DOCTOR OF PHILOSOPHY

Interactions between components of rubber agroforestry systems in Indonesia.

Williams, Sandy E.

Award date:
2000

Awarding institution:
Bangor University

INTERACTIONS BETWEEN COMPONENTS OF RUBBER AGROFORESTRY SYSTEMS IN INDONESIA

Sandy E. Williams

A thesis submitted for the degree of Doctor of Philosophy in the University of Wales

School of Agricultural and Forest Sciences
University of Wales, Bangor
United Kingdom

February 2000

DEDICATION

This thesis is dedicated to the memory of my father,
as promised

ACKNOWLEDGEMENTS

This research was funded by a two-year 'Study Abroad Studentship' from the Leverhulme Trust, and a scholarship from the School of Agricultural and Forest Sciences, University of Wales Bangor. I would especially like to thank Mrs Jean Cater of the Leverhulme Trust for her support, and the Indonesian Institute of Sciences (LIPI) for permission to conduct research in Indonesia.

I would like to thank Dr John Healey for his guidance and for supervising this study from its inception, especially during the writing-up phase. It was a pleasure to work with Dr Meine van Noordwijk, ICRAF-S.E. Asia, who supervised my research in Indonesia, and who provided invaluable creative input, advice, suggestions and support. Many thanks are due to M. Eric Penot, for allowing me to collaborate with the Smallholder Rubber Agroforestry Project (SRAP) and also for his generous hospitality in Bogor (and especially the live music!). I would like to thank Dr Chairil Anwar for allowing me to conduct a study at the Indonesian Rubber Research Institute's Sembawa Research Station, and I would also like to thank Dr Gede Wibawa for sharing his technical expertise with me and for making me so welcome at Sembawa. I am extremely grateful to Dr Fergus Sinclair who gave me his time, good advice and great motivation in the final stages of this thesis.

This research would not have been possible without the support and co-operation of the people of Muara Buat and Rantau Pandan, and of the collaborating farmers in particular. I wish therefore to thank Pak Yani, Pak Ismael, Pak Azahri and Pak Saryono, and especially Pak Bustami (and Ibu Hameeda and family) who welcomed me into their home for two years. The assistance provided by Mbak Yusnidar was absolutely invaluable and she was both an integral part of this project and a very dear personal friend. I especially wish to thank Katrine Smith for spending her sandwich year placement with me, and for her tremendous support and enthusiasm, and also Natasja Spaargaren for her assistance and energy. 'Merci!' to Isabelle Clement for her great camaraderie and many enlightening discussions in Muara Buat, and to Quirine Ketterings, not least for the musical evenings in Muara Bungo. Dr Thomas Fairhurst was most helpful and always an inspiration, as was Dr Steve Vosti.

I would especially like to thank Ir. Pratiknyo Purnomosidhi for his practical expertise (and humour!) in the implementation of the trenching experiments. I would also like to thank the SRAP field staff in Muara Bungo: Ir. Iwan Komardiwan, Ir. Gerhard Manurung and Ir. Ratna Akiefnawati; and also Mbak Ati, Mbak Mira and Bang Udin. The SMTP placement students were a superb help in the field. I am very grateful to the ICRAF staff in Bogor, especially Mbak Betha and Mbak Yayuk for introducing me to the joys of Genstat and Ibu Josephine and Ibu Niniek for helping me with the endless bureaucracy involved in being a foreign researcher. Discussions with Hubert de Foresta and Genevieve Michon were always extremely interesting, and Fred Stolle, Rien Beukema and Bruno Verbist ensured that my brief stays in Bogor were a great pleasure, and very sociable.

I am very grateful for the love and support given to me by my family and friends, especially by my mother, my sister Cath who has been with me all the way, and my partner Jim, who has made thesis-writing so much more enjoyable, has shared the highs, lows and late nights, and has added much humour to the proceedings. Kate Hardwick, Dominic Knorpel, Yasmin Cajas-Giron, Sara Namirembe, John Tay, Vikki Grime, Penny Fraser, Jonathan Davies and David Miller have also been a great help and great friends.

ABSTRACT

A prototype agroforestry system, which combined the low-input features and environmental benefits of the traditional Indonesian multi-species 'jungle rubber' system with high yielding rubber clones developed in monoculture plantations, was tested under on-farm conditions. Secondary forest was allowed to regenerate between weeded rows of clonal rubber. Clonal rubber establishment was studied, and the interactions between it, secondary forest species and farmer management were investigated using a combination of researcher- and farmer-managed weeding trials.

In one trial, alteration of below-ground resources (using root barriers and trenches to create three soil volumes) did not affect above or below-ground growth of clonal rubber, although weeding significantly increased stem diameter and volume. It was concluded that secondary forest regrowth interfered with resource capture at the level of individual roots; interference was not due to depletion of total available resources. Shoot:root ratios and ratios of horizontally- to vertically-oriented proximal roots were not affected by weeding. Growth of clonal rubber in N-fertilised plots, in the presence of weeds, was significantly greater than in corresponding unfertilised plots, indicating that N-addition may overcome some negative effects of competition in the system. However, a bioassay of nutrient limitation showed no significant differences in root biomass or root-length density, for either rubber or weed root-ingrowth into soil cores enriched with various nutrients.

The second researcher-managed trial, on steep slopes, showed that the survival rate of clonal rubber was 33% higher than that of the 'seedling' rubber variety traditionally used, and that mean stem height and diameter of clonal rubber trees were significantly greater than those of seedling rubber, 21 months after planting. Damage to trees by banded leaf monkeys (*Presbytis melalophos nobilis*) and feral pigs (*Sus barbatus*) was severe, unexpected, and greater for seedling than for clonal rubber. For undamaged trees, weeding frequency within the rubber-tree row had no significant effect, indicating that the major influence on rubber tree growth was interference from secondary forest regrowth between rows, operating both above- and below-ground.

In a farmer-managed, trial, vertebrate pest damage was the major influence on clonal rubber establishment, explaining almost 70% of the variation in rubber growth. The amount of labour invested in weeding was positively correlated with rubber growth. However, farmers generally decided to completely cut back the secondary forest regrowth between rows of rubber trees, including potentially valuable trees, rather than weeding within the rows and selectively pruning inter-row trees. Farmers considered that the inter-row vegetation may harbour vertebrate pests and compete with the clonal rubber, and they had access to fruits, firewood and non-timber forest products on other land. Thus, contrary to expectations, when offered clonal germplasm, these 'progressive' farmers opted to use plantation methods to protect what they considered a valuable asset suited to monoculture, rather than maintain the traditional multispecies strategy they use with local germplasm. Thus, although clonal rubber can technically be established in a 'jungle rubber'-like system (albeit with lower growth rates than achieved in plantations), not all farmers may be prepared to adopt this type of system.

TABLE OF CONTENTS

LIST OF TABLES

LIST OF FIGURES

LIST OF PLATES

LIST OF APPENDICES

CHAPTER 1

INTRODUCTION

1.1 AIMS AND OBJECTIVES

The general aim of this thesis is:

To investigate the growth of genetically-improved clonal rubber trees, under on-farm conditions, in a prototype agroforestry system based on a traditional land use system ('jungle rubber'), where secondary forest species are allowed to regenerate in association with planted rubber trees. The prototype system consisted of rows of clonal rubber trees (which were weeded only within the rows), with secondary forest regrowth in the inter-row area.

The specific objectives are:

1. To quantify the effects of interference from secondary forest regrowth on the above-ground growth of clonal rubber trees, and to determine how the outcome of that interference is controlled by variation in the total amount of below-ground soil resources.

2. To investigate effects of interference from secondary forest regrowth and variation in the total amount of below-ground soil resources on the response of allocation within clonal rubber trees (roots versus shoots, and vertically- versus horizontally-oriented roots).

3. To identify the most limiting nutrient to clonal rubber growth in the clonal rubber-secondary forest regrowth environment.

4. To compare the effect of two levels of weeding on the survival and above-ground growth of clonal rubber in the prototype agroforestry system, on sloping land, and to compare this with the above-ground growth of the unimproved rubber variety that is traditionally used by farmers.

5. To assess the effect of alternative management regimes on the above-ground growth of clonal rubber in the prototype agroforestry system, when implemented by farmers, on sloping land.

6. To identify other factors (in addition to interference from weeds) that influence the growth of clonal rubber under smallholders' conditions.

7. To investigate the ability of farmers to adopt the new techniques involved in planting clonal rubber, and the acceptability of the prototype system to farmers.

8. To produce, based on the above, recommendations compatible with the resources of smallholders, on weeding management of clonal rubber in the prototype agroforestry system.

In this chapter, the rationale and justification for the research will be considered with respect to the traditional 'jungle rubber' complex agroforestry system (Section 1.2.1), and the intensification of smallholder rubber production (Section 1.2.2). The research strategy and structure of this thesis will be described in Section 1.3. A review of the literature relevant to this study will then be presented, focusing on rubber tree biology (Section 1.4), and on previous studies concerning the effects of inter-specific interference on rubber tree performance (Section 1.5).

1.2 RATIONALE AND JUSTIFICATION

1.2.1 Complex agroforests

Complex agroforests can be defined as forest structures planted and managed by farmers for the production of various forest and agricultural products on the same piece of land (de Foresta and Michon, 1996). Established through a complex succession of development and production stages involving the planting of crops as well as various commercial and useful tree species, agroforests mimic natural forest structures, with a complex multistrata structure and a closed or almost closed canopy that is usually dominated by a few tree species (de Foresta and Michon, 1996). These systems can be found in areas of smallholder agriculture throughout the humid tropics (Nair, 1989). Examples include Kandy forest gardens in Sri Lanka (Southern, 1994; Hitanyake, 1996); Miang tea gardens in Thailand (Preechapanya, 1996) and 'jungle cacao' in Cameroon (Gockowski and Drury, 1999). In Indonesia, the 'jungle rubber' agroforests, damar (*Shorea javanica*) agroforests (Torquebiau, 1984) and fruit/timber/spice agroforests (Michon *et al.*, 1986) cover an estimated area of 4 million hectares in Sumatra alone.

The environmental benefits of the forest-like structure are the protection of soils and water resources, and the high degree of spontaneous regeneration which allows conservation of a proportion of the original forest biodiversity (de Foresta and Michon, 1992). In a rural development context, these systems are important as they provide cash income to farmers, and a diverse range of products (Werner, in press) which suit farmers' risk avoidance strategies, yet require only low capital, labour and cash inputs. The agroforests are simple to establish and maintain and can be rejuvenated in a number of ways, including plant by plant regeneration; thus they preserve a high range of potentialities for further development (Michon and de Foresta, 1996).

Systems such as these, however, have largely been neglected by the research and development community. The 'pure plantation' model which is dominant in agricultural and silvicultural research (de Foresta and Michon, 1996) has resulted in the development of genetically improved varieties of valuable agricultural crops in the humid tropics (e.g. rubber, cacao, coconut) suited to cultivation in high-input monocultural plantation conditions. Smallholder farmers would benefit greatly from the increased yields possible from this improved genetic material if it could be integrated into their agroforests (van Noordwijk *et al.*, 1995a). However, in reality, development programmes have focused instead on integrating smallholders into the monoculture plantation model. There is a great need to improve the productivity of complex agroforests with moderate changes in management, if they are not to disappear from the landscape under pressure from monocultural systems which may be more risky, but which are more profitable in the short term, especially in terms of income per unit area of land (Tomich *et al.*, 1998).

1.2.2 The 'jungle rubber' complex agroforestry system

1.2.2.1 Economic importance

This system is a good example of a complex agroforestry system based on the production of an economically important commodity. Social and economic constraints on this system are typical of agroforests throughout the humid tropics (Gouyon *et al.* 1993). These constraints and the system's ecological characteristics have been well documented (Gouyon and Nancy, 1989; Kheowvongsri 1990; Tomich, 1991; Penot, 1994, 1995; Gouyon, 1995), making it an obvious choice for research on, and testing of methodologies applicable to, complex agroforests globally.

This system covers an area of over 2.5 million ha in Sumatra and Kalimantan, and provides an income for over 5 million people (Gouyon *et al.*, 1993). This figure rises to 12.5 million when people involved in the processing and marketing of rubber are taken into account. Rubber is Indonesia's most important agricultural export commodity, and 74% of this production comes from smallholder jungle rubber (GAPKINDO, 1997).

1.2.2.2 Ecological importance

Jungle rubber provides a range of non-rubber products, and environmental benefits typical of a complex agroforest. Biodiversity values can be high in mature rubber agroforest, as was found in an ecological study in Muara Buat village (Chapter 2). Its secondary forest-like structure consists of three main strata: 0-10 m - undergrowth (shrubs and small trees, with seedlings and saplings of canopy species); 20-25 m - rubber tree canopy; > 25 m - emergent timber and durian trees (Kheowvongsri, 1990). Rubber trees occupy the niche usually filled by *Macaranga* species in secondary forest. De Foresta (in press) found 268 plant species in addition to rubber, which all originated from natural forest, including 91 tree, 27 shrub, 97 vine, 23 herbaceous, 28 epiphytic and 2 parasitic species.

With the loss of lowland primary forest in Sumatra, rubber agroforests are, in fact, increasingly acting as a reservoir for biodiversity in these areas. Current ICRAF research is critically considering the value of this concept within the 'segregate vs. integrate' debate for biodiversity conservation (van Noordwijk *et al.*, 1995b). Is it best to segregate areas of agriculture and nature conservation, to ensure maximum economic and conservation benefits respectively from each (e.g. high intensity monocultures and effective forest reserves)? Or is it best to integrate conservation and agricultural land use, by intensifying production as little as strictly necessary, thus maximizing the biodiversity of land under human use? Research is ongoing, considering biodiversity and productivity trade-offs in mature rubber agroforests (Beukema *et al.*, in press). However, in the real world, the situation appears to be that without strong policy interventions, the 'segregate' scenario is not likely to become reality, and at present the question under consideration is whether productivity of agroforests can be raised sufficiently to compete with the theoretically higher cash income opportunities of agricultural monocultures.

1.2.2.3 The history of the 'jungle rubber' system

"The history of agriculture probably has not seen any other case where the introduction of a single crop had such a dramatic effect on the economic condition of smallholders in vast areas, as the introduction of Hevea brasiliensis *in Indonesia.....*
.... Within a period of twenty years, vast areas where the population had been completely economically isolated before then, and had hardly any other means of production than primitive food crop production and collecting forest products, were exporting rubber worth tens of millions of guilders fully for their own benefit...
.... Large areas suddenly were converted into a tree cultural system which provided welfare and jobs. All of this is due to that peculiar tree which one simply puts in the ground and leaves unattended, but which by its fast height growth survives among the other plants and matures in a few years time into a tree which one can wound to tap its blood, but which still recovers when left alone. All of this is the product of the wonderful product of nature, Hevea brasiliensis, *the near indestructible."* (van Gelder, 1950).

In Sumatra's peneplains, virtually all shifting cultivation has been transformed into rubber-based agroforestry since the introduction of rubber at the beginning of the 20th century (van Noordwijk *et al.*, 1995a). Smallholders originally received seedlings from Malaysia through traders, not through any development efforts by the Dutch colonists who had also started planting rubber as a plantation crop in their estates (Dijkman, 1951). At first, European planters adopted too high a management intensity, including clean weeding, which ultimately was not suitable for the soil and rainfall conditions (Watson, 1989a). However, smallholder farmers quickly learned that *H. brasiliensis* was very amenable to extensive management systems, and could easily be integrated into their existing shifting cultivation system by planting trees with the rice crop and leaving them to grow with the subsequent fallow vegetation (van Gelder, 1950).

Tree planting was recognised as a claim to land, and so the extensive management strategy was the dominant one until recent decades in Sumatra, similar to the case in Kalimantan (Dove, 1993, 1994). This was a very flexible system which suited farmers well, acting as a bank of resources to be tapped in times of need. Moreover, the fact that it was diversified made sense in the high risk environment in which they lived (Colfer *et al.*, 1988).

Rubber cultivation, however, facilitated a development from shifting cultivation to a more permanent settled form of agriculture[1], hence the current interest in the system (van Noordwijk *et al.,* 1995a) as a possible alternative to the unsustainable slash-and-burn agriculture still practised in some areas of the moist tropics (Bandy *et al.,* 1993). In Kalimantan this process was described as "a shift from a tribal political economic formation to a peasant formation" (Dove 1994). The original 'improved fallow' system where rubber was considered a source of income, but priority given to rice production through shifting cultivation, was replaced by the establishment of an agroforestry rubber cropping system where rubber became the priority, and provided around 80% of the total farm income (Gouyon, 1995).

From the 1920s onwards, the jungle rubber system expanded over larger and larger areas, and population density increased. The areas of other land use systems (including government-sponsored transmigration programmes, and logging concessions[2]) also increased, and therefore the land available for an extensive system such as jungle rubber was reduced (Penot, 1997a). Intensification of rubber production on smaller areas of land became a key issue (Gouyon and Nancy, 1989).

After the 1920s, great advances were made in the plantation rubber sector, with the breeding of higher-yielding genetically-improved material, and the development of the technique of grafting buds of this onto well developed rootstock stumps to produce 'clones'. These clones are capable of yielding two to three times more than the 'unselected' material (regenerated seedlings collected from existing agroforests) being used by smallholders (Gouyon and Nancy, 1989). These technological advances have facilitated the progression from 'Stage I' ('Emergence from Subsistence'), in the development of smallholder tree-crop agriculture, to

[1]The traditional form of shifting cultivation in Sumatra could support 25 people per km^2; one household can be supported by 3-5 ha of jungle rubber (Gouyon, 1999).
[2] From 1979 to 1999, in the Province of South Sumatra alone, around 4 million hectares of land have been allocated to transmigration, logging and agro-industrial companies (Gouyon, 1999).

'Stage II' ('Agricultural Transformation'; Barlow and Jayasuria, 1986), since the 1970s, when clonal rubber was made available to smallholders (Section 1.2.3.1).

1.2.3 Intensification of smallholder rubber production

1.2.3.1 Monoculture plantations

Since the 1970s, the Indonesian Government's attempts to develop the rubber smallholder sector followed the monoculture, high-input plantation model, using high-yielding clonal rubber. Block planting projects on a large scale were intended to produce large increases in yields, however, they proved very costly, difficult to implement and only benefited a small fraction (13%) of rubber smallholders in Indonesia (Tomich, 1991). As Indonesia's economic situation changed due to declining oil prices, and the priorities of international donors shifted to environmental concerns, the rate of initiation of large rubber development projects declined (van Noordwijk *et al.*, 1995a).

1.2.3.2 Smallholder innovations

Smallholder farmers untouched by these projects had themselves attempted to intensify production, with five 'endogenous innovations' identified by Penot (1997a). Not all these innovations are practiced by the same farmer, and indeed there are still smallholders who do not practice any. The first innovation concerned planting material. As high yielding clones were not generally available to smallholders outside government projects, enterprising individuals collected seeds that had fallen from the clonal trees in project areas or plantations, and grew them as 'clonal seedlings'. These clonal seedlings do not have the high yielding characteristics to the same extent as the parent clones (Blencowe, 1989), however, they still have a yield advantage when compared with the naturally regenerated 'unselected' seedlings in farmers' existing agroforests (as these were descended from less genetically improved, earlier varieties). For comparison: in terms of dry rubber yield, 'unselected' seedlings can produce 500-600 kg ha^{-1} yr^{-1}, 'clonal' seedlings 700-800 kg ha^{-1} yr^{-1}, whereas production of 'clones' can reach 1500 kg^{-1} ha^{-1} yr^{-1} (under smallholder management in South Sumatra; Gouyon, 1999) and up to 2000 kg^{-1} ha^{-1} yr^{-1} under more intensive management (Penot, 1997a).

A second innovation (Penot, 1997a) was the planting of trees in lines (15-20 years ago), to reduce the time taken for tapping and thus improve return to labour. A third innovation was to invest time in weeding/selective cutting of other species (once per year) as opposed to no weeding at all as was the case previously. This could reduce the time taken for tree girth to reach a tappable size. (*cf.* estate practice which involves weeding 12 times per year).

A fourth innovation (Penot, 1997a) was to switch to planting intercrops between trees, instead of allowing secondary forest regeneration, however this only occurred in areas close to markets. The fifth innovation was made by farmers in areas where *Imperata cylindrica* is a dominant weed, in order to reclaim land. Rubber is planted at a very high density, and initially, glyphosate herbicide is used to control the weed until the rubber canopy closes, and can shade out the *I. cylindrica* (Penot, 1997a).

These innovations do not require large inputs of capital, or of labour, and have led to productivity increases, however, there is great potential to intensify these further (Penot, 1997a). The introduction of genetically improved planting material is a key issue, in order to improve yields per unit area, and to close the 'technology gap' (Kumar and Nair, 1997) between smallholders and plantations in this respect.

