soil moisture content
(Ea)	actual evapotranspiration

the moisture index can then be determined using the water balance approach proposed by Thornthwaite and Mather (1957).

$APWL$ is calculated as the difference between P and Ep (i.e. $APWL = P - Ep$).

If $APWL$ is positive, Ea is assumed to equal Ep, and the surplus of water will increase storage or soil moisture content (ST) up to the field capacity $(ST$ max).

, If *APWL* is negative, it is necessary to calculate the change in soil moisture content (ΔST) in order to derive the actual evapotranspiration (*Ea*). The equations for *ST* and ΔST are:

$ST = ST\max \times \exp(-a \times APWL)$

$\Delta ST = ST_t - ST_{t-1}$

where *a* is a constant, and *APWL* is negative.

Different equations to calculate soil moisture content (*ST*) are required, corresponding to changes in field capacity (*ST* max). The equations can be seen in Table 1.

Table 1. Equations used to calculate soil moisture content (ST) at varying ST max

ST max	Equation
100 mm	$ST = 100*\exp(-0.01013\ APWL)$
150 mm	$ST = 150*\exp(-0.00678\ APWL)$
200 mm	$ST = 200*\exp(-0.00506\ APWL)$
250 mm	$ST = 250*\exp(-0.004042\ APWL)$
300 mm	$ST = 300*\exp(-0.003363\ APWL)$
350 mm	$ST = 350*\exp(-0.002877\ APWL)$
400 mm	$ST = 400*\exp(-0.002515\ APWL)$

Ea is then calculated as the sum of rainfall and the change in soil moisture.

$Ea = P + \Delta ST$ when $P < Ep$ this indicates that stored moisture is used

$Ea = Ep$ when $P > Ep$

In calculating the moisture index for latex, fraction of available soil water (*FASW*) is calculated, using the following equation:

$$FASW = (ST - WP) / (ST\max - WP)$$

where *WP* = wilting point.

As an example, the monthly soil moisture content (*ST*) is calculated for Palembang (Table 2). Maximum soil moisture content (*ST* max) and wilting point (*WP*) are 400 mm and 200 mm, respectively, for 1 m soil depth. The monthly rainfall and potential evapotranspiration are obtained from RePPProT (1988).

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Table 2. The monthly soil water balance at Palembang.

	Jan	Feb	Mar	Apr	May	June	July	Aug	Sept	Oct	Nov	Dec	Annual
P	262	207	266	300	171	110	99	106	128	197	312	349	
EP	110	103	121	118	119	108	111	122	119	128	114	111	
P–Ep	152	104	145	182	52	2	–12	–16	9	69	198	238	
APWL							–12	–16	–12	–15	–12	–15	
ST	400	400	400	400	400	400	388	373	382	400	400	400	
ST	0	0	0	0	0	0	–12	–15	+9	+18	0	0	
Ea	110	103	121	118	119	108	111	121	119	128	114	111	
FASW	1.00	1.00	1.00	1.00	1.00	1.00	0.94	0.87	0.91	1.00	1.00	1.00	
MI (latex)	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	0.99
MI (tree)	1.0	1.0	1.0	1.0	1.0	1.0	1.0	1.0	1.0	1.0	1.0	1.0	1.00

Once these intermediate variables are computed, the two moisture indices, MI [tree] and MI [latex], can be calculated.

The moisture index [tree] is calculated assuming that the relationship between Ea/Ep and tree growth is linear. The annual moisture index [tree] is calculated as:

$$MI_{[tree]} = \Sigma(Ea / Ep) / 12$$

where Ea = monthly actual evapotranspiration, and Ep = monthly potential evapotranspiration

The result of the soil moisture index [tree] calculation for Palembang is presented in Table 2.

When calculating the moisture index [latex], a relationship between monthly $FASW$ and monthly GT 1 latex yield is used (Thomas and Lasminingsih 1994):