1.2.3.3 Improved rubber agroforestry systems

The issue of improving smallholder rubber productivity, at affordable levels of capital and inputs, while maintaining some of the environmental benefits of jungle rubber has been addressed by the Smallholder Rubber Agroforestry Project (funded by ICRAF[3], GAPKINDO[4], CIRAD-CP[5] and USAID[6]). Thirty hectares of farmer-managed on-farm trials have been set up in three provinces of Indonesia to assess the planting of clonal rubber under smallholder conditions (Penot, in press). One type of trial, 'RAS 2', involves intercropping rubber with various annual and perennial crops, including fruit and timber trees (Penot *et al.,* 1994). Another type of trial, 'RAS 3', was designed for areas infested with the perennial weed *Imperata cylindrica*, and involves establishment of shrubby leguminous cover crops and fast-growing tree species between rows of clonal rubber, with the aim of shading out the *I. cylindrica* (Penot *et al.,* 1994).

<u>The prototype agroforestry system tested in this thesis</u>

One rubber agroforestry system which is being tested in the Smallholder Rubber Agroforestry Project is 'RAS 1', and is the system that will be examined in this thesis (hereafter referred to as the prototype agroforestry system). It comprises rows of clonal rubber trees, planted with a spacing of 3 m within the rows, and an inter-row area, 6 m wide, where secondary forest species are allowed to regenerate (Penot *et al.,* 1994).

---

[3] International Centre for Research in Agroforestry
[4] Indonesian Association of Rubber Producers
[5] Centre de Co-operation Internationale en Recherche Agronomique pour le Developpement
[6] US Agency for International Development

This prototype system combines the technological advantages of high-yielding rubber clones with the low-input and biodiversity-related benefits of the traditional jungle rubber system. It was designed to address the research needs identified by Gouyon *et al.* (1993):

- to develop new selected rubber management methods based on agroforestry to reduce maintenance costs, which could enable smallholders to plant high-yielding rubber without losing too much of the present biodiversity and economic diversity.
- to obtain a better knowledge of the behaviour of selected rubber cultivars associated with perennial species, in order to propose new cropping methods using shrub or tree species, including natural bush cover, as cover crops against grass weeds.
- to gain a better understanding of the nature of competition between rubber and other perennial species such as the ones in jungle rubber.

1.3 RESEARCH STRATEGY AND THESIS STRUCTURE

The research strategy employed in this thesis involved three main experiments (Chapters 3, 4 and 5), which investigated the survival and growth of clonal rubber in the jungle rubber-like prototype agroforestry system, in response to weeding management.

The three experiments were all conducted on-farm. They ranged from a small scale researcher-managed trial which considered biophysical interactions in the system in detail, to a farm-scale trial which included a comparison of the growth of clonal rubber and the 'unimproved' planting material that farmers currently use, and lastly to a more applied multi-locational and farmer-managed trial which evaluated various weeding management regimes, and which considered practical issues related to adoption of the system. Details of the experiments are presented below, within the description of the thesis structure.

Chapter 1: This chapter presents the aims and objectives of the research, its rationale and justification, the research strategy and thesis structure, and a general review of literature on rubber and inter-specific competition.

Chapter 2: This comprises the characterisation of the study area, both geographically and socio-economically, and includes farmers' indigenous knowledge about rubber agroforestry systems. This chapter also describes the methods used that were common to all experiments, such as those used in planting clonal rubber and in characterising the secondary forest regrowth.

Chapter 3: The small-scale researcher-managed trenching experiment described in this chapter was designed to address Objectives 1, 2 and 3 (Section 1.1). Around clonal rubber trees (planted at standard plantation spacing), below-ground resources were experimentally altered by installing trenches and root barriers to create three different volumes of soil.

Different weeding treatments were imposed on these soil volumes. Thus, the roots of both the rubber and secondary forest components of the system were restricted to foraging for the limited resources within each soil volume. The effects of interference from secondary forest regrowth on the above- and below-ground growth of rubber trees could therefore be quantified, in relation to the total amount of below-ground resources. To address Objective 3, nutrient limitation in the system was investigated by studying root in-growth into cores of soil which were enriched with various nutrients.

Chapter 4: This describes a field-scale researcher-managed experiment, that was conducted on sloping land, and that was designed to address Objective 4 (Section 1.1). The performance of clonal rubber in the prototype agroforestry system was investigated in relation to two frequencies of weeding within the rubber tree rows (1 m either side of the trees, along the entire length of each row). In this experiment, growth and survival of clonal rubber was compared against a baseline, i.e. the performance of the unimproved rubber seedlings used in the traditional jungle rubber system, under the same two weeding regimes, in the prototype agroforestry system.

Chapter 5: Here, a participatory on-farm weeding trial is described, in which Objectives 5, 6 and 7 were addressed. The experiment was designed to assess the survival and growth of clonal rubber in the prototype agroforestry system, in response to three frequencies of weeding within the rubber tree rows, and to compare clonal rubber growth against a baseline treatment which represented the intensive management of monoculture rubber, where a legume cover crop was planted in the inter-row area. This chapter also considers other factors that affect the growth of clonal rubber under on-farm conditions, farmer adoption of new clonal rubber planting techniques, and farmers' views on the prototype agroforestry system.

Chapter 6: Here, the experimental results are synthesised and discussed in relation to the objectives of the thesis; the growth of clonal rubber in the prototype agroforestry system is compared across all experiments, and conclusions are drawn regarding the future of improved rubber agroforestry systems in Indonesia.

In the introductory sections of Chapters 4, 5 and 6, the literature that is specific to each chapter is reviewed. However, in order to gain an overview of the biology of the rubber tree and to identify parameters which would reflect the effects of interactions within the prototype agroforestry system, an initial and comprehensive review of the literature on rubber, and on studies involving competition between rubber and other species, was carried out (Sections 1.4 and 1.5).

1.4 RUBBER TREE BIOLOGY

1.4.1 Introduction

Hevea brasiliensis (Willd. ex A. de Juss) Mueller-Argoviensis, native to the South American tropics, is a fast growing tree species, tolerant of acidic and nutrient-poor soils, which in the wild may grow to over 40 m in height and may live for over one hundred years (Webster and Paardekooper, 1989). However, in plantations established in S.E. Asia, it rarely grows to more than 25 m in height because its growth is reduced by tapping, and it is usually replanted after 20-25 years when yields fall to an uneconomic level (Webster and Paardekooper, 1989). Optimum climatic conditions for growth of *H. brasiliensis* are those found in wet equatorial regions, with an annual rainfall of 2000-4000 mm, evenly spread through the year, with not more than one dry month (Watson, 1989a).

There are two phases in the growth of the rubber tree, the immature and mature stages. In economic terms, maturity is classed as beginning when the tree reaches a girth of 45-50 cm (at 1 m above the ground) when tapping of rubber can commence (Paardekooper, 1989). This minimum girth of 45-50 cm is dictated by the fact that when trees are tapped their growth rate (and girth increment) decreases. Therefore, if tapping is started when a tree has a small girth, then its subsequent girth increment will be poor, and latex yields will be low (because latex yield is positively correlated with girth).

The age of the tree at commencement of tapping depends on its growth rate, i.e. faster growing trees reach the minimum tappable girth at an earlier age than slower-growing trees. Factors affecting this include genetic composition (clone type), planting material (i.e. seedlings or bud-grafted clones) environmental conditions (soil type, nutrient availability, light environment, competition from weeds and other vegetation etc.) and management (inputs of fertiliser, weeding). It ranges from 4.5 to 6 years on well managed plantations with improved genetic material (Pushparajah, 1995), to 10-11 years in smallholdings with unimproved material, minimum management inputs, and competition from weeds, intercrops and forest regrowth in the case of "jungle rubber" (Barlow and Muharminto, 1982).

The tree actually starts producing rubber soon after germination. Rubber particles are synthesised from carbohydrate (mainly sucrose) which undergoes glycolysis to Acetyl CoA, and various condensation and reduction reactions to the monomer isoprene $C_5 H_8$. These units are then polymerised to long hydrocarbon chains of molecular weight 10^5-10^7. Latex vessels (within which rubber is formed and stored) are present in all organs of a mature tree, however, their most important concentration occurs in the secondary phloem of the stem (Webster and Paardekooper, 1989).

Tapping of latex involves a diagonal incision in the bark of the tree to within 1 mm of the cambium, which severs the maximum number of latex vessels and induces a flow of latex (Webster and Paardekooper, 1989). Latex consists mainly of water, with 30-40% rubber particles, and 3.5% general plant cell contents (proteins, carbohydrates, phospholipids with N, P, and metal ions, *e.g.* K, Ca and Mg) (Sethuraj, 1992). The system of tapping used (i.e. the length of cut, and length of time between successive tappings) affects the rate of regeneration of latex, its dry rubber content, and the partitioning of assimilates between tree growth and rubber production (Sethuraj, 1985).

1.4.2 Rubber tree growth

Maximisation of tree growth is important in the immature stage as it reduces the length of the unproductive period before tapping can be commenced (Pushparajah, 1995), and continued biomass accumulation is also necessary through the mature stage to replace assimilates lost in latex, and to prolong the tapping life of the tree (through bark regeneration).

1.4.2.1 Root Development

Lateral roots are initiated from the radicle at germination and extend 2 cm before the radicle grows rapidly to form the primary tap root (Marattukalam and Saraswathyamma, 1992). This growth continues, with many fine root hairs at its tip, then further laterals are initiated below the first ring (Thaler, 1996). In deep, 'light' soils, after three years, the tap root can reach 1.5 m in length, and the laterals can extend 6-9 m horizontally (Rubber Research Institute of Malaya, 1958). At 7-8 years, root lengths can be 2.4 m and over 9 m respectively (Rubber Research Institute of Malaya, 1958).

The major lateral roots arise in a whorl within 30 cm of the soil surface, and grow horizontally and only slightly downwards (Templeton, 1969). Fine (or "feeder") roots are 1 mm in diameter, derived from laterals and are mainly responsible for absorption of nutrients and water (Soong, 1976). Fine root biomass was found to vary amongst clones and amongst soil types, being significantly greater in sandy soils than in clayey soils (Soong, 1976). In the upper 45 cm of most of the soils studied, around 50% of the fine roots were found in the top 7.5 cm of soil; the proportion decreased rapidly with depth, until only 10% of fine roots were found at a depth of 30 to 45 cm (Soong, 1976).

Distribution of rubber roots in plantation conditions was studied, by coring, on a number of soil types, for trees ranging in age from one to twenty-two years (Rubber Research Institute of Malaya, 1958). From studying this chronosequence, it was concluded that roots were initially localized close to the trunk, then concentrated in the space between the rows of trees. Then, as the roots of other individuals were encountered, soil closer to the trunk was exploited, eventually giving a fairly even distribution across all rows of trees (Rubber Research Institute of Malaya, 1958). The exception was where roots branched profusely on entering a patch of particularly well aerated, moist, or nutrient-rich soil trees (Rubber Research Institute of Malaya, 1958).

1.4.2.2 Shoot and crown development and function

Girth of stems increases continuously, however, stem elongation is intermittent (rhythmic). Stem length increases for 2-3 weeks, towards the end of which a cluster (whorl) of leaves is produced. Extension growth then ceases for 2-3 weeks before elongation resumes (Halle and Martin, 1968). Leaves live for nearly one year (Halle and Martin, 1968). Maturity is reached at 35 days, when they are fully expanded (a system has been designed to age leaves according to their angle with the petiole; Samsuddin *et al.,* 1978). The maximum photosynthetic rate in the field ranges from 0.36-1.14 mg CO_2 m^{-2} s^{-1} (Ceulemans *et al.,* 1984).

Leaves of four-year old trees and older are shed annually ("wintering") (Webster and Paardekooper, 1989). Most leaves fall at the same time if there is a marked dry period, however, if the distribution of rainfall is more continuous, this occurs more gradually. Refoliation usually occurs within three weeks of leaf fall (Webster and Paardekooper, 1989), and this coincides with the maximum annual growth of fine roots (Soong, 1976). Cambial activity in the trunk may cease during these drier periods during leaf fall and when the trees are leafless, and yields of latex are correspondingly depressed at these times (Webster and Paardekooper, 1989).

<u>Growth of untapped trees</u>

Definitive and comprehensive studies were carried out by Templeton (1968) into the growth of untapped trees of two clones of *H. brasiliensis* (RRIM 501 and RRIM 503), in Malaysia, between 0 and 81 months after planting. The main results are presented in this section. For both clones, total dry weight per tree (roots plus shoots) increased exponentially to 39 months (i.e. the biomass doubled every six months), and then the rate of increase levelled off over the subsequent 42 months. Mean girth increment increased from 0.8 cm per month (over the period 9 to 15 months after planting) to a maximum of 1.1 cm per month (between the measurements at 27 and 39 months) and then declined to 0.5 cm per month in the period 63 to 81 months after planting. The relative growth rate (in terms of total tree biomass) declined from 0.04 g g^{-1} $week^{-1}$ at 9 months, to 0.005 g g^{-1} $week^{-1}$ at 81 months.

In both clones, leaf area ratio reached 12 cm^2 g^{-1} between 9 and 39 months after planting and then declined; this reflected the increasing proportion of biomass in trunk and branches. Leaf area index was 5.8 from 50-60 months after planting (at canopy closure) to 81 months. Net assimilation rate declined from 0.0032 g cm^{-2} $week^{-1}$ at 9 months, to 0.0013 g cm^{-2} $week^{-1}$ at 81 months, due to increased self shading.

1.4.3 Environmental factors affecting growth

The Jambi region in Sumatra (Chapter 2) is optimal for *H. brasiliensis* growth with respect to altitude, temperature and rainfall (Watson, 1989a). In theory, *H. brasiliensis* can tolerate the acidity and aluminium status of the Ultisols there, as, with good soil management and correct husbandry, tree performance may be similar on taxonomically different soils (Watson, 1989a).

1.4.3.1 Nutrients as factors limiting growth and yield

Numerous studies have been conducted on the response of *H. brasiliensis* to fertilisation, which is a common practice in all plantations, especially during the immature period. This aims to promote vigorous growth, in order to shorten the time taken for trees to attain a tappable girth (Watson, 1989c). Of course, different responses to nutrients will be observed on different soils, but the following review will provide an indication of how recommended fertilisation regimes were derived.

Bolton (1960) found that by far the greatest response to fertiliser was in the immature stage. In Sri Lankan trials, N was found to be the most limiting factor for growth in both mature and immature stages of development. Addition of urea proved successful, especially in combination with K in the form of KCl (Yogaratnam *et al.*, 1984).

In contrast, P gave the greatest increase in girth in pre- and post-tapping phases in a Brazilian study, also resulting in a 97% increase in rubber production (Reis and Cabala-Rosand, 1988). K has been proved to increase latex yield due to its activation of invertase, which regulates the glycolysis of sucrose, and also has a positive effect on the transport of sucrose to the latex vessels (Samaraweera, 1984). Regarding micro-nutrients, Bo deficiency can be corrected with 0.1 ppm addition (Bueno *et al.*, 1988), and Co is also important (Bolle-Jones and Mallikarjunes, 1957).

Best responses have been to N, P and K fertilisation together on Ultisols (Onuwaje, 1983), and on most soil types in plantations full N, P, and K fertilisation is conducted (Watson, 1989c). Effects on the tree have been noted on girth first (one to two years afterwards) and also in yield (six, five and three years after fertilisation in three different studies) (Watson, 1989c).

In one study, liming was found to have no positive effect on growth of rubber rootstocks, and was found to be deleterious if soil pH was increased to 6.8 and above (Pereira and Pereira, 1987). In one trial in Malaysia, ground magnesium limestone was applied to soil to increase crop growth, however, the amounts were not sufficient to have any deleterious effects on rubber growth, and the Mg itself may have had a positive effect (Edwards *et al.,* 1991).

Tree nutrient status and deficiencies can be successfully diagnosed by foliar analyses (leaves and petioles) (Yew and Pushparajah, 1984). Nutrient ratios are also important: leaf N/K and K/P ratios were more or less constant and unaffected by plant origin, soil, season, age or management methods. However, in the case of nutrient deficiency, ratios varied considerably from the norm (Beaufils, 1955). The lag between fertiliser application and changes in respective leaf nutrient concentration is longer for P than for N and K (Yew and Pushparajah, 1984). The use of foliar nutrient analyses, in combination with the characterisation of soil nutrient status is common practice in Malaysian rubber plantations (Watson, 1989c), and can lead to improved efficiency in the use of fertilisers.

As would be expected, when the various studies above are considered, a comparison of fertiliser recommendations for immature rubber in eight countries (Pushparajah, 1983), showed that these varied widely in terms of quantities per unit area. However, the recommendations in all countries included N, P, K and Mg fertilisers (except for Ghana, where Mg was not included). The recommended fertiliser levels for estate plantations in Sumatra during the immature period (per hectare per year) were 251 kg N, 274 kg P_2O_5, 217 kg K_2O and 50 kg MgO (Pushparajah, 1983).

According to Watson (1989c), N deficiency is likely to be seen in young rubber on poor soil infested with competitive weeds such as *I. cylindrica*, or unchecked growth of bushes and ferns. Unless corrected, this can lead to reduced leaf size, poor girth growth, and eventually to stunting of the tree (Watson, 1989c).

1.4.3.2 Water as a factor limiting growth and yield

Low soil moisture content has an effect in reducing latex yields due to low turgour pressure in latex vessels, and also contributes to 'brown bast', the phenomena of 'dry trees' (where latex production has ceased) (Wickremasinghe *et al.*, 1987). The growth rhythm of *H. brasiliensis* is affected by water availability, as the rhythm results from a competition for water between the developing leaves and the meristem from which they originate (Halle and Martin, 1968).

Photosynthesis was reduced to zero after nine days with no rainfall, however, it recovered one day after the trees were watered (Ceulemans *et al.*, 1983). Soil moisture deficits lead to a linear decrease in leaf water potential, a fast increase in stomatal resistance, a sharp decrease in transpiration rates (da Conceicao *et al.*, 1985), and in general to a reduction in leaf number, flushes of shoot elongation growth and shoot length and diameter (da Conceicao *et al.*, 1986).

1.4.4 Latex yield

In this section, the factors affecting latex yield per tree are described with respect to environmental conditions and inherent characteristics of the tree. The effects of tapping systems on yield, in the short and long term are then discussed. Finally, differences in yield between clones (genotypes) are considered.

1.4.4.1 Factors affecting yield per tree

<u>Environmental conditions and water relations in the tree</u>

The water content of latex is between 65 and 75%, and water relations in the tree play a major role in the tree's response to tapping (Paardekooper, 1989). When a tapping cut is made in the bark, latex flows out of the latex vessels because the usual high turgour pressure in the vessels (10-15 atm. in the early morning) is reduced to ambient pressure at the cut surface (Buttery and Boatman, 1967). The initial flow of latex is due to elastic contraction of the vessel walls under the pressure of the surrounding cells which are still turgid (Sethuraj, 1992). The flow is then regulated by capillary forces, and eventually ceases as the latex coagulates and plugs the vessels; flow duration can vary from thirty minutes to three hours (Paardekooper, 1989). As the turgour pressure is highest at night and early morning, before water losses through evapo-transpiration occur, latex yields are highest at these times; positive correlations have been found between pre-tapping latex vessel turgour and initial flow rate of latex (Sethuraj, 1992).

At low soil moisture levels, the rate and duration of latex flow, as well as total latex yield, are reduced (Buttery and Boatman, 1967). The reduced duration of flow is caused by quicker plugging of latex vessels under conditions of water stress (Sethuraj, 1992). This has been attributed to changes in the biochemical composition of latex, which result in increased flocculation of rubber particles, and increased plugging of vessels (Premakumari *et al.*, 1980).

<u>Characteristics of the tree</u>

With increasing tree age and girth, bark becomes thicker and thus the amount of latex-bearing tissue increases (Webster and Paardekooper, 1989). This has a direct influence on the initial flow rate of latex on tapping (Sethuraj, 1985). Also, as any one tapping system is based on the percentage of the tree circumference that is cut, then it is clear that with greater tree girth, the length of the cut will be longer, more latex vessels will be severed, and latex yields will be greater than for trees of smaller girth (Sethuraj, 1992).

1.4.4.2 Effect of different tapping systems on latex yield

The standard tapping system involves making one diagonal cut around 50% of the circumference of the tree, at an angle of 30° to the horizontal; this is known as a 'half-spiral' (Paardekooper, 1989). If the length of the cut is increased (e.g. to a 'full spiral', around the entire circumference), or if additional cuts are made, then more latex vessels will be severed, and the yield per tapping will increase (Sethuraj, 1992). However, if trees are tapped regularly with long cuts then, in the long term, virgin bark reserves will be depleted quickly, and previously-tapped bark may not have regrown to a sufficient thickness to allow re-tapping (Paardekooper, 1989). Length of cut has also been found to be related to plugging of latex vessels (Southorn and Gomez, 1970); plugging is slower on long cuts than short ones, and thus the duration of latex flow is longer.

Tapping frequency also affects yields. Increased tapping frequency results in lower latex yields per tapping, due to the shorter length of time the trees have to recover between tappings and synthesise latex to replace that extracted on tapping (Sethuraj, 1992). Increased tapping frequency thus requires greater quantities of nutrients, water and assimilates.