$$Y_i = (1.05 \times FASW) / (0.05 + FASW)$$

where Y_i = relative latex yield and $FASW$ = fraction of available soil water

A graph of the relationship is shown in Figure 2.
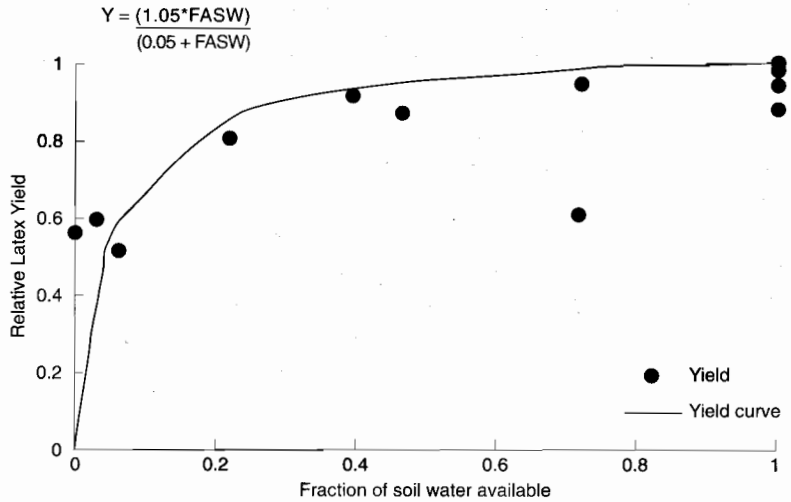
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$$Y = \frac{(1.05 * FASW)}{(0.05 + FASW)}$$

Figure 2. Relationship between fraction of soil water available and relative latex yield.

The monthly moisture index [latex] is calculated as follows:

$MI[\text{latex}] = S(Y_i) / 12$

where Y_i is the relative latex yield.

The result of a calculation of the moisture index [latex] for Palembang is shown in Table 2.

Thermal index

Girth data from an Indian rubber clone trial was used to develop the thermal index (Sethuraj et al. 1989). The girth data from a traditional rubber-growing area (mean temperature of 27°C) are used as a base and are given a thermal index of 1. The air temperature in these trials was in the range 21.7– 26.6°C and relative girth attained in the range 0.7–1. Additional information from a Chinese experiment (Huang and Zheng 1985; Xu and Pan 1990) was used to develop the relationship shown in Figure 3. Because information on the effect of air temperature on latex yield is scarce, it is assumed that its effect is the same as that on tree growth. This is based on relationships between tree growth rates and yield (Westgarth and Buttery 1965; Huat 1981).
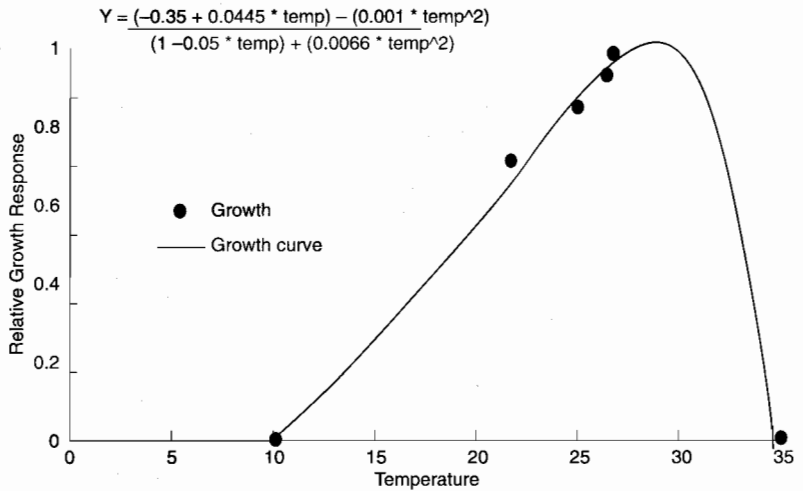
$$Y = \frac{(-0.35 + 0.0445 * temp) - (0.001 * temp^2)}{(1 - 0.05 * temp) + (0.0066 * temp^2)}$$

Figure 3. Relationship between temperature and relative growth response.

Light index

As information on the light/growth relationship for rubber is scarce, the general light index information from the original GROWEST classification system (Fitzpatrick and Nix 1970) is used here.

The light index equation from GROWEST is:

$$LI = 1.0 - e^{-3.5R}$$

where

R = daily solar radiation (MJ m^{-2} day^{-1}) expressed as a fraction of the upper limit to daily solar radiation

= (daily solar radiation) / 22

In the version of the light index developed by Fitzpatrick and Nix (1970), R = (daily solar radiation)/31.4. For rubber this was changed to R = (daily solar radiation)/22, as rubber is grown only in tropical areas. In the tropical zone in which rubber is grown (23°S to 29°N), regional daily solar radiation is restricted to a much tighter band. The maximum solar radiation was considered to be 22 MJ/m^2/day. This slightly alters the curve associated with the light index, but provides an index better suited to rubber than the general index developed by Fitzpatrick and Nix (1970).

Currently, most weather stations in Indonesia use the Campbell Stokes sunshine recorder. To convert sunshine duration to light intensity, the Angstrom formula is used (Frere and Popov 1979):

$$R / Ro = a + (b \times n / N)$$

where R = actual light intensity, Ro = light intensity received at the limit of the atmosphere, n = actual duration of sunshine, N = maximum possible duration of sunshine, and a and b = empirical constants (see below).

Based on FAO experience (Frere and Popov 1979), there are three sets of coefficients for a and b, appropriate to different climate zones (Table 3).

Table 3. The coefficients a and b used for calculating light intensity in different climate zones.

Zones	a	b
Cold /temperate	0.18	0.55
Dry tropical	0.25	0.45
Humid tropical	0.29	0.42

An example of light index calculation is presented in Table 4. Rubber grows only in the humid tropical zone, thus only the coefficients for this region will be used in calculations below.

Climate index

Once the three indices (moisture, thermal and light) have been obtained, they are combined to give an overall climatic index. The climate index is calculated by the following formula:

$CI = MI \times TI \times LI$

where CI = climatic index or growth index, MI = moisture index, TI = thermal index, and LI = light index.

The value of CI will be in a range from zero to one.

Table 4. Light index calculation for Palembang (using coefficients for the humid tropical zone)

Months	n(hours)	$R(MJm^{-2}day^{-1})$	Light index
January	3.59	15.64	0.92
February	3.68	16.21	0.92
March	4.07	16.99	0.93
April	4.74	17.06	0.93
May	5.27	16.63	0.93
June	5.17	15.81	0.92
July	4.86	15.78	0.92
August	5.28	17.18	0.93
September	4.52	17.05	0.93
October	4.58	17.53	0.94
November	4.24	16.48	0.93
December	3.70	15.64	0.92
Average			**0.93**

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Soil Index

Physical and chemical characteristics of soil affect the growth and yield of rubber. The physical characteristics of soil that are important for rubber are soil depth, slope, texture and drainage (Pushparajah 1981). Soil fertility and pH are important soil chemical characteristics affecting rubber growth and yield.

Table 5. The soil parameters used for determining soil suitability

Parameter	Good		Moderate		Bad	
	Range	Score	Range	Score	Range	Score
Slope	1–10%	19	10–20%	12	>20%	7
Soil depth	>100 cm	19	45–100 cm	12	<45 cm	7
Drainage	medium	12	fast/slow	7	v. fast / v. slow	4.3
% Rock	0–15%	19	15–40%	12	>40%	7
Soil texture	clay loam, loam, sandy clay loam	12	loam clay, clay (clay 50–70%)	7	clay (>70%)	4.3
Nutrient level	very high to high	12	medium	7	low	4.3
pH	4.5–5.0	7	5.0–6.5	4.3	>6.5, <4.5	2.4

A soil suitability assessment method proposed by Sugianto (1987) is used here in association with the climatic index developed above. The soil suitability is calculated on the basis of the seven soil parameters presented in Table 5. Each soil parameter is categorised as good, moderate or bad, then scored. The score given to each soil parameter depends on the expected magnitude of its impact on rubber growth. The total scores from the seven soil parameters can be grouped as soil suitability classes (Table 6).

Table 6. Soil suitability classes

Soil class	Total score	Additional requirements
Highly suitable	100	No bad category for physical parameters
Suitable	75–99	No bad category for physical parameters
Marginally suitable	50–74	—
Not suitable	<50	—

Site index

The site index is calculated by multiplying the climate index and the soil index. More formally:

$$\text{Site index [tree]} = \text{Climate index [tree]} \times \text{Soil index}$$

$$\text{Site index [latex]} = \text{Climate index [latex]} \times \text{Soil index}$$

where the climate index is an index between zero and one, and the soil index is an index between zero and 100, this results in a site index between zero and 100.