The quantity of assimilates produced by a plant depends on its total leaf area, the photosynthetically active radiation absorbed per area of leaf and thus its net assimilation rate. In many plants these assimilates are partitioned predominantly to vegetative growth (or else to reproductive structures). However, in the case of trees with copious latex production, such as *H. brasiliensis*, there is significant competition for the assimilates derived from photosynthesis between latex production and growth processes. Annual girth increments of tapped rubber trees decline with a greater offtake of latex (increased tapping frequency or length of tapping cut), i.e. latex is produced at greater cost to biomass production (Simmonds, 1982).

1.4.4.2 Differences among clones in yield components

There are large differences among clones (genotypes) in latex yield (Simmonds, 1989). Characters which affect initial flow rate of latex, have been found to vary among clones, i.e. number of latex vessels (Gomez *et al.*, 1972), angle of latex vessels (Gomez and Chen, 1962), and latex vessel turgour pressure (Buttery and Boatman, 1967). Furthermore, characteristics which affect the duration of latex flow, such as latex vessel plugging and coagulation on the cut, differ among clones (Gomez, 1977; Premakumari *et al.*, 1980). Different clones also vary in the degree to which their girth increment is reduced by tapping (Paardekooper, 1989).

1.4.5 Intraspecific competition between rubber trees

1.4.5.1 Planting density experiments, and plantation management practices

The planting density of rubber has direct effects on growth and thus on the duration of the immature period which controls the percentage of trees reaching a tappable size at different ages. It affects rubber yield through its influence on net assimilation rate, partitioning of assimilates between growth and yield, the thickness of bark and the rate of bark renewal after tapping. These factors affect the yield per area and per tree (Webster, 1989a).

An experiment comparing different planting densities of rubber from 119 trees per hectare (9.14 m spacing) to 1074 trees per hectare (3.05 m spacing) ran for 28 years in Malaysia (Buttery and Westgarth, 1965). Fertiliser amounts were constant per unit area. Therefore, at increasing density, there was increasing competition between the rubber trees for water and nutrients. No thinning was practiced except for damaged or diseased trees (Buttery and Westgarth, 1965). Different stages were identified:

1. 1-2 years after planting: no competition between young trees..
2. A crown development stage (the age at this stage depends on planting density): trees start to compete for light, water and nutrients.
3. Pre-tapping stage: growth from the crown-development stage (girth increment rate) decreases with increasing density, and therefore there was a delay in trees reaching tappable size in the high density plots.
4. Six years after planting: the percentage of tappable trees decreases with increasing density (however the <u>number</u> of tappable trees increases). Some trees at the highest densities never reached tappable size, i.e. at 119 per hectare, 90% of trees were tappable at the end of three years, however at 1074 trees per hectare, 31% still had not reached a tappable girth after 19 years (Buttery and Westgarth, 1965).

A similar study by Mainstone (1970) found that there was a similar initial period where growth was unaffected by density. In some circumstances, after this stage there was a six-month period where the girth increment was greatest at the <u>highest</u> densities. He explained this by the fact that earlier canopy closure at closer spacings suppressed the cover crop reducing its competition for water and nutrients, and more nutrients were available to rubber from the decomposition of the cover crop. In these circumstances, there then followed a further period of up to six months where growth was again not affected by density. This was explained by the fact that the effects of suppression of the cover crop were balanced by inter-tree competition (Mainstone, 1970).

Characters affected by intra-specific competition:

1. Height of lowest branch: this was greater with increased density. This is because heavier shading causes increased branch shedding (Buttery and Westgarth, 1965).
2. Thickness of virgin and renewed bark (after tapping), and rate of bark renewal after tapping: these are decreased with increasing density (Buttery and Westgarth, 1965).
3. Yield per tree: this decreases with increasing density. Dry rubber content of latex is also slightly reduced (Buttery and Westgarth, 1965).

However, yield per hectare varies little over a wide range of planting densities as, with increasing density, the lower yield per tree is offset by the increased yields obtained from the greater number of trees. The optimum density for greatest yield per hectare depends on the clone (genotype) (Webster, 1989a).

In plantations, girth is the usual early indicator of tree performance, as test-tapping during immaturity may identify precocious yielders which cannot sustain high yields over many years, and yield per tree can be variable in the early years of tapping (Paardekooper, 1989). On these bases, selective thinning may be carried out; this reduces the mean immature period and improves the growth and yield of the remaining trees, due to a reduction in competition for light, water and nutrients (Webster, 1989a).

1.4.5.2 Average and recommended planting densities

Estates: A final density of 400 trees per hectare is recommended by Paardekooper and Newall (1977). This entails an initial planting density of 440 trees per hectare (assuming an initial loss of 10%) or 500 trees per hectare initially if planting material is very heterogeneous (Paardekooper and Newall, 1977).

Smallholdings: 500 trees per hectare is recommended by Paardekooper and Newall (1977), as maximum yields are required over 35-40 years, therefore bark renewal must be good (even though profits may increase up to densities of 617 trees per hectare due to the use of family labour or share tappers for tapping; Barlow and Lim, 1967).

Actual densities on smallholdings in Malaysia ranged from 400 to 500 trees per hectare (independent smallholders) and 300-400 on settlement schemes. Initial planting densities were 600-750 per hectare and 500-600 trees per hectare respectively (Sepien, 1980).

Jungle rubber: In a 30-40 year old mature system in Jambi Province, Sumatra (Gouyon *et al*, 1993) there were 490 rubber trees per hectare growing together with 260 non-rubber forest trees over 10 cm dbh (10 species), and in a 40-45 year old mature system, there were 200 rubber trees per hectare with over 300 non-rubber forest trees per hectare. Initial planting densities in jungle rubber are much higher than this: 1000-2000 rubber seedlings per hectare (Gouyon *et al*, 1993), as seedling mortality is very high, with losses due to weed competition and pests.

In a sample of 251 jungle rubber gardens of tappable age, in South Sumatra Province, Barlow and Muharminto (1982) found an average of 407 tappable trees per hectare. In three villages in South Sumatra Province, Gouyon and Nancy (1989) found that planting density increased with decreasing areas of available land; mean tree density was 780 trees ha^{-1} in a village where there was a large reserve of free land, but 1730 trees ha^{-1} in a village where there was no more available land. Farmers estimated that only 65-70% of the trees they planted would reach maturity (Gouyon and Nancy, 1989).

1.5 COMPETITION BETWEEN RUBBER AND OTHER SPECIES

Numerous studies have been reported in the literature regarding the intercropping of rubber with annual and perennial food crops, forage grasses and other species of trees. Moreover, many publications have considered the effects of weeds, and natural and leguminous covers on the growth of rubber, and these are reviewed in the following sections.

1.5.1 Intercrops

Studies of rubber intercropping have included characterisation of intercrops used by smallholders (Chandrasekara, 1984, in Sri Lanka and Joseph *et al.*, 1988, in India). Some studies have also considered the economics of smallholder intercropping systems in India (Sreenivasan *et al.*, 1987, for ginger, turmeric and bananas; Rajesekharan, 1989, for pineapple), and in the Philippines (Pamplona, 1987).

However, the intercropping literature is dominated by reports of experimental trials which aim to investigate the effects of intercrops on the growth of rubber trees, or the effects of rubber trees on intercrop yields[7], or both. No data could be found in the literature regarding latex yields of trees that were previously intercropped during immaturity. Most intercropping studies tend to be location-specific, and comparison of results between trials is difficult. This is because rubber tree age, and the planting density of rubber vary widely amongst trials (see Section 1.4.5 for the implications of this). Furthermore, fertilisation rates of rubber and intercrops differ, and even the stem height at which rubber tree diameter is measured is not standardised. Therefore, general and, necessarily, qualitative results are presented below.

[7] For example, the study by Laosuwan *et al.* (1988a), which reports that mung bean yields were only 6% lower under immature rubber than in an open-field trial, and the study by Laosuwan *et al.* (1988b), which reports intercrop yields for upland rice, groundnut, soybean, pineapple and banana.

1.5.1.1 Mature rubber plantations

In mature rubber plantations, it has been shown that cardamom (*Elettaria cardamomum*) intercropping is possible (Sumarmadji *et al.*, 1989; Sivadasan and Nair, 1989). In the former study in Indonesia, addition of farmyard manure increased cardamom yield. In the latter, in Sri Lanka, cardamom yields of 250 kg ha^{-1} were obtained, and also latex yields from the rubber trees were increased in comparison with sole-cropped rubber; this was attributed to the addition of fertiliser to the cardamom (Sivadasan and Nair, 1989).

In Brazil, Bovi *et al.* (1990) reported that heart of palm (*Euterpe edulis*) could be successfully intercropped in forty-year old rubber plantations, yielding 1612 kg of palm hearts per hectare, although no information on latex yields was provided. Also in Brazil (de Filho *et al.*, 1988), cocoa (*Theobroma cacao*) was underplanted in mature rubber plantations which had suffered high levels of leaf loss and mortality, due to South American Leaf Blight (caused by the fungus *Microcystis ulei*). Yields of both cocoa and rubber latex were greater per hectare than for either crop planted in monoculture (de Filho *et al.*, 1988).

1.5.1.2 Immature rubber plantations

Food crops

The majority of rubber intercropping studies have been conducted in immature rubber, in the first two to three years after planting, before canopy closure. During this time, light levels in the inter-row area are sufficient to grow a variety of crops (Watson, 1989b). For smallholders, intercropping is important as it can provide food for subsistence (and/or marketable products), during the six to seven year immature period before income can be obtained from tapping the trees (Rodrigo *et al.*, 1997).

Considering the case of annual food crops, greater girth increments of rubber were obtained for mung beans with groundnut, and upland rice with maize, than with soybean (Laosuwan *et al.*, 1987). No significant negative (or positive) effects on rubber girth, six years after planting, were observed when various food crop rotations (including upland rice, maize, peanut, cassava and plantain) were implemented during the first three years of rubber growth in Gabon (Enjalric *et al.*, 1997). In this study, there were also no significant differences in rubber tree girth between the food crop treatments and a *Pueraria* sp. (legume cover crop) treatment which represented conditions in monoculture rubber plantations (Enjalric *et al.*, 1997).

Positive effects of food crops on rubber girth (as compared with control treatments of legume cover crops) were observed in Cote d'Ivoire by Keli *et al.* (1990), and in Malaysia (Edwards *et al.*, 1991; Zainal *et al.*, 1992). The reason for this, given by Keli *et al.* (1990), was that the rubber benefited from the fertiliser applied to the food crops (rice, maize and groundnut). It is possible that the application of ground magnesium limestone (2 t ha^{-1}) to the intercropped groundnut and maize in the trial reported by Edwards *et al.* (1991), had a similar effect, especially as Keli *et al.* (1990) also reported that leaf nutrient levels of Ca and Mg were lower in rubber trees that had been intercropped with food crops than with legume cover crops. Evidence that fertilisation of intercrops does indeed result in better growth of rubber trees is provided by the results of a study by Wibawa and Rosyid (1997) in Indonesia. At three years after planting, mean girth of rubber trees intercropped with upland rice that had been fertilised with 100 kg urea, 100 kg TSP and 75 kg KCl per hectare was significantly greater (by 25%) than mean girth of trees where no fertiliser was applied to the upland rice, (Wibawa and Rosyid, 1997).

In an intercropping trial in South Sumatra, where no fertiliser was added to either intercrops or rubber trees, Wibawa and Thomas (1997) found that mean stem diameter of rubber trees intercropped with upland rice for two years was only 70% of the mean diameter of trees which had been clean weeded, at 39 months after planting. Mean diameter of trees with a legume cover crop was 75% of that of the clean weeded trees, but trees intercropped with pineapple, or pineapple and banana had, respectively, mean diameters 85 and 83% of that of the clean weeded trees (Wibawa and Thomas, 1997). Therefore, rubber growth in the cover crop treatment (which was the monoculture 'control' treatment in many of the studies reviewed above), was greater than in the upland rice treatment, but lower than in the pineapple intercropping treatments.

The implication arising from these studies is that the greater tree girth achieved with intercrops than with LCCs in the first few years after planting (whether this is due to fertilisation or intensive weeding of the intercrop), results in trees reaching tappable size more quickly. This enables farmers to obtain income from rubber-tapping sooner, and thus to obtain a faster return on their investment.

Perennial crops

Intercropping black pepper (*Piper nigrum*) with rubber in Brazil (da Cunha *et al.*, 1989) increased rubber growth relative to that in monoculture plots, and thus led to earlier tapping of the trees. In Sri Lanka, Rodrigo *et al.* (1997) found that rubber girth and height was significantly greater when intercropped with banana (*Musa* sp. cv. Kolikuttu), even up to a density of 1500 plants ha^{-1}, than when grown as a sole crop. The differences between intercrop and sole crop treatments became significant eight months after planting for tree height, and sixteen months after planting for tree girth.

In a review of trials where rubber was intercropped with woody perennials in Thailand, Buranatham *et al.* (1997) reported that neem trees (*Azadirachta excelsa*), planted 2 years after rubber, did not have a significant effect on rubber girth, six years after planting, relative to sole-cropped rubber. However, when planted at the same time as rubber, *Acacia mangium* caused a 13% reduction in rubber tree girth relative to sole-cropped rubber (Buranatham *et al.*, 1997), at three years after planting.

1.5.2 Cover crops

The use of legume cover crops (LCCs) is standard practice in plantations (Watson, 1989b). These have been shown to control soil erosion in Malaysia (Zainal *et al.*, 1992), and their other beneficial effects on soil properties are discussed in Section 5.4.2.2. In Indonesia, Siagian and Sunarwidi (1990) investigated the competitive effects of LCCs on rubber growth by weeding circular areas around each tree, with radii of 15 cm and 1 m, and also weeding the entire planting row, 1 m either side of the trees. In this trial, during the first 12 months after planting, there was no significant difference in rubber girth between these treatments, indicating that even at distances of only 15 cm, the presence of LCCs did not affect rubber growth (Siagian and Sunarwidi, 1990).

However, two studies have shown that *Pueraria phaseoloides* ('Pueraria') may compete strongly for water with rubber. Enjalric *et al.* (1997) showed that soil moisture levels in a Pueraria treatment were consistently lower than in any intercropping treatment, and attributed this to higher water consumption by the LCC than any food crop. Wibawa and Thomas (1997) also found that soil moisture levels under Pueraria were lower than in any intercropping treatment and, in addition, that evapotranspiration was highest in the Pueraria treatment. During dry seasons, stem diameter increments of rubber planted with Pueraria were among the lowest observed for any intercrop (Wibawa and Thomas, 1997). Further more, at a dry site in Sri Lanka, Yogaratnam *et al.* (1984), reported that *Stylosanthes gracilis* had adverse effects on rubber growth, due to competition for water by this species.

1.5.3 Grasses

In Indonesia, Siagian and Sumarmadji (1989) found that planted forage grasses (*Pennisetum purpureum*, *Paspalum dilatum* and *Panicum maximum*), had no significant effect on rubber girth increment, nor on the number or diameter of latex vessels, when compared with trees grown in monoculture.

In contrast, however, two Sri Lankan studies demonstrated the competitive effects of forage grasses on rubber tree growth (Waidyanatha *et al.*, 1984; Dissanayake and Waidyanatha, 1987). Rubber tree girth at six years after planting was decreased (relative to controls of Pueraria and of slashed natural covers) by 19, 12 and 3% when planted in association with *Brachiaria brizantha*, *Panicum maximum* and *Brachiaria milliformis* respectively (Waidyanatha *et al.*, 1984). This was despite the fact that the grasses were clipped back to a height of 10 cm every 6 weeks, that both trees and grasses were regularly fertilised, and that a circle 0.75 cm in radius around each tree was kept grass-free (Waidyanatha *et al.*, 1984). In a second trial (Dissanayake and Waidyanatha, 1987), where grasses were clipped and fertilised in the same manner, rubber tree girth and height were significantly lower when grasses were planted at a distance of 1 m from the trees, than when they were planted 1.5 m away from trees. It was also found that 2.5 years after planting, rubber tree girth was decreased (relative to a control of Pueraria) by 15 % when planted in association with *Brachiaria ruziziensis* and *Panicum maximum* (Dissanayake and Waidyanatha, 1987).

1.5.4 Weeds

Weeds are a problem in rubber plantations, because they compete with rubber for light nutrients and water (Watson, 1989b). Furthermore, dense coverage of species such as *Asystasia gangetica, Ischaemum muticum, Stenochlaena palustris* and *Pennisetum polystachion,* and the presence of thorny species (*Mimosa pudica* and *Mimosa invisa*) can physically obstruct maintenance operations in rubber plantings (Chee, 1993b). However, Chee (1990) noted the value of naturally regenerated vegetation (weeds) as a ground cover in steep or hilly areas, where planting a legume cover crop may contribute to soil erosion.

Many studies on weed control in rubber plantations have been reported in the literature (Rai, 1976; Duckett, 1985; Teoh *et al.*, 1985; Anwar and Bacon, 1986; Mathew *et al.* 1986; Mangoensoekarjo *et al.*, 1987; Bogidarmanti, 1988; RRIM, 1993a). These have generally recommended the use of herbicides, due to their greater efficacy than manual weeding due to their residual effects on weed regrowth (Ahmad Faiz, 1992), as well as their greater efficiency in terms of labour use, which is important on the scale of estate plantations. However, Chee (1993a) recognised the problems associated with the over-use of herbicides, including contamination of soil and ground-water, and also the fact that this may have contributed to the rapid expansion of one weed species, *Asystasia gangetica*. Chee therefore proposed selective weeding of a number of 'noxious or undesirable' species, and suggested that other weed species were 'acceptable' under rubber (Chee, 1993b; see also Table 2.6). This classification was based on the results of two earlier studies by Chee *et al.* (1990) and Chee (1994), described below.

In immature rubber plantations, Chee *et al.* (1990) found that the most noxious weeds (i.e. those which had a severe effect on rubber tree growth), were *Imperata cylindrica, Mikania micrantha, Asystasia gangetica, Pennisetum polystachion* and *Chromolaena odorata* (a woody shrub). In an experiment where clonal rubber trees were planted with various non-woody weed species in large polythene bags (90 x 150 cm) for one year, the percentage reduction in rubber growth due to each weed species was calculated, relative to a weed-free control treatment (Chee, 1994). It was found that some of the most highly competitive weed species were *P. polystachion, I. muticum* and *I. cylindrica*, causing 57, 53 and 40% reductions in dry weights of rubber trees, respectively. The same grasses caused 42, 35 and 29% reductions in rubber tree height, respectively. Chee (1994) also observed that these grasses had very large root systems, which resulted in poor growth of rubber tree roots in these treatments (although no data on this was presented). Furthermore, the tall *P. polystachion* and *I. cylindrica* tended to shade the rubber trees, even though the latter had already developed two whorls of leaves at the start of the experiment (Chee, 1994).

At a field scale, an RRIM[8] trial showed that, compared with the legume cover crop *Pueraria phaseoloides*, rubber growth was 19, 25 and 29% lower when grown with *Asystasia gangetica*, with *Mikania micrantha*, and with a mixture of grasses *(Axonopus compressus* and *Paspalum conjugatum*), respectively (RRIM, 1993b).

The perennial grass weed *Imperata cylindrica*[9] is a serious problem for smallholder rubber farmers in Indonesia (Bagnall-Oakeley *et al.*, 1996). In a trial in South Sumatra, rubber tree girth in an *I. cylindrica* treatment was approximately 50% lower than in a clean-weeded treatment, 39 months after planting (Wibawa and Thomas, 1997). A much earlier study (Anon., 1938), showed that in the presence of *I. cylindrica*, rubber tree girth was 48% lower than the girth of clean-weeded trees, and of trees planted with a legume cover crop (five years after planting).

A woody weed, *Chromolaena odorata* was identified as the greatest problem encountered in smallholder rubber plantations in Cote d'Ivoire (Fadiga and Akpagni, 1983). The presence of this weed in rubber plantations in West Africa was regarded as a fire hazard by M'Boob (1991), but the report recognised that the weed may add organic matter to the soil due to its abundant production of leaf litter. However, in these two publications, no data were presented regarding the effect of *C. odorata* on rubber tree growth.

1.5.4.1 Malaysian cover plant trials in the 1950s and 1960s

A number of large-scale trials were conducted in Malaysia in the 1950s to assess the effect of various types of cover plants on the growth of rubber, and also on the nutrient status of the trees, cover plants and soil (Mainstone, 1963, 1969; Watson *et al.*, 1964a, 1964b; Wycherley and Chandapillai, 1969). A number of these trials included treatments which are relevant to this thesis, i.e. where naturally regenerated grasses and woody species were used as 'natural covers' (although these were regularly slashed back to a height of 1 m). Relevant results from these trials are reviewed below.

---

[8] Rubber Research Institute of Malaysia
[9] See Brook (1989) for a review of the literature on this species

In one experiment[10], Watson *et al.* (1964a) showed that at five years after planting, mean girth of rubber trees grown with 'naturals' (woody shrubs, creepers and ferns) was significantly ($p<0.05$) lower (by 25%) than mean girth of trees grown with a legume cover crop. In the same experiment, mean tree girths in a mixed grass treatment (*Axonopus compressus* and *Paspalum conjugatum*), and in a *Mikania micrantha* treatment were 7 and 16% lower, respectively, than mean tree girth in the legume cover crop treatment (these differences were also significant at the 5% level). However, in other experiments in the same series of trials (Watson *et al.*, 1964a), conducted on more fertile soils, the legume covers showed little advantage over the woody, grass and *Mikania* cover types.