Adapting the RRYIELD spreadsheet to accommodate the new site index

To include the new site index in the RRYIELD model, the original structure of Section 2a (the section dealing with the old site index) is maintained. The new climate variables are written over the top of the old climate variables, and the number of variables in this section is extended to thirteen to allow some of the intermediate steps to be shown during calculation of the climatic indices. The rainfall variable is retained and three new input variables (potential evapotranspiration, mean temperature and mean daily solar radiation) are added. These input variables are then used in the calculation of four intermediate variables (change in soil moisture, actual evapotranspiration, the evapotranspiration ratio [actual divided by potential] and fraction of available soil water). These intermediate variables are shown in the inputs section of the model. Also included in the inputs section are the calculations for the four climate index variables (moisture index [tree], moisture index [latex], thermal index and light index). Two input variables (field capacity or maximum soil moisture content, and wilting point) needed to calculate the moisture index in the new site index calculation are not included in this table. They are provided with the soil input variables in Section 2b.

The equations used to derive moisture index [tree], moisture index [latex], thermal index and light index are described earlier. The Macro loop 'ILOOP' is used to make these calculations. Finally, the aggregate climate indices for tree and latex are calculated and provided in the last two columns of the inputs table. The calculation of the aggregate climate index is carried out by the Macro loop 'ILOOP'.

Section 2b of the spreadsheet presents the soil variables to be used in the model. Although the framework for handling the soil index is unchanged from the old site index, the variables used and the method of calculation have been revised. The new soil index has seven variables: slope, soil depth, drainage, percentage rock, soil texture, soil nutrient level and soil pH. These are listed with a provision for the user to include the appropriate class for the specific site. The Macro loop 'INDCON' is then used to provide a numerical value for each class used. These numerical values are shown in Section 2c of the model. The Macro loop 'INDCON' then calculates the final soil index. Whereas the variables were multiplied in the old site index, in the new index they are added to obtain the soil index. At the bottom of the 'INDCON' loop, soil and climate indices are combined to calculate the new site index.

> *Despite these improvements, use of the site index remains problematical. Further research is needed to improve it. Meanwhile, the site index override function can be used to calibrate the model to prevailing yield and growth conditions.*

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Modifications to RRECON

Limiting costs

It was necessary to modify the model to allow herbicide use in only the first few years, including the costs in these years and excluding them from later years. This was achieved by adding a new parameter to the input section of RRECON. This parameter, 'years of weed control', restricts the costs of weed control to the years preceding the value of this parameter. It acts as a switch, turning the cash and labour costs for herbicide use 'on' if weeds are controlled in the given year or 'off' if they are not.

Similar parameters—'years of fertilizer use' and 'cropping years' were added for fertilizer and crop costs.

Stand density

In the original version of the BEAM model, stand density was fixed in the initial year of the model simulation and remained constant for the life of the plantation. As a result, only the initial year stand density was carried over from RRYIELD into RRECON. The initial year stand density was then used in calculations of establishment, tapping and harvesting costs. This was appropriate given the conditions in the original model.

The inclusion of fire risk in the modified RRYIELD model, leads to a reduction in tree numbers per hectare (stand density) over time. The change in stand density is measured and can be observed in the outputs table of RRYIELD. To incorporate this change in the RRECON model, the annual stand density was included in the extract carried over into the economic model. In RRECON, annual stand density was added to the annual cost and revenue calculation table. Annual stand density is then used to calculate annual costs of establishment, tapping and harvesting. As a result, as the stand density reduces, costs of tapping and harvesting also fall because there are fewer trees to be tapped and therefore less tapping time.

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Appendix: Tutorials

Example 1—a simple application of RRYIELD version 2

Loading RRYIELD

Open QuattroPro. To open the RRYIELD2 file from the disk, type **/** to access the main menu, **F** to open the *File* menu and **O** to *Open* an existing file (or use the mouse to select the same combination). Then type **Esc** to select the current directory name, **Backspace** to delete existing directory and type **a:** to access directory *A* (the floppy disk drive). Or use the mouse to select drive **a:**. Then use the mouse or arrows to select **A:\RRYIELD2.WQ1.**

RRYIELD Version 2 should appear as a worksheet. The title page will appear, press **Home** to get to the top of the worksheet.

Move around the worksheet, with the directional arrows, **Page Up/Down** and the **Home** key. **Ctrl** and the left or right arrow, will allow you to move sideways a page at a time.

Note: Down the page from the home position are the *Input* factors and at the bottom of this section is the *Yield Model Template*. Right from the home position are the *Climate Index* input factors. Further right from these is the *Output* table, and at the extreme right of the worksheet are the *Macro Functions* of the model.