In one experiment,[11] Wycherley and Chandapillai (1969) reported that at five years after planting, rubber tree girth was significantly ($p<0.05$) lower in a woody 'natural cover' treatment, than in a LCC treatment, but only by 5%. In that natural cover treatment, phosphate fertiliser (ground rock phosphate) had been applied to the cover, at the same rate as in the LCC treatment. In two other treatments, the same amount of phosphate was applied, but in one case only to the rubber tree row, and in the second case it was divided equally between the rubber tree row and the natural cover. It was found that in the first case, rubber girth was 13% lower than in the baseline LCC treatment, and in the second case, 9% lower (Wycherley and Chandapillai, 1969; Field 24). Therefore, evidence was found that direct fertilisation of the natural cover may reduce competition for P between rubber and these naturally regenerated woody species. Also in this experiment, it was found that latex yields in the first six months of tapping (in terms of grams tapping^{-1} tree^{-1}) were not significantly different between trees in the natural and legume cover treatments (Wycherley and Chandapillai, 1969; Field 24).

In a second experiment, in Field 23, Wycherley and Chandapillai (1969) compared the effects of various woody shrub species on rubber growth, against a baseline of a legume cover. Three woody species which were tested are also common in the study site considered in this thesis, namely *Melastoma malabathricum, Chromolaena odorata* and *Ficus* sp. It was found that these three species reduced rubber girth (relative to the LCC) by only 5, 6 and 7% respectively, at five years after planting, and these reductions were not significant (Wycherley and Chandapillai, 1969; Field 23). However, in this study, no information was presented regarding the fertilisation of either the rubber trees or the covers.

A third experiment (Field 17) included two treatments of pioneer trees which were common in the study area considered in this thesis; the treatments were 'mahang' (*Macaranga* spp. and *Mallotus* spp.) and 'heavy weeds' (*Fagrea racemosa* with wild ginger, *Zingiber zerumbet*) (Wycherley and Chandapillai, 1969). At 18 months after planting, rubber girth in the 'mahang'

---

[10] Experiment 'S', where all covers were fertilised with rock phosphate during the first two years after planting, and all trees were fertilised with N, P and K for the first 18 months after planting, only.

treatment was 4% lower than in the LCC treatment, and in the 'heavy weed' treatment, 5% lower than in the LCC treatment. At six years after planting, rubber girth in the 'mahang' treatment was still 4% lower than in the LCC treatment, but in the 'heavy weed' treatment (where *Fagrea racemosa* had become dominant) girths were 9% lower than in the LCC treatment (Wycherley and Chandapillai, 1969; Field 17). In that study rubber trees were fertilised according to the standard estate recommendations, but no information was given regarding fertilisation of the covers (Wycherley and Chandapillai, 1969; Field 17).

1.5.4.2 Measurable indicators

From this review of the literature on rubber, rubber intercropping systems and studies on weeds, it appears that relatively straightforward measurements of rubber tree height and diameter would be sufficient to detect the effects of interference from secondary forest regrowth, and would facilitate comparison with other studies.

In a number of the above studies, it was found that the nutrient contents of rubber tree leaves was correlated with tree girth (Wycherley and Chandapillai, 1969), and that there were significant differences in nutrient contents and biomass production amongst covers (see Broughton, 1977 for a review). Therefore, it would seem important to quantify foliar nutrient contents of rubber trees, and the nutrient contents, cover and biomass of regenerating secondary forest species in this study, for their use as potential indicators of the differences between treatments, and also to be able to compare the results with other studies.

It is also important to characterise the soils in each trial, as the composition of weed or secondary forest regrowth differs for soils of differing fertility (Watson, 1989b), and the magnitude of the effects of inter-specific competition also varies with soil fertility (Watson, 1964a). Therefore, these findings were taken into account when designing the experiments in this study, and all measurements made are described in the methods sections of individual chapters.

[11] 'Field 24', Sungei Buloh Research Station.

CHAPTER 2

STUDY SITE CHARACTERISATION AND GENERAL EXPERIMENTAL METHODS

2.1 STUDY SITE CHARACTERISATION

The study area of the Rantau Pandan sub district in the Sumatran province of Jambi (101°47'-102°1' E and 1°33'-1°45' S, Figures 2.1 and 2.2) has been identified by ICRAF as representative of the traditional jungle rubber farming system developed by local farmers over the last 75 years (van Noordwijk *et al.*, 1995a). The experiments described in this thesis were located in the villages of Rantau Pandan and Muara Buat (Figure 2.2). Much of the data presented here was collected by teams of Indonesian scientists participating in the ASB project's characterisation of this 'benchmark' area (Rachman *et al.*, 1995; Hadi *et al.*, 1995; Gintings *et al.*, 1995 and Rosalina-Wasrin *et al.*, 1995).

The study area represents the system in the piedmont area of Sumatra, as it was located in the foothills of the Bukit Barisan mountain range which extends the length of the west coast of Sumatra, the upper part bordering the buffer zone of Kerinci-Seblat National Park (KSNP), with altitude ranging from 100-500 m above sea level. Half of the land area has 16-40% slope, one third has 3-15% slope and one fifth has 40% slope or more (Hadi *et al.*, 1995).

2.1.1 Climate: rainfall and temperature

In the district of Bungo Tebo, in which Rantau Pandan is located, annual rainfall varied from 1,656 to 2,982 mm during 1987-1993 (Hadi *et al.*, 1995). Rainfall data collected at Muara Bungo (Figure 2.2), by the Government agricultural office (Dinas Pertanian) showed that annual rainfall varied from 1145 to 3289 mm during 1990-1995 (average over this six year period was 2225 mm). Mean monthly rainfall over this period is shown in Figure 2.3a. Generally, the dry season occurs from April/May to September, the rains starting in September, and becoming heavy from November until February.

There is however, year to year variation in rainfall per month, frequently caused by supra-annual climatic events such as the El Nino phenomenon. This was the case in 1991, 1994 and 1997, when monthly rainfall decreased during the dry season, and the dry season was extended until October. Rainfall in an El-Nino year is often followed by above-average rainfall

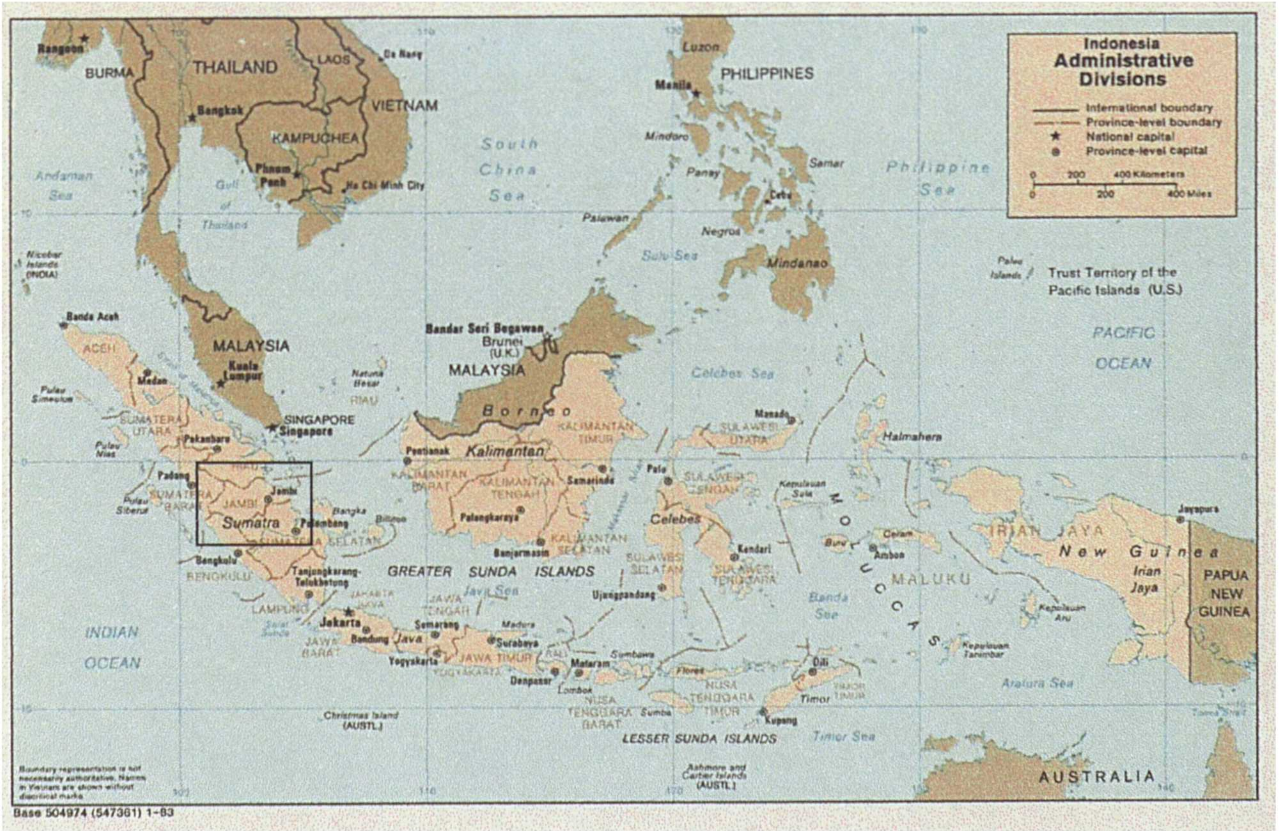


Figure 2.1 Map of Indonesia showing Jambi Province, Sumatra, where the study site was located.

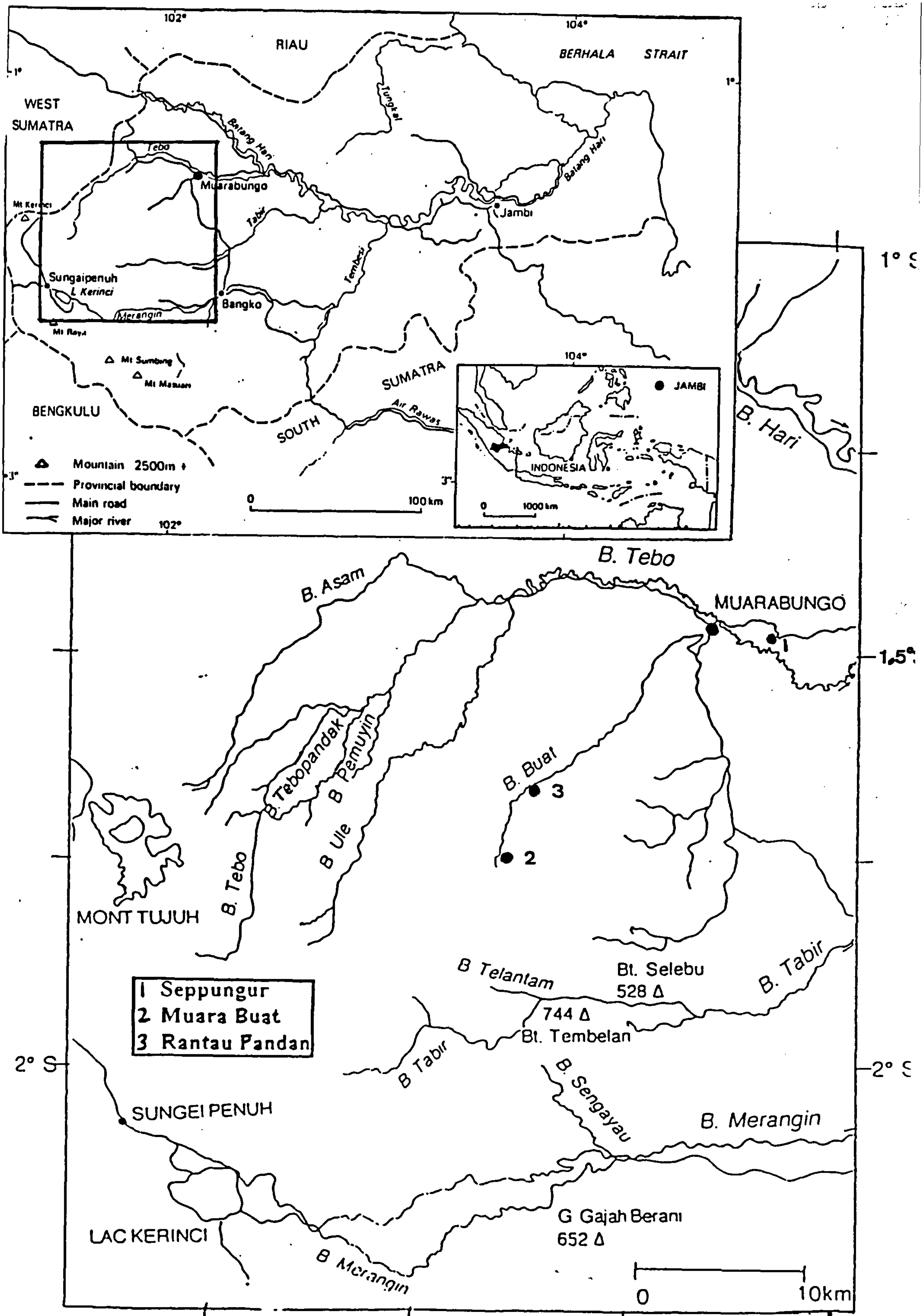


Figure 2.2 Location of Muara Buat and Rantau Pandan, the two villages where the study was conducted. The villages are located within the Sub-District ('Kecematan') Rantau Pandan, Jambi Province, Sumatra. (Map of SRAP study sites prepared by, and reproduced with the permission of, E.Penot.)

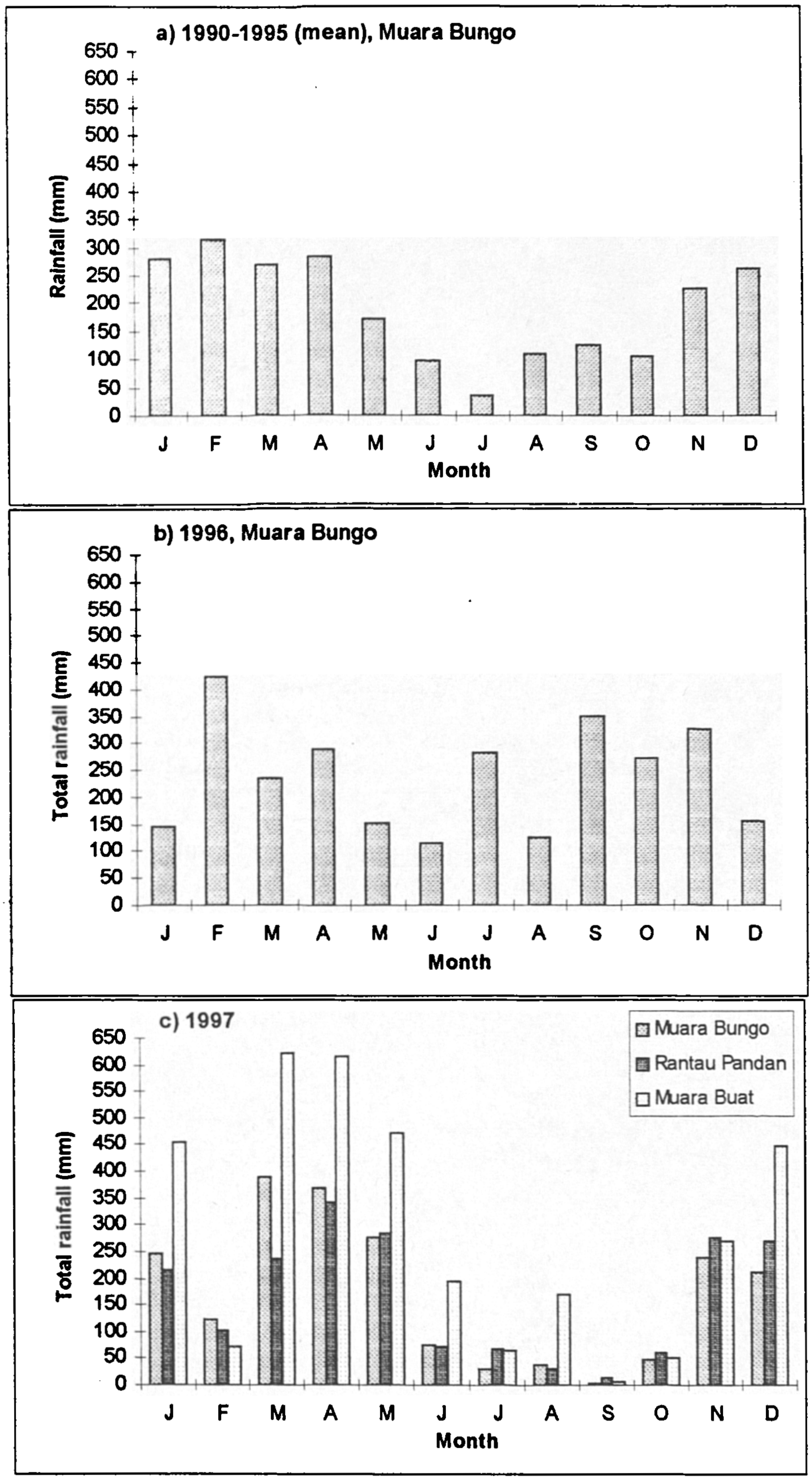


Figure 2.3 Monthly rainfall near, or in, the study area: a) Mean monthly rainfall from 1990 to 1995, in Muara Bungo, Bungo Tebo District; b) Actual monthly rainfall in 1996 in Muara Bungo (first year of experimental programme); c) Actual monthly rainfall in 1997 in Muara Bungo, and in the villages of Rantau Pandan and Muara Buat, Sub-district of Rantau Pandan (second year of experimental programme). Sources: Muara Bungo data from Dinas Pertanian (Muara Bungo), and Rantau Pandan and Muara Buat data from raingauges set up by SRAP (Smallholder Rubber Agroforestry Project).

in the following year ('La Nina'). In 1997, a particularly severe El Nino event was observed, as can be seen by comparing the period June to October in Figures 2.3a and 2.3b, with that in Figure 2.3c.

The rainfall over the two years of the experimental programme (1996 and 1997) is presented in Figures 2.3b and 2.3c, the latter including data from raingauges set up by SRAP (Smallholder Rubber Agroforestry Project). The rainfall in Rantau Pandan (in the field of the trenching experiment, Chapter 3), was lower than that in Muara Buat (in the field of the experiment described in Chapter 4). From January to June 1997, rainfall in Rantau Pandan was more or less comparable with the mean rainfall (1990-1995) in Muara Bungo, but in Muara Buat, rainfall over the period January-August 1997 was nearly double that in Rantau Pandan (possibly due to topographical/rainshadow effects). However, towards the end of the extended dry period related to the El Nino event, rainfall in Muara Buat decreased to levels comparable with Rantau Pandan.

Mean monthly temperatures do not vary greatly across the year, due to the proximity of the site to the equator. Mean annual maximum and minimum temperatures are 31.8°C and 22.4°C respectively, with mean maximum temperatures varying from 30.9°C in January to 32.3°C in May and October, and mean minimum temperatures varying from 22.1°C in July and September to 22.7°C in April and May (Rachman *et al.*, 1995).

2.1.2 Soils

The soils of Rantau Pandan are derived mostly from parent materials of granite (giving USDA Soil Taxonomic Unit: Oxic Dystropepts), and andesitic lava in more mountainous areas (giving Typic and Lithic Dystropepts) (Rachman *et al.*, 1995). In valley bottoms and flat land adjoining the river, deposition processes are dominant, giving rise to Typic Tropofluvent soils (Table 2.1).

Table 2.1 Rantau Pandan soil types and distributions (Rachman *et al.*, 1995)

Soil Family (USDA)	Slope (%)	Relief	Land form	Parent Material	Area (ha)	Area (%)
Fine mixed, acid, isohyperthermic, Typic Tropofluvents	<1	Level	River flat	Clay & sand, river alluvium	650	12.26
Fine, loamy, kaolinitic, isohyperthermic, Oxic Dystropepts	15-30	Hillocky	Hillocks	Colluvium	500	9.43
Fine, kaolinitic, isohyperthermic, Oxic Dystropepts	15-30	Hillocky	Hillocks	Colluvium	250	4.72
Fine, kaolinitic, isohyperthermic, Typic Dystropepts	25-45	Hilly	Hills	Andesitic lava	1,400	26.42
Complex of clayey skeletal, Oxic Dystropepts and kaolinitic, isohyperthermic, Lithic Dystropepts	25-45	Hilly	Hills	Granite	1,300	24.53
Complex of fine Typic Dystropepts and clayey, kaolinitic, isohyperthermic, Lithic Dystropepts	>45	Mountainous	Mountains	Andesitic lava	1,200	22.64

Both soil type and the topography determine land use to a certain extent (Table 2.2), as can be seen by the fact that irrigated rice is grown on the river flats, where the soils are Typic Tropofluvents. The fact that tree-crop gardens are planted on Oxic Dystropepts (Table 2.2) is more likely to be due to the topography, than to the properties of that soil type *per se*.

Table 2.2 Summary of soil properties of Rantau Pandan in relation to land use (Rachman *et al.*, 1995)

Land Use	Paddy (Wet Rice)	Jungle Rubber	Mixed Garden	Ladang (Upland Rice)	Secondary Forest
Soil	Tropofluvents	Oxic Dystropepts	Oxic Dystropepts	Oxic Dystropepts	Oxic Dystropepts
pH	4.9	4.6	4.0	3.8	4.0
CEC (cmol kg^{-1})	6.67	9.91	16.84	16.84	10.89
Available P (mg kg^{-1})	13.4	1.3	1.0	5.0	5.8
C-Org (%)	1.48	2.22	3.86	1.0	2.55
Bulk Density (g cm^{-3})	1.24	1.19	-	-	0.93
Texture					
Sand (%)	28	53	11	49	37
Silt (%)	49	12	38	23	39
Clay (%)	23	35	51	28	24

2.1.3 Vegetation Types

Eight different vegetation types (Table 2.3) have been identified in Rantau Pandan from SPOT satellite data (Laumonier and Djailany-Syafi, 1989) and ground surveys by H. de Foresta in 1993. The areas of these were quantified using Landsat TM images from 1994, by Rosalina-Wasrin *et al.* (1995) (Table 2.3), although it was difficult to distinguish jungle rubber from secondary forest, as they are structurally very similar (Stolle *et al.*, in press).

Table 2.3 Classification of vegetation types, and their extent in the Rantau Pandan sub-district (Rosalina-Wasrin *et al.*, 1995)

Vegetation Type	Area (ha)	Area (%)
1. Lowland primary forest	518	0.81
2. Hill primary forest	2,891	4.53
3. Lowland logged-over forest	22,517	35.33
4. Old secondary forest	16,702	26.21
5. Mosaic of smallholder rubber and young secondary forest	6,471	10.58
6. Mosaic of smallholder rubber and thickets of shrubs	11,802	18.52
7. Upland rice and cassava fields ('ladang', shifting cultivation)	830	2.72
8. Mosaic of paddy fields, fruit trees and settlement.	1,731	1.3
Total	63,732	100.00

The landscape of this area is dominated by logged-over forest, secondary forest and mosaics of smallholder rubber with secondary forest regrowth (Rosalina-Wasrin *et al.,* 1995). Large-scale logging activities have been taking place at the expense of primary forest; at present the forest only exists in the hilly areas and is very limited in the lowlands. Based on BPS[12] (1993) statistics on the state-owned forest located in this sub district, nearly 42,000 ha was categorized as production forest and 35,700 ha as protected forest (Kerinci-Seblat National Park), *i.e.* nearly the whole area was categorized as forest. In practice, much agriculture has been found on the so-called State Forest Land. This conflict has arisen because the designation of "Forest Status" by the State was declared when local communities had already settled in the area and established agricultural activities.

The geographical location of the various land use types varies with the landscape (pers. obs.). There is a road along the river valley from Muara Bungo to Rantau Pandan and Muara Buat villages (Figure 2.2); villages have been built along this, and around the villages, the land use type 8 occurs (Table 2.3). The fruit gardens within this land use type include the tree species:

Durian (*Durio zibethinus*)
Cempedak (*Artocarpus integer*)
Duku (*Lansium domesticum*)
Kelengkeng (*Dimocarpus longan*)
Petai (*Parkia speciosa*)
Rambutan (*Nephelium lappaceum*)
Mangga (*Mangifera indica*)
Nangka (*Artocarpus heterophyllus*)
Sawo (*Manilkara zapota*)

Between villages, there are also smallholder plantations of 'kayu manis' (*Cinnamomum zeylanicum*), but generally, land use types 5 and 6 (jungle rubber; Table 2.3) are dominant. On the valley sides, jungle rubber is still dominant and is sometimes interspersed with upland rice and cassava fields (land use type 7; Table 2.3). With increasing distance from the road and villages, land use changes to type 4, and eventually to type 2 (pers. obs.).

2.1.4 Land Use and Farming Systems

Land use and farming systems in this area were characterised from the farmers' perspective by Hadi *et al.* (1995) as follows:

1. 'Sawah' (irrigated rice). This belongs to family clans and is categorized as 'harta berat', *i.e.* cannot be sold, and can only be inherited by women. Since its area is small (usually confined to

[12] Indonesian Government Department of Statistics.

valley-bottom areas), families within the same lineage have to take turns in using it. Sawah only yields one crop of a local rice variety per year (six months duration), and yields are generally not sufficient for family subsistence for that year (Hadi *et al.,* 1995).

2. Belukar (secondary vegetation, also called 'sesap' or 'semak'). This actually constitutes fallow fields dominated by small trees and bushes/shrubs. There are two kinds of tenure and utilization of this land. The first is belukar which is categorized as communal land. This can only be used for annual crops, especially upland rice, for food security. This land is relatively fertile and located near the village/residential areas. Usually there are many plots of communal belukar. Members of the community are free to use it, but those who do not have inherited land have priority. Outsiders must obtain permission from the village leader to use it. Generally, one household is able to open 1 ha of this land per year by slash and burn techniques. Farmers practice rotation on this land, with the average fallow period ranging between three and five years (Hadi *et al.,* 1995).

Private belukar, the second category, is belukar that belongs to individuals or clans/families. Usually use is limited to family members; other farmers have to request permission from the owner to use it, and are not permitted to plant perennials. The owner usually plants upland rice for one to two seasons, and then moves to another plot within the belukar. If the land is suitable for planting rubber or cinnamon, e.g. if it is on a suitable slope, rubber is usually interplanted from the start and subsequently, when there are no annuals, this land is called 'kebun' (Hadi *et al.,* 1995).

3. Kebun (mixed garden). The kebun is usually privately owned and tradeable. The land originates from belukar or forest, and is planted with rubber and/or cinnamon. In 1992 the State declared the boundary of KSNP and, simultaneously, farmers were prohibited from clearing land for cultivation. Since the regulation was implemented after decades of forest use by local farmers, there are many kebuns in the park. Now farmers are allowed to gather NTFPs[13] and latex from kebuns, but are not allowed to plant new crops or new areas. Many forest areas have also been distributed for transmigration projects, industrial wood plantations, and estate crop plantations. Therefore, clearing forest for cultivation is now more difficult (Hadi *et al.,* 1995).

Jungle rubber lands are passed down from generation to generation and whole-field replanting is rare due to: 1) limited access to better planting material, 2) loss of potential income before the young rubber trees grow up to maturity and 3) problems of wild pigs eating young rubber (Hadi *et al.* 1995). The farmers will only replant their jungle rubber (with new jungle rubber) after its yields fall to very low levels and they need land for their food crops (which are grown for the first year when jungle rubber is planted). The size of rubber and/or cinnamon kebuns per household range between 0.5 and 4 ha. Jungle rubber provides a cash income for farmers, and other

[13] Non Timber Forest Products.

cash crops such as coffee, cocoa, and of course kayu manis (*Cinnamomum zeylanica*) are often integrated into the rubber agroforest. Timber trees and rattan are also grown within the jungle rubber, for sale in Muarabungo (the nearest town), or used for house construction (Hadi *et al.* 1995).

Livestock (cattle, buffalo, sheep and goats) are also kept. Cattle are viewed as an investment and a means of saving, buffalo are also used in sawah. Sheep and goats are often sold at the market (they are rarely consumed by the villagers themselves). All animals roam freely, and there are no enclosures. Recently fishponds have been created. On average, an area of 0.1 ha of pond per family can produce 93 kg fish per year, generating an income of 324,000 rupiah (Hadi *et al.* 1995).

2.1.5 Farmer income and expenditure

A survey of 45 households in four villages (Gintings *et al.*, 1995) found that farmer income was low (Table 2.4), and derived mainly from tree gardens of rubber and cinnamon (Table 2.5). Average household expenditure was 1 222 000 Rp per annum. 85% was for basic needs (food, household goods, and toiletries), other small expenditures were for clothes, education and medical care.

Table 2.4 Distribution of income classes in 45 households in the Rantau Pandan sub-district (Gintings *et al.*, 1995).

Income class (thousand rupiah[1])	% of farmers
<500	24
500-1000	34
1000-1500	21
>1500	20

[1] £1 was equivalent to 3500 rupiah in 1995.

Table 2.5 Annual farmer income, Rantau Pandan Sub-district, 1993-1994 (average of 45 households) (Gintings *et al.*, 1995).

Component of farming system	Annual income (thousand rupiah)	Total (thousand rupiah)
Lowland fields:		
Rice	363.83	
Soy bean	3.18	366.96
Upland fields:		
Upland rice	30.90	
Chilli	9.73	40.63
Perennial plots		
Rubber	956.08	
Cinnamon	8.57	
Fermented durian	1.88	966.53
Livestock (total)	17 66	17.66
TOTAL ON FARM INCOME		**1 391.78**
NET ANNUAL INCOME (Total on-farm income less average annual expenditure of 1 221 990 Rp)		**169.79**

2.1.6 Population

In 1994 the population of the entire Sub-district of Rantau Pandan was 22,563, consisting of 5,231 families with 4.3 members on average (BPS, 1993). Population density is 18 km^{-2}. Population dynamics tend to be quite stable, with relatively little in and out migration. It is notable that the annual population growth rate has decreased from 2.55% in the 1970s (1971-1980) to 1.2% in the 1980s (1981-1990), (Hadi *et al.*, 1995).

2.1.7 Indigenous knowledge about the management of jungle rubber with respect to weed and tree competition, and farmers' views on improved planting material

Indigenous knowledge regarding weed and tree competition in jungle rubber, weed management and farmers' views on improved planting material were elicited from a group interview that I conducted with seven male farmers from the village of Muara Buat in December 1995. Specific information regarding the establishment of jungle rubber gardens, and the factors affecting seedling growth obtained from this interview are presented in Chapter 4 (Section 4.1.4). Comments, although paraphrased for ease of translation, are the farmers' own; any additional explanation that has been inserted has been placed in square parentheses.

2.1.7.1 Two methods of establishing jungle rubber, and associated weeding management

In Muara Buat, when establishing a rubber garden, only 20% of farmers clear a whole field using slash-and-burn techniques. In this system, farmers usually plant upland rice (a six-month variety), at the same time as they plant rubber, but have to make a fence because wild pigs 'smell' the disturbance, and attack the crops. The rice is weeded twice, at one and three months after planting. After the rice harvest, the rubber is usually circle-weeded twice a year. This 20% of farmers often make the most of their investment of time, labour and money by planting cinnamon (and/or coffee) in the inter-row area. If cinnamon is planted, the whole field is weeded well (3-4 times per year throughout the development of the cinnamon), for at least eight years.

The other 80% of farmers do not clear vegetation from an entire field. Instead, they only clear rows (approximately 1 m wide) through secondary forest regrowth ('sesap') which is about 2 m high, and plant the rubber in these rows at a spacing of 3 m x 4 m. Only after two to three years do they clear all the inter-row vegetation, because at that age the rubber does not attract pigs. Some farmers said this was because pigs like to eat the roots of the young trees (they suggested that this may be because they are sweet), and after two to three years, the roots are too big. The undergrowth in the inter-row also helps prevent deer getting to the rubber; deer are also a problem because they eat the young leaves of the trees. Again after two to three years, deer were not perceived to be a problem as they were not able to reach the leaves. In this system, rubber trees are weeded twice a year, in a 1 m circle around the trees, until they reach the diameter of a farmer's thigh, usually after four years. Then only one weeding per year is necessary, as the canopy casts too much shade for many weeds to grow.

In general, the 80% of farmers who use this method to establish jungle rubber do so because they do not have enough labour to invest in intensive management, due to off farm employment (for example they might own shops or be involved in wood-cutting activities).

2.1.7.2 Effects of weeds on rubber, and the control of problem weeds

The effects of weeds on rubber are most serious in the first four years after planting, before the canopy becomes very dense. In addition, the effects of climbing weeds are more serious on smaller trees, as the weight of these on the crown can cause the stem to break.

Three weed species were named by the farmers as a major problem. The first mentioned was a climber, 'rumput tunggul tunggul' [*Mikania* sp.], which could cause even relatively large trees to break. Apparently, it had only become a serious problem in the previous two years.[14] It has medicinal uses, and previously people could search for a whole day to find it; now it is

[14] pre-1993.

everywhere. It regenerates very quickly when slashed (one week to twenty days), and it can be killed by digging up the roots, but farmers have very little time for this. These farmers said that there is no herbicide which works on it.

The second 'problem' weed mentioned was 'rumput gajah' [*Pennisetum purpureum*], which does not grow 'too' tall, but grows very fast and spreads very quickly. This can be slashed with a machete and left as mulch (in contrast to the Mikania, which farmers believed could put out roots from stems left on the ground). The third weed mentioned was 'alang alang' [*Imperata cylindrica*], but farmers said that this was not usually a problem after the fourth year, as it was shaded out by the rubber canopy. Round-up [a glyphosate-based herbicide] is used if it can be afforded, otherwise some farmers press it down with a board, and allow other weeds to grow over it.

2.1.7.3 Tree species deliberately planted in jungle rubber gardens

Durian [*Durio zibethinus*, a fruit tree] is the most popular species usually planted at the same time as rubber, but at a maximum density of twenty stems per hectare. These trees are planted around the edge of the plots only. Farmers said this is because durian trees 'grow big very quickly' and 'disturb' the rubber which cannot grow upwards. In addition, the shade it casts causes the rubber trees to have a very thin trunk.

Other fruit trees are usually planted deliberately around the 'pondok' [field hut] or around the sides of the field only, not distributed through the rubber garden. These include 'duku' [*Lansium domesticum*], 'manggis' [*Garcinia mangostana*], 'cempedak' [*Artocarpus integer*], 'nangka' [*Artocarpus heterophyllus*] and 'tampun' [*Artocarpus rotunda*].

Some farmers plant timber trees deliberately, but again, these are planted only around the edge of the plots. According to farmers, the most abundant timber trees in the area were 'medang' [a number of species from the Lauraceae: *Alseodaphne* spp., *Dehaasia* spp. and *Phoebe grandis*]. Other species sometimes planted were 'meranti' [*Shorea* spp.], 'balam' [*Ganua* spp.], 'kelat' [*Eugenia* sp.] and 'kulin' [*Eusideroxylon zwageri*], although the latter was quite rare.

2.1.7.4 Useful tree species which regenerate naturally in jungle rubber gardens

Useful fruit trees which regenerate naturally in jungle rubber in Muara Buat were listed by farmers as: 'mata kucing' [*Dimocarpus longan*], 'petai' [*Parkia speciosa*] 'jengkol' [*Pithecellobium jiringa*], 'tampun' [*Artocarpus rotunda*] and 'salak' [*Salacca edulis*, a palm]. Farmers believed that these species do not cause too much disturbance to the rubber if they regenerate in the middle of the plot (as they are not usually taller than rubber), and so do not cut them down. No-one in the village bothers to plant 'petai' or 'jengkol' as they are very abundant around the village.

In contrast, however, farmers said that if timber trees regenerate in the middle of their gardens, then they will either move the seedlings to the edge of the plot, or cut them, because they are too competitive (they take up nutrients, and less latex is produced from rubber trees near them).

2.1.7.5 Farmers' views on, and experience with improved rubber planting material

Some farmers in the village have planted 'clonal seedlings' [Section 1.2.3.2]. These were grown from the seed of clone GT 1 and sold as 1.5 m-tall seedlings in Muara Buat by a trader from Muara Bungo (who obtained the seed from a government-owned clonal rubber plantation). Bud-grafted clonal rubber stumps [Section 1.2.3.2] have also been planted, but only by one farmer, about 2 km from the village. He has to weed it regularly. However, the clonal seedlings are managed under a similar regime to local seedlings obtained from jungle rubber [Section 4.1.4].

Farmers were not yet sure how the growth of the different planting materials compared with each other, as the clonal seedlings and the bud-grafted clones were still young. However, they thought the amount of weeding was important and also that the bud-grafted rubber did not do very well if only weeded twice per year. Also, the shoot from the bud-graft of these trees was susceptible to breaking off if the climbing weed [Mikania] was present. The farmers said that local jungle rubber seedlings reach a tappable size (their criterion is a stem diameter of 30 cm), more slowly if not weeded sufficiently (10 years as opposed to 8 years).

Again, as the new types of planting material were still young, the farmers did not know how yields would compare with their local jungle rubber seedlings. However, they stressed the fact that a garden of local seedlings could be tapped for a much longer time than clonal rubber (up to 60 years), because when the originally-planted trees have reached the end of their tapping life, the naturally regenerated progeny of the original trees can be tapped. Grafted clonal rubber, on the other hand, can be tapped for maybe 20 years and then has to be replanted. Farmers thought this was an important advantage of the jungle rubber system.

Farmers also stressed that it was a lot more expensive to establish clonal rubber – perhaps costing up to millions of Rupiah, and this was a crucial factor. They thought it was important I took this message back to ICRAF in Bogor.

2.1.7.6 Latex yield variation amongst trees in jungle rubber

An interesting outcome of this group interview was that it became apparent that farmers recognised that there was great variation in yield between individual trees within their jungle rubber gardens, and that they could identify two types of seedling rubber trees with different morphologies and yield characteristics. These were labelled 'red' and 'yellow' trees, due to different shades of bark colouration. Farmers said the red-barked trees were more desirable, as their bark was harder when it regenerated after tapping, and the trees yielded more latex when tapped. Therefore, seeds were often collected from under these red-barked trees. To investigate this further, and also to elicit farmers' indigenous knowledge on latex yields in mature jungle rubber, and how these may be influenced by management and inter-specific competition, a series of informal semi-structured interviews was conducted in December 1996. Transcripts from these can be found in Appendix 2.1.

2.2 GENERAL EXPERIMENTAL METHODS

2.2.1 Standard methods used in planting clonal rubber in all experiments

The methods used in all trials were based on standard recommendations for smallholders (Delabarre and Benigno, 1994; Junaidi *et al.,* 1996, which are the references for all information in this section).

2.2.1.1 Field preparation, planting and phosphorus fertilisation

After slashing and a general burn, remaining vegetation (large branches and tree trunks) were cut into smaller lengths and burned in piles according to traditional practice (Ketterings *et al.*, 1999). Planting holes were marked out with bamboo stakes at 3 x 6 m intervals, using string on flat land, and an 'A' frame to position planting rows along contours. 40 cm by 40 cm holes were dug to a depth of 40 cm.

At planting, one rubber tree in a polybag was placed in each hole, and the bag slit down one side and across the base with a razor blade. The excavated soil was fertilised with 113 g of triple super phosphate ('SP 36') granules (equivalent to 13 kg P ha^{-1}), then half placed in the hole. The polybag was removed, and the soil compacted by hand. The hole was then filled with the remaining soil, compacted by hand and finally, trodden down.

Boundaries of experimental plots were marked out with large wooden stakes (3 cm in diameter, 2 m in height), the tops of which were painted red, to aid visibility. Thick yellow plastic cord was tied between stakes.

2.2.1.2 Nitrogen fertilisation

The trees were fertilised with 50 g of urea per tree three months after planting; the urea was placed in a shallow groove which extended in a circle around the tree at a distance of 50 cm. This was repeated at three-monthly intervals for the first two years, giving an annual application of N equivalent to 55 kg ha^{-1}. It should be noted that trees in the trenching experiment (Chapter 3) were not fertilised with urea after planting.

2.2.1.3 Maintenance

Weeding protocols were designed for each experiment individually (Chapters 3, 4 and 5). Lateral branch pruning was carried out whenever side shoots were produced, up to a height of 2.4 m (Webster, 1989b), to ensure that height growth was rapid, and that the lower stem was free of branches to enable easy tapping. Fungal leaf diseases (*Colletotrichum* sp. and *Oidium* sp.) were controlled by regular spraying with Dithane. Branch induction was initiated when the trees reached a height of 3 m, by bunching the uppermost whorl of leaves over the apical bud and securing them with an elastic band.

2.2.2 Characterisation of vegetation

Following the approach used by Preisinger *et al.*, (1994), weeds were recorded by growth-form; namely, trees, shrubs, herbs, grasses, ferns and climbers. For reference, the most commonly encountered species within each growth-form are presented in Table 2.6. Species were identified from illustrations in Haines (1934), Dijkman (1951), SEAWIC[15] Weed Information Sheets (various dates) and Wijayakusuma (1995). Indonesian names for plants were translated to the botanical equivalents using Levang and de Foresta (1991).

[15] South East Asian Weed Information Centre, SEAMEO-BIOTROP, P.O. Box 116, Bogor 16001, Indonesia.