A sample application

To change factors within the model simply move to, using the directional arrows, or click the mouse, on the cell you wish to change. Then type in the new number or character, and press **Enter**.

Change the following inputs

Field Layout—Change *Tree Spacing* by entering '**4.0**' at Tree Spacing n/s and '**4.0**' at Tree Spacing e/w. The *Tree Spacing* will make the number of stems per hectare **625**.
Leave the *Crop Row Calculation Method* as Productivity (p) but change the *Crop Row Calculation Value* to **0.4**.
Changing the *Crop Row Calculation Value* will reduce the minimum acceptable rice yield to 40% its initial value, i.e. below a rice yield of 40% of the initial yield, the model will not calculate a rice crop.

Tree Management Criteria—Leave the *Rotation Calculation Method* as Years (y), but decrease the number of years (*Rotation Calculation Value*) from **30** to **25**. *Buttlog Length* and *Canopy Permeability* can remain as they are. This will reduce the length of the rotation to 25 years. Buttlog length is used in the model to define the difference between log volume and smallwood

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volume. Canopy permeability defines the level of light penetration after canopy closure. Other values such as tapping and fertilising calculations, and fire risk calculations should remain as they are. These will be considered in greater detail in later Tutorials.

Product Prices—Specify Product Prices at the following levels: *Latex* **1.2** (corresponding to Rp 1200 per kilogram), *Timber* **4**, *Firewood* **4**, *Rice* **0.4**, and *Discount Rate* **0.05**. These prices are based on wood and latex prices for the Palembang region, Sumatra, Indonesia (Grist et al. 1995)

Crop Data—Adjust *Monoculture Yield* to **1000** and the *Inter* and *Intra Row Spacing* to **0.5**. This makes the expected rice yield (given no competition through shading) one tonne per hectare. Row spacings determine the space between rice plants, thus number of plants per hectare.

Site Schedules—At this stage, bypass the *Site Index Calculations* and skip to the *Site Index Override Option* at point 2(d) in the spreadsheet. Tutorial 4 will deal with changing the site index calculation.

Site Index Override Option—Type **Yes** for both *Override Index* options, and give both *Latex* and *Timber Indices* a value of **75**. This provides for a moderate (medium or average level) site quality, but can be specified at any level.

The inputs section is now complete and you are ready to run the model

Go to CREATING OUTPUT FILES FOR USE WITH RRECON and place a **p** in the blue/green cell. This sets the model to calculate a polyculture of rice and rubber trees. Then run the model by pressing **Alt E**. The calculations will then take place. Note: this will take some time (between 2 and 10 minutes, depending on the speed of your computer) due to the large number of calculations required. The only indication that the model is running is that the label "**Macro Ready**" will appear in the lower right hand corner of the screen. The screen will be locked while the model is running so you will not be able to scan through it or make changes during this time. When the model is finished you will hear a 'beep' and the label "**Ready**" will appear in the bottom right hand corner of the screen.

If, instead of Polyculture, you wish to examine Monoculture, place an **m** in the blue/green cell beside CREATING OUTPUT FILES FOR USE WITH RRECON, and press **Alt E**.

Once the model has been run for Polyculture and/or Monoculture, scan through the output using the **Page Up** and **Down** keys, the **Home** and directional arrows,

First, **Page Down** from the *Creating Output Files* position, to look at the YIELD MODEL TEMPLATE. Note: this will form the extract that is transferred into RRECON.

Then press **Home** to return to the top of the page and **Ctrl** and the **Right Arrow** to scan across to the SECTION labelled ANNUAL TREE AND CROP OUTPUT. Pay particular attention to the *Crop Yield, Latex Yield* and *Tree Girth* values.

Create an extract file as explained below to transfer to the RRECON model.

Press HOME and then return to the *Yield Model Template* (4) at the bottom of the *Inputs* Section. The extract file has already been created as a Macro function of the model, which makes life easy as all that is required is to run this Macro function. To do this simply press **Alt M**. A box will appear asking you to give the Extract a name. Call the extract **A:\EXTRACT1.WQ1** (You will need to type the full directory and filename, i.e.. **A:\EXTRACT1.WQ1**). The model is running and 'WAIT' appears at the bottom right hand corner of the screen.

Saving the model

To save your changes to the model use the mouse to select the options from the menu or follow this sequence of keys: **/** to select the menu, **F** to open the file menu and **A** to save with a new filename. Then type in a new filename for the model, **A:/MODEL.WQ1**, and press **Enter**.