Table 2.6 Most commonly encountered species within each growth-form, and their classification in terms of desirability as ground cover in rubber plantations

Growth-form	Species	Family	Desirability[1]
'Tree'	*Trema orientalis*	Ulmaceae	Acceptable
	Macaranga spp.	Euphorbiaceae	Acceptable
	Mallotus spp.	Euphorbiaceae	Acceptable
	Peronema canescens	Verbenaceae	-
	Artocarpus spp.	Moraceae	Acceptable
	Psychotria viridiflora	Moraceae	Acceptable/desirable
	Eugenia spp.	Myrtaceae	Acceptable
	Maesa ramentaceae	Myrsinaceae	Acceptable
	Dendrocnide stimulans	Urticaceae	-
	Hevea brasiliensis	Euphorbiaceae	Acceptable
'Shrub'	*Blumea balsamifera*	Asteraceae	Acceptable
	Chromolaena odorata	Asteraceae	Undesirable
	Melastoma malabathricum	Melastomataceae	Undesirable
	Lantana camara	Verbenaceae	Undesirable
	Eurya acuminata	Theaceae	Acceptable/desirable
	Clidemia hirta	Melastomataceae	Undesirable
	Mimosa pudica	Mimosaceae	Acceptable
'Herb'	*Ageratum conyzoides*	Asteraceae	Acceptable
	Crassocephalum crepioides	Asteraceae	-
	Borreria latifolia	Rubiaceae	Desirable
	Asystasia nemorum	Acanthaceae	Acceptable/desirable
	Asystasia ganganetica	Acanthaceae	Undesirable
	Hedyotis congesta	Rubiaceae	Desirable
'Grass' [2]	*Axonopus compressus*	Poaceae (Graminae)	Undesirable
	Paspalum conjugatum	Poaceae (Graminae)	Acceptable/undesirable[3]
	Panicum repens	Poaceae (Graminae)	Desirable
	Pennisetum polystachion	Poaceae (Graminae)	Undesirable
	Cyperus rotundus	Cyperaceae	Undesirable
	Scleria sumatrensis	Cyperaceae	Undesirable
'Fern'	*Selaginella atroviridis*	Selaginellaceae	Acceptable/undesirable
	Nephrolepis biserrata	Polypoidaceae	Acceptable/desirable
	Lygodium flexosum	Schizaeceae	Undesirable
	Lycopodium cernuum	Lycopodiaceae	Undesirable
'Climber'	*Mikania micrantha*	Asteraceae	Undesirable
	Passiflora foetida	Passifloraceae	Acceptable/undesirable

[1] According to Haines (1934) and Chee (1993b); (-), not classified by either author.
[2] Sedges (*Cyperus* spp. and *Scleria* spp.) were included in this category.
[3] Undesirable in young plantations

CHAPTER 3

EFFECTS OF SECONDARY FOREST REGROWTH ON THE ABOVE- AND BELOW-GROUND GROWTH OF CLONAL RUBBER:

A RESEARCHER-MANAGED TRENCHING EXPERIMENT

3.1 INTRODUCTION

As explained in Chapter 1, a low input rubber agroforestry system was designed, where secondary forest species are allowed to regenerate naturally in the area between rows of planted clonal rubber trees. Some of these species are perceived as useful by farmers who plant rubber in the traditional 'jungle rubber' system (Section 2.1.7).

Under intensive plantation conditions, naturally regenerating woody and herbaceous species are perceived to be weeds, which compete with rubber, and so are removed and replaced with a uniform legume cover crop (Watson, 1989b). In contrast, in the case of jungle rubber or this prototype rubber agroforestry system, these 'weeds' are an integral part of the system. However, it is not known how much competition they actually exert, and what the interactions involved are (Gouyon *et al.,* 1993).

There is evidence that competition from weed and crop species affects the above-ground growth of rubber trees, in terms of height and diameter (Section 1.5), and also in terms of foliar nutrient content (Watson, 1964a). Studies on the effect of weed and crop competition on the below-ground growth of rubber, however, are much less numerous, but effects have been observed on fine root density, biomass and distribution (Mainstone, 1969; Soong, 1976; Samarappuli *et al.*, 1996). An investigation on the effects of below-ground competition on rubber tree roots in an intercropping system (Williams *et al.,* in press; Appendix 3.1), using a new method of analysing tree root systems based on fractal geometry (van Noordwijk and Purnomosidhi, 1995), showed that with increasing levels of competition, rubber shoot:root ratio decreased (relatively more resources were allocated to root than shoot growth). It was also shown that within the root system, there was more allocation to roots exploiting lower rather than upper soil layers (Williams *et al.,* in press; Appendix 3.1). Therefore, any research on the effects of inter-specific interference on rubber tree growth should also include below-ground studies.

3.1.1 Below-ground resource competition and resource manipulation

Plant-plant interactions are not direct effects of plants on each other, but effects on the environment, which acts as an intermediary (the 'response and effect' principle) (Goldberg, 1983). The nature of the interactions concern the ways in which a plant can influence its neighbours by changing their environment (through 'interference'); examples of this include the addition or subtraction of nutrients in the soil, or uptake of water ('resource competition') (Harper, 1977).

Reducing the volume of soil around a rubber tree would reduce the total amount of available below-ground resources (nutrients and water). In addition, the presence of competing plant species would reduce the amount of common resources available to each component in the system (here, the rubber tree and the secondary forest regrowth). The interaction between these two factors (total amount of below-ground resources, and competitive presence of secondary forest regrowth) would be of interest when considering two theories of competition. The first theory (Grime, 1979) predicts that with increased soil resources, total plant biomass increases, and thus both root and shoot competition is increased. The second theory is that with increased soil resources root competition decreases, shoot competition increases, and thus total competition should remain constant (Tilman, 1985, 1987). Tilman's model predicts that root competition should predominate where soil resources are limiting. Empirical evidence to support this has been provided by Putz and Canham (1992), who found that in shrublands, with increasing soil resources, root competition decreased.

In the case of rubber, in one trial where secondary forest regrowth was used as a 'natural cover', increased soil resources (in the form of added nitrogenous fertiliser) resulted in significantly greater growth of rubber, compared with unfertilised secondary forest regrowth (Mainstone 1963, 1969). As the secondary forest regrowth had been slashed back to a height where there was no above-ground competition with the rubber trees, then the increased soil nutrient resource in that study clearly led to a reduction in root competition between the rubber and the secondary forest species (Mainstone, 1963, 1969). The same response was seen in another trial, where N-fertilised grasses exerted less below-ground competition on rubber trees than did non-N- fertilised grasses (Pushparajah and Chellapah, 1969). Thus there is evidence that manipulation of below-ground resources would affect competitive interactions between rubber trees and naturally regenerated vegetation.

3.1.2 Experimental approach

On the basis of the above, and to address Objectives 1 and 2 of the thesis (Section 1.1, and below), a small-scale experiment was designed, in which the below-ground environment, and thus the total amount of available below-ground resources (nutrients and water), was experimentally manipulated. This was done by partitioning different volumes of soil around the rubber trees using trenches. Root barriers were also installed in these trenches to restrict the foraging of roots to these specific soil volumes. Three different-sized soil volumes were created (Section 3.2.1.1). Thus, the use of trenching in this experiment is analogous to use of different-sized pots of soil[16] (but on a larger scale). The function of the trenches was <u>not</u> to exclude root competition from other species around a target plant (or plants), as has often been used in treatments in ecological experiments (e.g. Denslow *et al.*, 1991; Canham and Putz, 1992; Riegel *et al.*, 1992; Swank and Oechel, 1992; Gerhardt and Fredriksson, 1995), and in agroforestry trials (e.g. those described by Ong *et al.*, 1991).

The direct effect of secondary forest regrowth on the environment was also manipulated by weeding treatments which were imposed on replicates of each soil volume. Thus, competition effects could be studied by comparing rubber tree growth in each of the three soil volumes, with and without the presence of regenerating secondary forest species.

3.1.2.1 Above-ground growth of rubber trees

Above-ground growth of rubber trees was measured in order to address Objective 1 of the thesis:

To quantify the effects of interference from secondary forest regrowth on the above-ground growth of clonal rubber trees, and to determine how the outcome of that interference is controlled by variation in the total amount of below-ground soil resources.

<u>Hypotheses</u>

1. Above-ground rubber tree growth will be less in smaller soil volumes, due to quicker exhaustion of limited resources.

2. Weeding significantly increases rubber-tree above-ground growth, due to reduced competition for limited resources.

3. Soil volume and weed competition will interact, resulting in a greater increase in rubber-tree above-ground growth with weeding, in a small soil volume, than in a larger soil volume.

---

[16] For example, a study by Awonaike *et al.* (1996) investigated the effects of competition from *Eucalyptus camaldulensis* on the growth and nitrogen fixation of *Leucaena leucocephala* in relation to rooting volume i.e. pots of soil containing 4, 10, 15 and 30 kg of soil.

4. Rubber tree growth in small volume, unweeded + N fertiliser plots will be higher than in small, unweeded plots with no fertiliser addition, due to alleviation of competition for nitrogen between trees and secondary forest regrowth.

5. After 22 months, below-ground resources of nitrate- and ammonium-nitrogen will be greater in clean-weeded than in unweeded plots, and greater in larger soil volumes than in smaller soil volumes. In addition, the effect of weeding treatments will be manifested in higher soil bulk density in clean-weeded than unweeded plots.

6. After 22 months, rubber tree foliar nutrient and water contents will be greater in clean-weeded than in unweeded plots (due to reduced resource competition from secondary forest regrowth) and will also be higher in trees growing in larger soil volumes than in smaller soil volumes (due to a greater quantity of below-ground resources per tree). Nutrient and water contents of secondary forest regrowth will follow the same pattern.

Above-ground rubber tree growth was monitored, as this was expected to be depressed under conditions of below-ground resource limitation; this could potentially be induced by decreased soil volume, and by weed competition. Foliar nutrient contents of the trees was also assessed, as this is a standard tool for diagnosing fertiliser requirements (Watson, 1989c), and could thus be used to assess potential nutrient deficiencies arising from competition.

An extra treatment was created to investigate whether addition of nitrogen fertiliser to the rubber trees could offset the competition from secondary forest regrowth in the system (as was found by Mainstone, 1963 and Pushparajah and Chellapah, 1969), and thus provide evidence that the trees and secondary forest regrowth were primarily competing for nitrogen, rather than for other nutrients or water. This approach was suggested by Schroth (1999), and in this experiment, nitrogen was chosen as the nutrient to be added, as the rubber trees had already been fertilised with P at planting (Section 2.2.1.1). The testing of this hypothesis is important, because a number of studies have shown that increasing nutrient resources by fertiliser addition does not necessarily lead to reduction of competition (Wilson, 1988; Woods *et al.*, 1992). In fact, N-fertiliser addition may actually increase the potential competition from associated species, due to stimulation of growth of their roots. This was seen by Campbell *et al.* (1994), for ryegrass (*Lolium perenne*) roots, in association with wild cherry (*Prunus avium*). Furthermore, it was found by Harcombe (1977) that addition of fertiliser to plots of early-successional vegetation decreased the dominance (cover and biomass) of woody shrub and tree growth-forms, and increased the dominance of herbaceous growth-forms, relative to unfertilised plots. Therefore, increasing the below-ground resource of mineral nutrients gave a competitive advantage to the herbs, over the first year of colonisation (Harcombe, 1977).

3.1.2.2 Allocation within the rubber tree

Allocation within rubber trees was studied in order to address Objective 2 of the thesis:

To investigate effects of interference from secondary forest regrowth and variation in the total amount of below-ground soil resources on the response of allocation within clonal rubber trees (roots versus shoots, and vertically- versus horizontally-oriented roots).

Hypotheses

1. Rubber shoot:root ratios will be increased by weeding, due to greater resource allocation to root growth where there is competition from secondary forest regrowth that is predominantly below-ground.

2. Rubber shoot:root ratio will be lower in trees growing in a smaller soil volume than in a large soil volume, due to greater resource allocation to root growth in conditions where total available below-ground resources are reduced.

3. Ratios of the number and cross-sectional area of vertically and horizontally oriented roots will be higher where there is competition from weeds, i.e. there will be a greater allocation to vertically oriented roots.

4. Ratios of the number and cross-sectional area of vertically and horizontally oriented roots will be higher in rubber trees growing in a small soil volume than in a larger soil volume, i.e. there will be a greater allocation to vertically-oriented roots.

Under conditions of below-ground resource limitation (decreased soil volume, and weed competition) it would be expected that proportionately lower amounts of assimilate would be allocated to stem growth than to root growth (Tilman, 1988). Shoot:root ratios were calculated on the basis of cross-sectional areas of stems and 'proximal' roots, i.e. roots arising from the base of the stem; a method described by van Noordwijk and Purnomosidhi (1995). This was the method used in a previous study to investigate allocation within rubber trees in relation to competition from various intercrops and weeds (Appendix 3.1). In that study, the assumptions on which the method was based were tested extensively, and it was found that roots of rubber trees aged 15 and 39 months conformed to a fractal branching pattern (Williams *et al.*, in press; Appendix 3.1). Ong *et al.* (1999) found that using this fractal method to quantify the total length of tree root systems worked well with the permanent structural root system (although length of fine roots was under-estimated). For that reason, the method was used in this trenching experiment to assess the effects of secondary forest regrowth on allocation within the rubber tree root system, in both large and small soil volume plots, with and without weeds.

3.1.2.3 Bioassay of nutrient limitation to rubber growth using the in-growth core technique

A bioassay of nutrient limitation to rubber growth using root in-growth cores was conducted to address Objective 3 of the thesis:

To identify the most limiting nutrient to clonal rubber growth in the clonal rubber-secondary forest regrowth environment.

<u>The root in-growth core technique</u>

A number of previous studies using this technique have been carried out in a variety of ecosystems, with various objectives and methodologies (Table 3.1). The three main uses of this technique have been:

1. To measure fine root productivity, turnover, biomass or morphology, especially with respect to seasonal variation e.g. Fabiao *et al.* (1985), Cuevas *et al.* (1991); using sequential sampling.
2. To compare root response to different treatments in field experiments e.g. Steen (1991, 1984), Hairiah *et al.* (1991).
3. To assess nutrient limitations; a form of bioassay, as is proposed here (Cuevas and Medina, 1988; Raich *et al.*, 1994).

In previous bioassay studies (Cuevas and Medina, 1988; Raich *et al.*, 1994), cores which were dosed with the nutrient for which there was the 'greatest demand', contained the greatest biomass of foraging roots at the end of the study. Because plant allocation to growth will be influenced by the relative limitation of different resources, it is assumed that root growth into a patch of a high concentration of a single nutrient will be greatest for the nutrient that was most limiting to the growth of the tree (Cuevas and Medina, 1988).

Therefore, the root ingrowth core technique could be used to diagnose specific nutrient limitations to rubber growth in the rubber-secondary forest regrowth environment, by studying relative amounts of fine root proliferation in nutrient rich microsites i.e. soil cores dosed with different nutrients.

Implementation of this study within the trenching experiment would also enable the root proliferation in response to nutrients to be compared between trees with high below-ground resource availability, and low below-ground resource availability, and also to assess the responses of weed roots to nutrient enrichment.

As the aim of this study was only to investigate the most limiting nutrient to rubber growth, sequential sampling was not conducted, as this would have effectively quadrupled the number of cores needed. Instead, a comparison of the gross root influx for the different treatments was made only once, at the end of the study period (after 20 weeks).

Table 3.1 Previous studies using the root ingrowth core technique

Author(s)	Objective of study	Bag / Cylinder	Mesh size	Core diameter	Core length	Rooting substrate	Soil depth	Treatments	Spatial position	Incubation period	Sequential sampling?	Replicates, samples/ treatment
Cuevas & Medina (1988)	Nutrient limitations to fine root growth in tropical forest ecosystem (Amazon)	C	4 mm^2	7.5 cm	10 cm	Vermiculite	0-10 cm and root mat	Cores imbibed 48 hrs in 0.1 M solutions: NH_4Cl, K_2PO_4, $CaCl_2$, river water	No info	1,2,3,4 mths	Yes	4
Raich *et al.* (1994)	Nutrient limiting factors in tropical forest ecosystem	C	3.71 mm x 1.7 mm (33% open area)	7.5 cm	10 cm	Calcined clay	1-11 cm	100 ml solutions: NH_4Cl (6.76 g/l) Na HPO_3 (8.1 g/l) KCl (1.67 g/l) $CaCl_2$ (3.28 g/l) Deionised water 40g/m^2	1 block (1 core of each treatment) placed at each of 6 positions on a 30m transect. Replicated with 5 such transects.	3,6,11 mths	Yes	10
Steen (1991)	Various experiments: response to fertiliser, soil compaction, herbicide use and seasonal dynamics (Sweden)	B	5-7 mm	7cm	50cm	Sieved soil	0-30 or 0-40 cm	Various experiments, 4-6 treatments, 4 reps of each	No specific info	Various	No info.	No info.
Steen (1984)	Effect of N, grass cutting & time on root production in a grass ley (Sweden)	B	6 mm	7cm	50cm	Sieved soil (2mm sieve)	0-30 cm	N (15.5% $Ca(NO_3)_2$) 50, 150 and 300 kg N/ha/yr; cutting: 0, twice per year. 16 reps/treatment		2,4,6 mths (with bag replacement at t=2,4,6 mths)	Yes	No info.
Hairiah (1991)	Effect of subsoil acidity on root distribution of Mucuna	B	4 mm	7cm	20cm	Soil	0-20, 20-40 cm	Subsoil & topsoil exchanged. 24 reps		3 mths	No	
Fabiao *et al.* (1985)	Variation in seasonal growth of fine roots of eucalypts (Portugal)	B	5 mm	7cm	40cm	Root free soil	0-40 cm	2 plantations: 11 yrs (sandy soil); 16 yrs (clay soil)	Cores placed 2 m from tree rows, 1 m apart.	2,4,6,12 mths (with bag replacement)	Yes	No info. 10 or 15
Cuevas *et al.* (1991)	Fine root growth in two ecosystems (Puerto Rico)	C	8 mm^2	7cm	10cm	Dry sieved soil	0-10 cm	Pinus plantation, secondary forest	20m x 20m plots used, no other info.	2,4,6,8,10, 12,18,24,30 36,42,48 mths	Yes	5

Hypotheses

1. N is the most limiting nutrient for rubber growth in this soil, when there is competition from weeds, as indicated by greater root proliferation (fine root biomass and root length density) in N-enriched soil cores, than in soil cores enriched with other nutrients.

2. Rubber trees growing in smaller volumes of soil will show a greater response of fine-root proliferation (fine root biomass and root length density) to nutrient enrichment than those growing in larger soil volumes.

3.2 MATERIALS AND METHODS

3.2.1. Trenching experiment

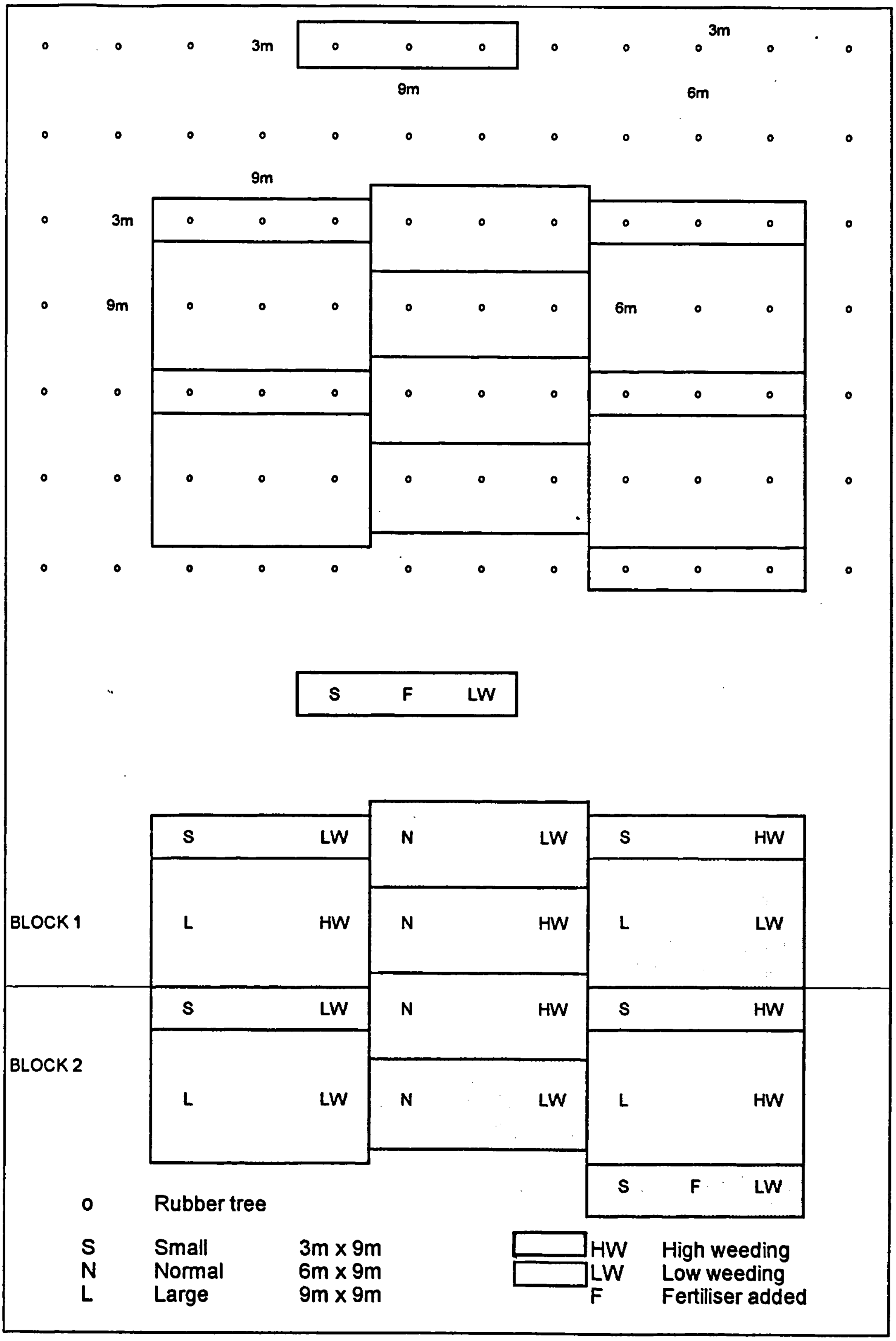
The experiment was conducted in a farmer's field in Rantau Pandan village (Figure 2.2), grid reference 1° 38' 999" S, 101° 56' 026" E, on flat land. Five years before the start of the experiment, the field had been cleared from mature jungle rubber (approximately 40 years old), and planted with upland rice. After one 6-month rice crop, the field was abandoned to secondary forest regrowth.

In April 1995, the farmer slashed the four year old secondary vegetation (which was dominated by *Chromolaena odorata* and *Melastoma malabathricum*) and then burned the field in July 1995. In November 1995 the farmer clean-weeded the field and dug the planting holes. The rubber trees (clone GT1) were planted from polybags in January 1996 at a standard planting density of 550 trees/ha, at a spacing of 6 x 3 m (3 m between trees in the rubber row). A starter dose of phosphate fertiliser (113 g TSP) was added to each planting hole, this being equivalent to 13 kg P/ha, and no further fertiliser was added.

The farmer clean-weeded the experimental area twice more in the period between planting the trees and implementation of the experimental treatments in April 1996 (see Section 3.2.1.1 below).

The experimental design consisted of two blocks, each containing one replicate of the six soil volume and weeding treatment combinations, and a single fertilised plot (Figure 3.1). In April 1997, six more replications of this experiment were implemented by ICRAF in two additional locations, however results from these are not analysed here, as only six months growth data were available.

Figure 3.1. Design of the trenching experiment, showing a) the position of each rubber tree and the trenches, and b) the experimental weeding and soil volume treatments.



3.2.1.1 Treatments

The experimental treatments were started in April 1996, when the trees had been successfully established, but before root growth had extended to the sites of the proposed trenches. Trenches were dug to 60 cm depth, lined with plastic and metal sheet, and backfilled with earth (Plate 3.1a). Trenches of different lengths created three soil volumes, as described below.

Soil volume

Surface areas of the available soil volume are quoted here, as trench depth is constant for each treatment. "Normal" is defined as the area which would be available, on average, for exploitation per tree in the standard plantation 6 m x 3 m planting arrangement. "Small" is one half of the above area, "Large" is one and a half times this (Table 3.2, Figure 3.1). The soil volume treatments were not allocated randomly due to the logistic need to minimise the length of trenches dug, this is considered further in Section 3.2.4.1.

Table 3.2. Area of available resources for each tree, and per plot

Treatment	Area per tree*			Area per plot			Normalised below-ground resources
	Length (m)	Breadth (m)	Surface area (m^2)	Length (m)	Breadth (m)	Surface area(m^2)	
'Normal'	6	3	18	6	9	54	1
'Small'	3	3	9	3	9	27	0.5
'Large'	9	3	27	9	9	81	1.5

*For practical purposes, trenches were dug around groups of three trees. Therefore 'Area per tree' describes the average area available to each of the three trees, and 'Area per plot' describes the actual size of the experimental plot containing the three trees.

Weeding Treatments

Two levels of weeding were implemented. 'High weeding' (HW) was clean weeding of the whole plot, nine times per year. 'Low weeding' (LW) was initially strip weeding 1 m either side of the rubber trees, every 3 months (from April 1996 to September 1996). The weeding treatments were allocated randomly to each soil volume plot within each block. However, after September 1996, weeding of the rubber tree row was discontinued in the LW plots, as regeneration of weeds was very slow (see Plate 3.1b which illustrates weed cover and rubber tree size, 21 months after planting the rubber trees). Thus, within each weeding treatment there was no difference in management of the 'row' and 'inter-row' areas from September 1996 onwards. The sparse weed regeneration was probably due to the fact that the farmer had clean weeded the experimental area three times between burning the plot and installation of the trenches, so it was likely that the soil seed bank was exhausted.

a

b

Plate 3.1 a) Installation of root barrier in trench four months after planting the rubber trees; b) The trenching experiment, twenty-one months after planting.

Fertilisation treatment

This consisted of one small soil volume plot per block, with the low weeding treatment, plus N fertiliser (50 g urea/tree, every three months, equivalent to 55 kg N ha^{-1} yr^{-1}).

3.2.1.2 Data collection

Rubber tree growth

Rubber tree growth was monitored every three months, for height (to the top of the stem), and stem diameter (at 10 cm above the graft). Diameter was calculated as an average of two measurements per stem, taken perpendicularly to one another.

Weed growth

Weed growth was assessed just before weeding was implemented in the high weeding plots *i.e.* at the incidence of highest weed biomass. Weeds were recorded as morphotypes (growth forms): trees, shrubs, herbs, grasses, ferns and climbers. A one metre square quadrat was used to record the percentage weed cover and average height of these growth forms, with three samples per plot, in both the low and high weeding treatments. The quadrats in the high weeding treatments were then harvested with clippers according to growth form, and fresh weights taken in the field. Samples were air dried on racks, then oven dried for 24 hours at 80°C to obtain dry weights of biomass. Weeds in the quadrats in the low weeding treatment were not harvested for determination of biomass because no weeding was implemented in this treatment after September 1996 (see Section 3.2.1.1 above), and removal of weed biomass would have affected the experimental treatments.

Soil analyses

Initial soil conditions (texture and chemical properties) were assessed in June 1996. Using a hand auger, six samples were taken at random positions in both the rubber row and inter-row (weedy) area in each plot, to a depth of 15 cm. These were pooled to give two samples per plot for analysis. The soil was air-dried on drying racks and sieved with a 2 mm sieve, then 100g samples bagged, labelled and sent away for commercial analysis at the Rubber Research Institute of Sembawa, South Sumatra. Samples were analysed for texture, pH, C_{org}, total N, $P_{Bray\ II}$, exchangeable K, Ca, Mg, Na and Al, and cation exchange capacity (CEC).

Ammonium- and nitrate-nitrogen concentrations were measured in October 1997. Six random samples per plot to 15 cm were pooled to give one sample per plot for analysis. These soil samples were wrapped in polythene bags and transported on ice in a cool-box to the field station of Universitas Brawijaya/ICRAF in North Lampung, Sumatra. They were analysed by Ir P. Purnomosidhi, using a flow-injection technique.

Soil bulk density

To compare bulk density of soils from the high and low weeding treatments, samples were taken at random in each of the 12 main treatment plots, one at 0-5 cm depth, the other at 5-10 cm depth, in October 1997. A bulk density corer of known volume (177 cm^3) was gently hammered into the ground until flush with the earth. The soil around was dug away, the core extracted and excess soil was trimmed from the base of the core using a sharp knife. The fresh weight of soil within the core was then measured. A subsample was taken, weighed and oven-dried to constant mass at 105°C. The oven-dried mass of this subsample was then found, and bulk density was calculated (Box 3.1).

Box 3.1 Calculation of soil bulk density

Fresh weight of total soil sample	= a g	
Fresh weight of soil subsample	= b g	
Proportion of water in soil subsample	$= \frac{b - \text{oven-dry weight of subsample}}{b}$	= c
Calculated dry weight of total soil sample	= (1- c) x a	= d
∴ Bulk density of oven-dried soil	= d / 177 (g cm^{-3})	

Foliar nutrient analyses

Rubber tree nutrient status was analysed in October 1997 (22 months after planting), on samples of leaves that experienced full sun conditions, and that were taken from the highest fully developed whorl of leaves on the stem (Watson, 1989c). Each of the three trees in a plot were sampled, then the leaves composited to give one sample per plot for analysis (24 samples in total). Fresh weight was taken in the field, samples were air dried and then oven dried at 80°C for 24 hours, dry weights taken, and water contents calculated. Nutrient analyses for concentrations N, P, K, Ca, Mg and Na were conducted at the Centre for Soils and Agro-Climatic Research in Bogor, Java.

Weed nutrient status in the LW treatment was also analysed in October 1997. Two randomly-placed one-metre square quadrats were harvested in each of six low-weeded plots: the two large soil volume plots, the two small soil volume plots and the two small soil volume + N plots. The harvested weeds were then separated into woody and non-woody growth forms (trees and shrubs in one sample; grasses and herbaceous weeds and climbers in the second sample). In addition, the stems of the woody species were separated from their leaves, so 18 samples were obtained in total (non-woody species, woody species' stems and woody species' leaves, with six replicates of each). These samples were processed and analysed using the methods described above for rubber tree leaves.

3.2.2 Allocation within the rubber tree

3.2.2.1 Fractal branching study

The method used in this study (van Noordwijk and Purnomosidhi, 1995), is based on the assumption that branching of tree roots follows a self-repeating or fractal pattern, and thus total root system size can be predicted from the diameters of proximal roots (the roots originating from the stem collar or tap root) (Spek and van Noordwijk, 1994; van Noordwijk *et al.*, 1994). For this to be true, the branching rules have to be the same at the origin of the root and at its distal end. Therefore the relationship between the diameter or cross-sectional area of a root before branching, and the diameters or cross-sectional areas of its branches after the branching point, should be independent of the root size.

This assumption was tested by assessing the fractal characteristics of the root branching patterns by measuring the length of links between branching points, the diameter of a root before branching (the 'parent') and the diameter of each subsequent branch (the 'offspring'), along the length of an excavated root (Plate 3.2a). Six roots were excavated from their origin to their end, from trees in both weeded and unweeded treatments. Data on individual branching points were analysed with a Genstat programme (M. van Noordwijk, pers. comm.), to test whether the rules for the change and allocation of root diameter upon branching depend on current root diameter.

3.2.2.2 Proximal root study

This study was conducted in October 1997, 22 months after planting the rubber trees. In order to compare the allocation of resources to rubber tree roots with and without competition from weeds, trees from weeded and unweeded plots in both the large and small volume treatments were excavated around the stem, as described by van Noordwijk and Purnomosidhi (1995)[17]. In practice, this involved exposing surface roots with a small trowel, then digging around and between them with a long-pronged fork. It was usually necessary for the hole to be approximately 40 cm in diameter from the stem, and 40 cm deep to expose the tap root to a depth where there were no more whorls of secondary roots branching from it (Plate 3.2b).

Diameters of the proximal roots were measured with calipers or tape, and they were classified as horizontally or vertically oriented (roots descending into the soil at angles greater than 45° were considered to be vertically oriented). Stem diameters at 1 m above the graft were also measured, to enable calculation of shoot: root ratios. Three trees from each plot were

[17] This is a non-destructive technique.

a

b

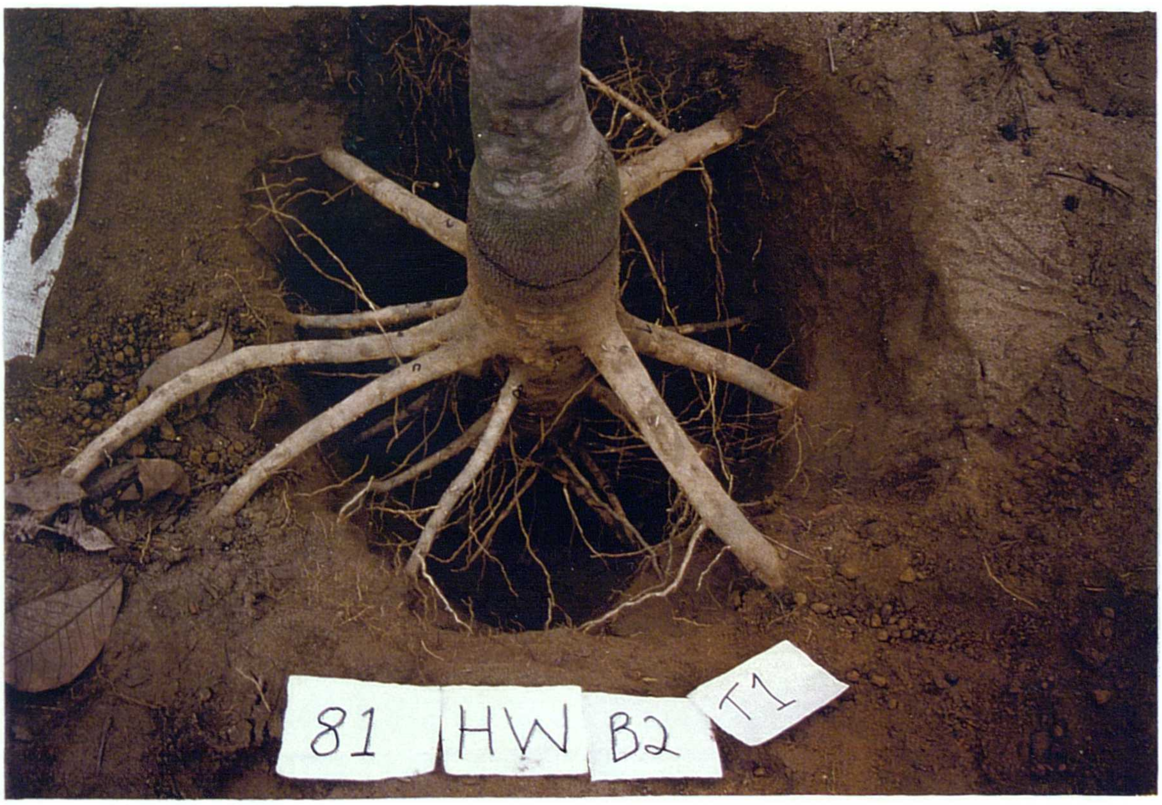


Plate 3.2 a) Excavation of lateral roots of rubber trees to test the assumptions of the fractal branching method (van Noordwijk and Purnomosidhi, 1995). Note that when the root encountered the barrier it grew along it and then turned inwards back into the plot. It did not cross the barrier. b) Excavation of proximal roots of rubber trees.

excavated, except for two trees where the presence of burned remnant stumps from the previous vegetation physically precluded this. Thus 22 trees in total were studied, 11 each from weeded and unweeded treatments, in 8 plots.

3.2.3 Bioassay of nutrient limitation to rubber growth using the ingrowth core technique

This study was implemented only in the low weeding treatment plots, in both the large and small soil volumes, and initiated 16 months after the trees were planted. Six cores of soil enclosed in mesh bags were installed around each rubber tree at a distance of one metre. Six nutrient treatments were allocated randomly to the cores, for each of the three trees in the large and small soil volume plots, in the two experimental blocks. In total, this gave 72 cores, placed around 12 trees. Each core was 30 cm in depth, and sub-divided into three 10-cm depth layers, to observe root ingrowth at 0-10, 10-20, and 20-30 cm depths.

3.2.3.1 Nutrient treatments

Nutrient treatments were chosen on the basis of rubber fertilisation recommendations for the widespread TCSDP (Tree Crop Smallholder Development Project) (Table 3.3). The total amounts of fertiliser added per tree were less than 1% of the recommended dose per tree, so fertiliser addition was not expected to have an effect on the above-ground growth of the tree.

Table 3.3. Calculation of fertiliser doses for nutrient treatments in root ingrowth cores, based on TCSDP fertiliser recommendations for rubber.

Treatment	Fertiliser/ nutrient	TCSDP recommendations (g / tree)[a]	Experimental treatments (g / core)[b]	Experimental treatments (kg / ha)[c]
1. Control 1	None		-	-
2. Control 2	None		-	-
3. N addition	Urea	60	0.500	994.6
	N	27.60	0.230	457.5
4. P addition	SP36 (TSP)	40	0.430	864.2
	P	6.33	0.068	135.3
5. K addition	KCl	25	0.210	417.7
	K	12.62	0.106	211.3
6. Ca/Mg addition	Dolomite	40	0.340	676.3
	Ca	8.82	0.075	148.8
	Mg	4.00	0.034	67.6

[a] Fertiliser applied to the rubber tree row, to a surface area of 60 000 cm^2 (3 x 2 m) per tree
[b] TCSDP recommendations per tree were scaled down to the surface area of the ingrowth core (50.27 cm^2), then increased by a factor of ten to ensure a response (M. van Noordwijk, pers. comm.).
[c] Fertiliser quantities (g/core) scaled up to kg/ha

3.2.3.2 Core installation

Soil cores were taken at six positions around each tree with a 7.5 cm diameter x 10 cm deep corer, to a depth of 30 cm (i.e. three 10 cm-depth cores were required to create each hole). Each 10 cm soil layer was bagged and labelled and weighed separately. Soil samples were air dried and sieved with a 2 mm mesh sieve to remove all roots. Each sieved soil sample was weighed. For each soil sample (each 10 cm depth or 'layer') all soil was mixed, then reweighed into original sample bags, to ensure that the same mass of soil would be replaced in each hole in the field, and bulk density would be the same as the original sample.

Nutrient doses were calculated per layer (i.e. one third of a core), fertiliser weighed out, ground with a pestle and mortar, then mixed evenly through each soil sample. The urea dose in the N addition treatment was split: half was applied at core installation, the remainder was applied as ureum solution, injected into the cores halfway through the experimental period, to avoid problems of negative osmotic effects, and possible leaching (M. van Noordwijk, pers. comm.).

The mesh bags were created from plastic fishing net of mesh size 4 mm x 4 mm, and hand sewn with nylon thread to give cylinders of 7.5 cm diameter, and 35 cm length. In addition, two pieces of plastic string were sewn perpendicularly to each other, down the side of each bag, across the bottom, and up the opposite side, to aid in the lifting process at the end of the experiment. These bags were installed in the holes using plastic drainpipe, then each 10 cm layer of soil was replaced in 5 cm increments, corresponding to a thin measuring stick placed in the hole. Each 5 cm layer was compacted with a wooden rod, then the soil surface roughened slightly before the next layer was added (Steen, 1984). To mark the boundaries of each of the three 10 cm layers, a circle of plastic sheet perforated with pinholes (to allow drainage) was placed at 20 and 10 cm depths. In the N treatments, small diameter plastic tubes were also installed from each layer to the soil surface, to allow subsequent injection of ureum solution (Rowe, 1999), then the open ends capped with plastic. Cores were installed between 24 and 25 May, 1997.

3.2.3.3 Core lifting and processing

Cores were lifted between 8 and 15 October 1997, giving an incubation time of 20 weeks. A combination of careful excavation with long-handled, chisel-like tools and lifting was used, with ingrowing roots being cut with sharp scissors, to ensure roots were not dragged out of the mesh bags. After lifting, cores were placed in sealed polythene bags on ice in a cool-box, and transported to the ICRAF field office where they were stored in a refrigerator until they were washed out (the longest storage time being two days).

Cores were washed out by firstly dividing them into their three constituent layers, which had been separated by plastic discs (root growth through the disks was found to be negligible). The three samples from each core were then soaked in water in colour-coded buckets for approximately one hour before they were washed out over a series of sieves, using a hand spray. Rubber and weed roots were separated, double checked by another team, then blotted and fresh weights taken. Separation was relatively easy[18], as fine roots of rubber are unsuberised and a pale yellowish colour, and mini-rhizotron photographs of rubber and weed roots could be consulted, in case of doubt. Root length density for all rubber root samples, and a sub-sample of weed roots were assessed with the line intersection method (Tennant, 1975), then air dried. All samples were shipped to Bangor, oven-dried, and their dry weights determined in November 1997.

3.2.4 Data analysis

3.2.4.1 Trenching experiment

<u>Rubber tree growth</u>

As the soil volume treatments were not randomly allocated, due to the logistics of trench construction, one of the assumptions of ANOVA (random allocation of treatments) did not appear to be satisfied. However, a statistical expert was consulted when designing the experiment, and two analyses were suggested that could prove that tree growth in adjacent plots was not related to tree or plot position (R. Coe, pers. comm[19].).

Each tree was assigned co-ordinates based on its 'horizontal' and 'vertical' distance (in metres) from a point of origin 0,0 (Figure 3.2). In the first analysis, a two-way ANOVA was conducted on rubber tree size (21 months after planting), with treatments soil volume and weeding, and two covariates: vertical and horizontal distance. The effect of the covariates was not significant ($p = 0.213$), which demonstrated that there were neither horizontal nor vertical trends influencing rubber tree growth in the area where the experiment was laid out. This finding was confirmed by a second analysis, where the residuals from a two-way ANOVA on rubber tree size, with treatments soil volume and weeding were plotted firstly against the horizontal co-ordinates of each tree, and secondly against the vertical co-ordinates of each tree. There were no patterns observed in these plots of residuals (Figure 3.3). This indicated that any variation in rubber tree growth that had not been accounted for by the ANOVA, was not related to either the horizontal or vertical co-ordinates of the trees in the experiment.