Now close the file by pressing **/**, **F** and **C** to close. A blank QuattroPro screen will appear.

Loading RRECON

Load RRECON by following a sequence similar to that used before. You may have to close RRYIELD before opening RRECON or vice versa. Type **/ F O** (or use the mouse to select the same combination). Then type **Esc** to get the current directory name, **Backspace** to delete existing directory and type **a:** to access directory A (the floppy disk drive). Or use the mouse to select drive **a:**. Then use the mouse or the arrows to select **A:\RRECON2.WQ1**

A box will appear giving you the option to either *Load Supporting* or to *Update Refs*. Press **L** for Load Supporting The model will then re-calibrate based on links to an existing file.

Because we wish to use the model based on links to **A:/MODEL.WQ1** we need to change our link file. To do this press **/** to access the Menu, **T** to access the Tools Menu, **U** for Update Links, **C** to change the link. The name of the existing link file will appear in a box labelled *Pick a Spreadsheet*. Press **Enter** to access the *Change* box. Then press a **Space** to unfreeze the existing name and **Backspace** to delete it. Now type in the filename for the extract from

RRYIELD2, **A:\EXTRACT1.WQ1** and press **Enter**. The model will then re-calibrate with links to **A:\EXTRACT1.WQ1**.

Entering data into RRECON is the same as for RRYIELD. The input data for RRECON has already been added, based on economic data for Palembang (Grist et al. 1995). Thus, there is no need to change any of the parameters in this worksheet. Scan through the file using the directional arrows, *Page Up* and *Page Down* keys and *Home* key. Take note of the input parameters especially:

The units of measurement
The discount rate
Product prices
Labour prices
Site establishment costs
Annual costs
Annual work rates
Harvest costs

A summary of *Total Costs* and *Systems Output* can be seen, and more detailed costs and revenue calculations can be seen by pressing Home and then **Ctrl** and the Right Arrow to scan across the screen.

When finished, save and exit. Press **/** to select the menu, **F** to open the file menu, **S** to save the file. A box will then appear asking whether you wish to *Replace* or *Backup* the existing file. Choose **R** to replace/update the existing file.

Now exit by pressing **/**, **F** and **X** to exit from QuattroPro. A box may appear asking *Loose Your Changes*, type **Y** for yes or **N** for No, and then **Enter**.

Example 2—changes in management practices

This tutorial will introduce changes in management practices, via: changes in the commencement of tapping; the use of fertilizers and clones, and weed control. This example begins with the data that was input in Example 1.

Load the model that was saved in Example 1, i.e. **A:\RRY2_M1.WQ1**. (See Example 1 for details on loading the model).

Change the following *Input Parameters* to reflect a lower level of management (the letters or numbers in bold indicate the changes):

Tree management criteria (1b)

Tapping	Yes (**y**)
Tapping Calculation Method	Girth (**g**)
Begin Tapping	**40** cm
Fertilised	Yes (**y**)
Fertiliser Effect	**0.2**

Beginning tapping at 40 cm rather than 45 cm (which is the standard girth at which tapping commences in most areas of Indonesia) will provide earlier returns for the smallholder, but will reduce the growth rate of the tree. Thus, there is a trade-off for the smallholder between more rapid growth of the tree (which affects latex yield) and earlier tapping (which provides earlier returns). Fertiliser is also introduced, which will improve the relative quality of the site. Within the model fertilizer has the impact of improving the site index. This leads to faster growth in the early years of tree establishment. As the effect of fertilizer varies relative to the type and quantity used, it is necessary for the user to specify the expected improvement in tree growth associated with the fertilizer.

Next change the following:

Site factors: —soil and topography (2b)

Clone	GT1 (**g**)
Ground Cover	**Rice**
Years Cropped	**2**
Years Cleared	**5**
Level of Weed Control	**0.6**

This introduces a GT1 clone, for faster growth and higher latex yield. A rice intercrop is specified for the first two years of the plantation (no weed control required), followed by three years of conscious decisions as to whether or not to implement weed control. Thus, the ground cover (weed competition) is essentially managed for the first five years of the plantation. In years 3, 4 and 5 the smallholder in this example does use herbicide but not in sufficient quantity to completely remove weeds . As a result, only 60% weed control is achieved in these years. Managing the weed ground cover in this way reduces

competition with the rubber tree, leading to earlier tapping time and higher returns.

Note: Again, the site index is not considered, so the site index override option is used.

Run the model by pressing ALT E, for both Polyculture and Monoculture as in Example 1

When complete, scan the model, paying particular attention to the *OUTPUT SECTION*. *Girth Increment* calculates the annual girth increase without losses, while *Tree Girth* calculates the cumulative girth (total of girth increments over time) and includes losses. *Girth Increment* is greater under the clone GT1 than would be expected with wildlings. *Expected Weed Density* determines the level of *Girth Loss Due to Ground Cover*. *Girth Loss due to Tapping* signals the impact of beginning tapping before the optimum girth of 45 cm (these losses will continue until the tree reaches 45 cm). *Latex Yield* production does not begin until the tree has a girth greater than the 35 cm specified in the input section. You will notice reductions in *Tree Girth* due to the early tapping (via *Girth Loss Due to Tapping*) and competition with ground cover (via *Girth Loss Due to Ground Cover*). There is also a rapid decline in the *Expected Weed Density* due to the faster growth of the tree associated with intercropping, clearing of weeds and the use of clones.

Extract

Create the Extract as in Example 1, only this time name it **A:\RRY2_X2.WQ1**.

Save the model as **A:\RRY_M2.WQ1** and close as before.

RRECON

Load RRECON as before. Note the *Systems Output* summary from the previous example.

Now change the link file as in Example 1, only this time use **A:\RRY2_X2.WQ1**.

Again scan the output of the file. Move to *Years of Clearing*, *Years of Cropping* and *Years of Fertiliser* variables. Align these variables with those in RRYIELD2, i.e.

Years of Clearing	5
Years of Cropping	2
Years of Fertiliser	5

Note in the *Revenue Calculations* section that crop costs occur only in the first two years, the *Latex Costs* in years 3, 4 and 5 relate to the *Years of Clearing*, and *Tapping* begins in year 7. These increased costs should be weighed against the revenue associated with beginning tapping earlier, higher latex yields and revenue from cropping.

Exit as before.

Example 3—fire risk

This tutorial will introduce fire risk and damage, in terms of a reduction in *Stand Density*. In this example the level of management relative to Example 2 will be reduced. At the same time fire risk and fire damage will be introduced via the *Probability of Fire* and *Imperata Density*. This example begins with the data that was input in Example 2.

Load the model that was saved in Example 2, i.e. **A:\RRY2_M2.WQ1**.

Change the following *Input Parameters* to reflect the lower level of management:

Tree Management Criteria (1b)
Begin Tapping Girth	**45** cm
Fertilised	No (**n**)
Fertiliser Effect	**0.0**

Site Factors (2b)
Ground Cover	**Imperata**
Years Cleared	**3**
Level of Control	**0.6**

Commencement of tapping is returned to the standard time (45 cm), and no fertilizer is added. There is no longer an intercrop in the first two years, and clearing of *Imperata* is only carried out for the first 3 years. Weed competition will be significantly higher than in the previous example, although a clone is still used, so the tree will retain a relatively high growth rate.

Now return to the *Tree Management Criteria* to introduce fire risk via the following variables:

Tree Management Criteria:
Probability of Fire	10% (**0.1**)
Fire Probability Value	**0.5**
Imperata Density Calculation	Site (**s**)

This introduces the probability of one fire every 10 years (10%). The risk of fire spreading from neighbouring plots is 50%, reflecting that fire risk from two sides of the plot is minimal due to some form of fire prevention in the neighbouring plot (i.e. control of *Imperata*). The *Imperata* density on neighbouring plots is the same as that of the plot being considered (*Imperata Density Calculation* - Site). That is, the neighbouring plot has a rubber plantation planted at the same time with the same management regime.

Note: Again, the site index is not considered, so the site index override option is used.

Run the model for both Polyculture and Monoculture as in Example 1.

When complete, scan the model paying particular attention to the *OUTPUT SECTION*. Note that *Fire Risk* declines as the plantation matures and the level of the flammable ground cover (*Expected Weed Density*) decreases. Rather than have a random event of fire, the effect of fire is averaged over time. As the *Fire Risk* and *Weed Density* are decreasing the *Damage* related to fire is also decreasing. Note the number of *Stems Per Hectare* is decreasing in accordance with the number of stems *Damage*d. This will impact on *Latex Yield* (as there are less trees to tap) and *Tree Girth* (as there is less inter-tree competition).

Extract

Create the Extract as in Example 1, only this time name it **A:\RRY2_X3.WQ1**.

Save the model as **A:\RRY2_M3.WQ1** and close as before.

RRECON

Load RRECON as before. Note the *Systems Output* summary from the previous example.

Now change the link file as in Example 1, only this time use **A:\RRY2_X3.WQ1**.

Again scan the output of the file. Align the *Years of Clearing*, *Years of Cropping* and *Years of Fertiliser* variables (5c) with those in RRY2_M3, i.e.:

Years of Weeding	**3**;
Years of Cropping	**0**; and
Years of Fertiliser	**0**.

Note, in the *Actual Annual Costs and Revenues* section (**Home** to return to the top of the page and **Ctrl** and the Right Arrow), that there are no longer any crop costs. Latex costs have decreased as less trees are being tapped. The *Net Present Value* (at (4) Systems Outputs) of the plantation has also decreased due to the impact of the Fire *Damage*, (i.e. a reduction in the number of trees that are tapped, although the establishment costs remain the same).

Exit as before without saving changes.

Example 4—the site index

This example will concentrate solely on the new site index developed in the model, thus we will focus only on RRYIELD.

Load the model from Example 1, **A:\RRY2_M1.WQ1,** using the same approach as used in Example 1 (/, F, O, delete the default file and type in A:\RRY2_M1.WQ1).

As we are now interested in using the *Site Index Function,* it is necessary to turn off the *Site Index Override Function.* Go to the *Site Index Override Function* and type in **No** for both the *Growth* and *Latex Index Overrides.*

Return to the Home position (press the **Home** key) then scroll one page right (**Ctrl** and **Right arrow**) to Section 2b of the *Inputs Section.* In this exercise it is assumed that the conditions are the same in every year so type **yes** in the position (line 8) above the four input variables (*Rainfall, Pot. Evapotranspiration, Temperature* and *Solar Radiation*). Change only the first line in each of the four input variables to read the following:

Rainfall	**1800**;
Potential Evapotranspiration	**1800**;
Mean Temperature	**28**;
Mean Daily Solar Radiation	**28**.

The other factors in this table (*Soil Moisture, Actual Evap., Actual/Pot. Evap* and *FASW*) will be calculated by the model when the Macro (**Alt. E**) is run.

Return to the Home position (press the **Home** key) then scroll down (**Page Down**) to the *Site Factors - Soil and Topography.* Carry out the following changes:

Slope	**good**
Soil Depth	**good**
Drainage	**moderate**
% Rock	**good**
Soil Texture	**moderate**
Soil Nutrients	**moderate**
pH	**good**
Max. Soil Moisture	**350**
Wilting Point	**200**
No. Dry Months	**3**
Tapping Days Lost	**35**

Clone and *Ground Cover* information remains the same (these were considered in earlier tutorials).

These changes to the site index are expected to lead to a relatively high site index.

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Run the model for Polyculture as in Example 1.

Return to the *Climatic Factors,* Section 2a (**Home, Ctrl. Right Arrow**), and observe the changes. The model has "Filled Down" for the four input variables (*Rainfall, Pot. Evapotranspiration, Temperature* and *Solar Radiation*), placing the same number that was written in the first row in every year. *Soil Moisture, Actual Evapotranspiration, Actual/Potential Evapotranspiration* and *FASW* have been recalculated, as have the *Moisture, Thermal, Light* and *Climate* Indices.

Now move to the *Site Index Calculations* Section 2c (**Home,** then **Scroll Down**). Observe that the *Climate Index* is calculated for the first year (which is the same as all other years in this example). An index value has also been calculated for each of the soil variables. These are then aggregated (added) to calculate the *Soil Index.* The *Climate Index* and *Soil Index* are then multiplied to provide the *Aggregate Site Index.* This is then used in calculations of *Girth* and *Latex Yield.*

This site index calculation was designed to be specific to rubber growing. It is considered to be effective in determining the ability of rubber to grow on a given site. The climate features are based on the GROWEST model and are modified so as to be specific to rubber growth. The soil and topographic features are based on an existing soil index designed specifically for rubber in Indonesia. This provides a site index that is suited to calculating growth and yield characteristics of rubber.

Save as A:\RRY2_M4.WQ1, and Close as in Example 1.