---

[18] Soong (1976) found that average diameter of tips of fine roots of rubber was 1.06 mm, and ranged from 0.8 to 1.2 mm. That author also stated that "the roots were so distinct in character that they could be distinguished from other types of roots without much difficulty".

[19] Dr Richard Coe is the senior biometrician at ICRAF headquarters in Nairobi, Kenya. This approach was further refined in discussions with Dr Savitri Abeysekera, from the Statistical Services Centre, University of Reading, UK.

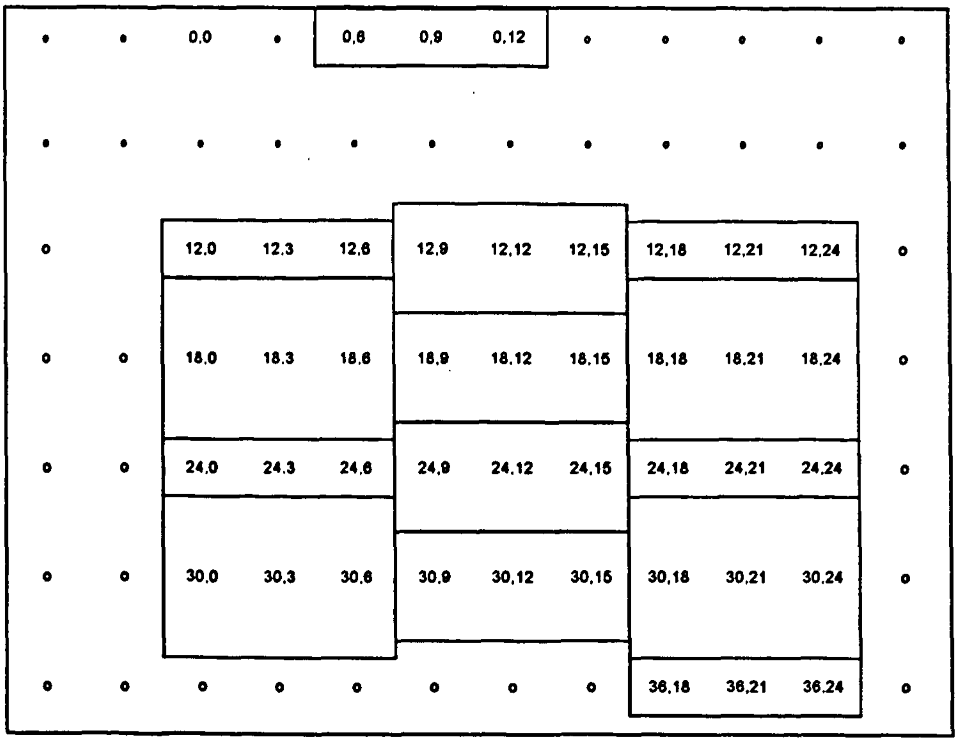


Figure 3.2 Assignment of co-ordinates to each tree position within the experiment, based on 'horizontal' (left to right across the page) and 'vertical' (top to bottom of page) distances from the origin (0,0), in metres.

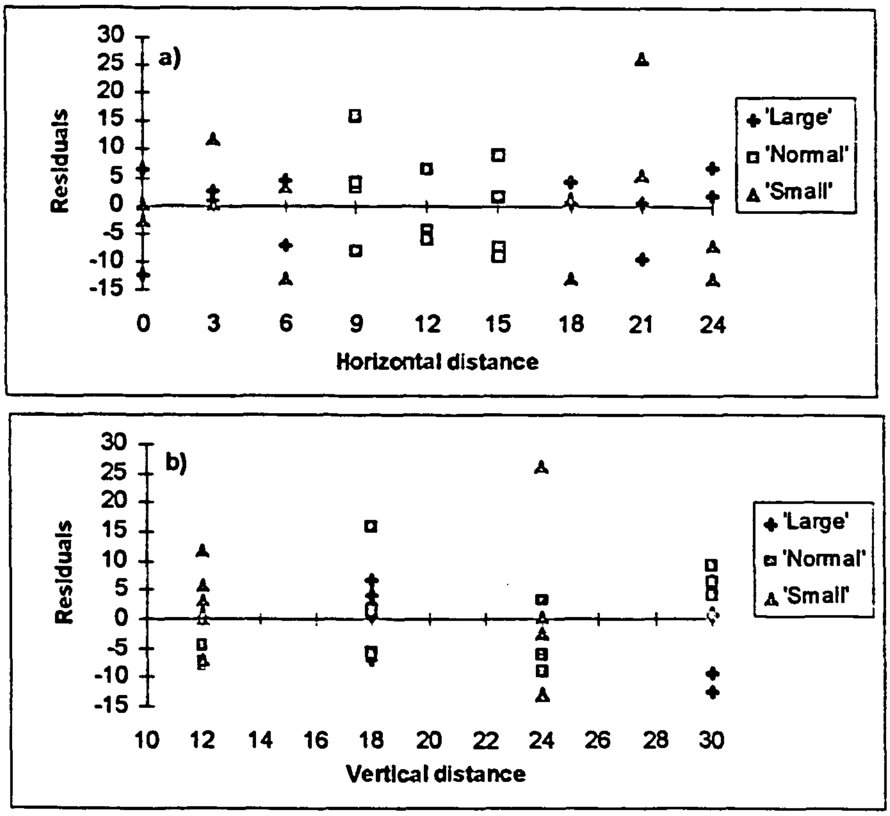


Figure 3.3 Residuals from a two-way ANOVA on rubber tree size (trunk volume), with soil volume and weeding treatments, in relation to spatial position of trees a) horizontally, and b) vertically, within the experimental area.

Data were also inspected for normality and homogeneity of variance, and as all assumptions of ANOVA were then found to be satisfied, two-way ANOVAs of the effects of the soil volume and weeding treatments and their interaction were conducted on plot means for tree height, diameter at 10 cm above the graft, and the variable 'trunk volume' (height multiplied by the square of the stem diameter) which would give an indicator of total tree size. Statistical analysis was with Genstat 5.32 for Windows, and the structure of the two-way ANOVA was:

Source of variation	Degrees of freedom (d.f.)
Block stratum	1
Treatments	
Weeding	1
Soil volume	2
Interaction	
Weeding x soil volume	2
Error	5
Total	11

Weed growth

Water contents of weed biomass were not calculated, as fresh weights in the field were not deemed to be reliable. This was because there was large variability in the time elapsing between sample harvest and weighing, and thus the time the cut samples had been left in the sun. Weed percentage cover and dry weights were analysed graphically to assess weed development over time.

Soil analyses

Soil bulk density data, and soil ammonium- and nitrate-nitrogen concentrations (21 months after planting) were subjected to two-way ANOVA (with the structure above) to assess the effect of soil volume and weeding treatments on these variables.

Foliar nutrient and water analyses

Foliar water and nutrient contents of rubber trees were not analysed statistically, due to an error in sampling, where leaf samples were not collected from high-weeded, small soil volume plots. Water contents and nutrient concentrations of weeds in the low-weeding treatment were analysed to investigate whether the soil volume treatments had affected these variables by the end of the 21-month experimental period, and whether these variables differed between woody and non-woody growth-forms, using two-way ANOVA:

Source of variation	Degrees of freedom (d.f.)
Block stratum	1
Treatments	
Weed type	2
Soil volume	2
Interaction	
Weed type x soil volume	4
Error	8
Total	17

3.2.4.2 Root allocation

The assumptions of the fractal branching model were tested using a Genstat 5.32 programme (M. van Noordwijk, pers comm.). For the proximal root study, two-way ANOVA was conducted on the numbers and total cross-sectional areas of horizontally and vertically oriented roots, and shoot: root ratio (on a cross-sectional area basis) for different soil volume and weeding treatments.

3.2.4.3 Bioassay of nutrient limitation to rubber growth using the ingrowth core technique

ANOVA was conducted on log-transformed dry weights of rubber and weed roots, to assess the effects of different soil volumes, nutrient treatments, and soil depths.

3.3 RESULTS

3.3.1. Trenching experiment

3.3.1.1 Characterisation of soil properties

The soils in the experimental plots were acidic, with pH (H_2O) 5.1, although aluminium saturation[20] was only around 16% (Tables 3.4 and 3.5). Concentrations of P and exchangeable cations were low, indicating a soil unsuitable for growing food crops, but suitable for rubber (Watson, 1989a). Variation between plots for values of P_{Bray} were confirmed by resampling, and could possibly have arisen from localised variation in burning. The soil was classified as a sandy loam, according to the USDA textural classification.

Table 3.4 Physical and chemical properties of soil (three months after planting), at 0-15 cm depth.

Variable	Units	Mean[1]	SE
pH (H_2O)		5.11	0.168
C_{Org}	%	2.16	0.173
N (Total)	%	0.08	0.004
P Bray	mg kg^{-1}	9.63	1.209
K	$cmol_e\ kg^{-1}$	0.31	0.067
Na	$cmol_e\ kg^{-1}$	0.06	0.017
Ca	$cmol_e\ kg^{-1}$	2.36	0.462
Mg	$cmol_e\ kg^{-1}$	0.49	0.064
CEC	$cmol_e\ kg^{-1}$	3.47	0.237
Al	$cmol_e\ kg^{-1}$	0.44	0.078
H	$cmol_e\ kg^{-1}$	0.16	0.019

Texture	
Sand	75%
Clay	13%
Silt	12%

[1]Mean values for each variable calculated from individual plot means(Table 3.5); standard errors of the means are shown in parentheses.

[20] The sum of Al and H concentrations, expressed as a percentage of the total concentrations of Al, H, K, Na, Ca and Mg

Table 3.5 Initial soil conditions (0-15 cm depth) in each experimental plot, three months after planting

Block	Plot size[1]	Weeding	Fertiliser	Row / Inter-row	pH (H_2O)	C_{org} %	N (Total) %	P (Bray) ppm	K	Na	Ca	Mg	CEC	Al	H
										cmol$_c$ kg^{-1}				cmol$_c$ kg^{-1}	
1	S	Low	-	I	5.02	1.90	0.11	36.10	0.40	0.01	2.00	0.56	3.56	0.36	0.26
1	S	Low	-	R	4.83	2.29	0.11	9.03	0.30	0.00	1.32	0.63	4.68	0.72	0.25
1	S	Low	+ N	I	5.31	2.34	0.10	5.00	0.35	0.06	2.43	0.68	3.61	0.46	0.00
1	S	Low	+ N	R	4.93	2.38	0.10	5.00	0.31	0.16	3.76	0.59	3.47	0.16	0.54
1	S	High	-	I	5.09	1.51	0.07	5.32	1.64	0.01	1.91	0.58	5.65	0.37	0.18
1	S	High	-	R	5.61	2.25	0.08	6.89	0.52	0.01	3.54	0.91	5.77	0.00	0.19
1	N	Low	-	I	5.32	2.11	0.09	5.00	0.32	0.12	2.72	0.72	2.60	0.00	0.26
1	N	Low	-	R	5.24	2.33	0.07	8.00	0.35	0.30	2.34	0.64	3.35	0.27	0.17
1	N	High	-	I	5.10	2.23	0.06	7.00	0.30	0.10	1.45	0.48	2.95	0.44	0.08
1	N	High	-	R	5.53	3.20	0.11	13.00	0.34	0.11	3.01	0.72	3.25	0.00	0.36
1	L	Low	-	I	6.20	2.23	0.09	11.00	0.35	0.01	4.40	0.79	3.49	0.00	0.17
1	L	Low	-	R	6.52	1.75	0.09	6.00	0.31	0.00	5.52	0.96	4.84	0.00	0.26
1	L	High	-	I	4.32	2.48	0.06	12.00	0.16	0.00	1.86	0.36	3.74	0.62	0.08
1	L	High	-	R	4.59	2.10	0.07	9.00	0.17	0.09	1.07	0.27	2.54	0.79	0.08
2	S	Low	-	I	4.45	1.41	0.06	3.23	0.05	0.01	0.94	0.14	3.94	0.90	0.18
2	S	Low	-	R	4.57	1.73	0.06	3.12	0.16	0.04	0.98	0.14	3.68	1.05	0.07
2	S	Low	+ N	I	4.66	1.63	0.07	10.00	0.45	0.11	1.33	0.31	2.63	0.62	0.13
2	S	Low	+ N	R	4.87	1.69	0.07	11.00	0.18	0.18	1.61	0.33	2.66	0.45	0.08
2	S	High	-	I	5.69	2.73	0.08	10.00	0.52	0.04	4.17	0.72	2.61	0.09	0.17
2	S	High	-	R	7.29	5.42	0.10	7.00	0.40	0.03	9.97	0.91	4.05	0.00	0.00
2	N	Low	-	I	4.76	1.73	0.07	12.00	0.12	0.10	1.26	0.37	3.42	0.66	0.03
2	N	Low	-	R	4.66	1.79	0.12	10.00	0.14	0.10	0.88	0.24	3.88	0.75	0.04
2	N	High	-	I	4.57	1.85	0.06	11.00	0.16	0.01	1.65	0.34	2.79	0.61	0.08
2	N	High	-	R	4.60	1.85	0.07	8.00	0.15	0.00	0.98	0.29	3.72	0.70	0.25
2	L	Low	-	I	5.27	1.43	0.06	12.00	0.10	0.00	1.62	0.29	2.94	0.26	0.09
2	L	Low	-	R	4.61	1.61	0.07	10.00	0.09	0.02	0.85	0.17	3.78	1.05	0.08
2	L	High	-	I	4.86	2.13	0.09	12.00	0.15	0.14	1.40	0.31	1.04	0.53	0.26
2	L	High	-	R	4.70	2.35	0.08	12.00	0.18	0.02	1.22	0.26	2.50	0.44	0.08

3.3.1.2 Characterisation of weed growth over time

Cover, height and abundance of growth-forms

There were clear differences between the high and low weeding treatments in terms of percentage cover (Figure 3.4a and 3.4c; note the different scales on the axes), and also the change in abundance of the different weed growth-forms over time. Percentage cover of herbs declined rapidly with time, most markedly in the high weeding treatment plots (Figure 3.4a), while percentage cover of grasses increased with time, notably in the low weeding treatment plots (Figure 3.4c). Cover of climbers in this treatment also increased with time, relative to the high weeding treatments.

Height growth of weeds followed the same general trends as percentage cover (Figure 3.4b and 3.4d), with a decrease in height of herbs over time in both the high and low weeding treatments. In the low weeding treatments, heights of grasses and trees were greater than in the high weeding treatment, which was of course due to the six-weekly slashing back of all regenerated vegetation in the latter treatment, and no cutting after July 1996 in the low weeding treatment. The decline in height of grasses (Figure 3.4d) could have been due to wilting in the severe El Nino dry season between May and November 1997. The peak in shrub height in March 1997 in the low weeding treatment (Figure 3.4d) is most likely due to the chance inclusion of particularly tall individuals at this sampling occasion, as a result of the random positioning of quadrats.

What is important is that the percentage cover of woody growth-forms (trees and shrubs) was very low, and average height of these did not exceed 40 cm. Therefore, the vegetation that regenerated in this experiment is not representative of the secondary forest regrowth commonly found in the study area. As the dominant growth-form was grass, of average height 40 cm (in March 1997, the greatest average height recorded), the effect on rubber trees of above-ground competition for light from weeds was assumed to be negligible.

Species composition

The most common species in the 'grass' category of growth-forms (Section 2.2.2) were *Paspalum conjugatum, Panicum repens*, and *Axonopus compressus* (pers. obs.). Small clumps (two to three individual stems) of *Cyperus rotundus* occurred occasionally throughout the plots. *Ageratum conyzoides* and *Crassocephalum crepioides* were by far the most abundant species in the 'herb' growth-form, and *Mikania micrantha* was the only species of climber present in the plots. No ferns occurred in the plots. In the 'tree' growth-form, the few individuals which established were *Trema orientalis* and *Mallotus* spp. Likewise, for 'shrubs' the only species present were *Melastoma malabathricum, Blumea balsamifera* and *Chromolaena odorata*.

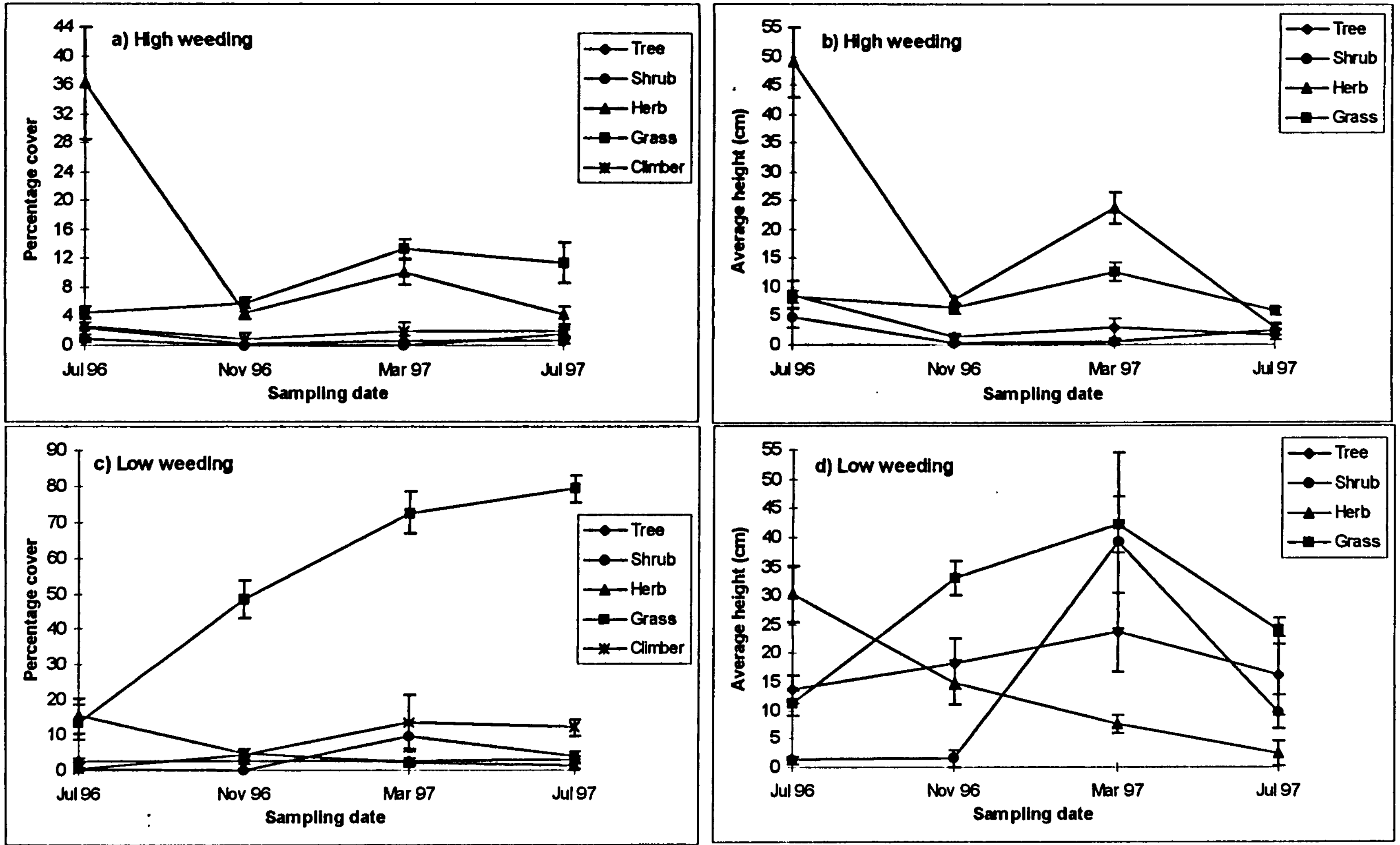


Figure 3.4 Weed abundance and height over time, for each growth form: a) percentage cover, high weeding treatments; b) average height (cm), high weeding treatments; c) percentage cover, low weeding treatments; d) average height (cm), low weeding treatments. Each treatment mean presented is the average of six plot means (these plot means derived from three 1 m^2 samples per plot); standard errors of treatment means also shown.

Weed biomass (high weeding treatment)

Total oven-dry biomass of weeds in the high weeding treatment plots increased in the period between November 1996 and March 1997 (Figure 3.5); this increase corresponding with the wet season. Similarly, the decline in the period March to July 1997 coincided with the dry season. The high initial biomass in the small soil volume plot in Block 1 was due to the very high cover of herbs which had established there after burning, but after these were weeded, in subsequent measurements, values for this plot followed the same general trend as the other plots. Overall, the weed biomass that regenerated in the six weeks between weeding events in this high weeding treatment was very small (ranging from 1.5 to 15 g m^{-2}), and thus effects on rubber tree growth were likely to be negligible.

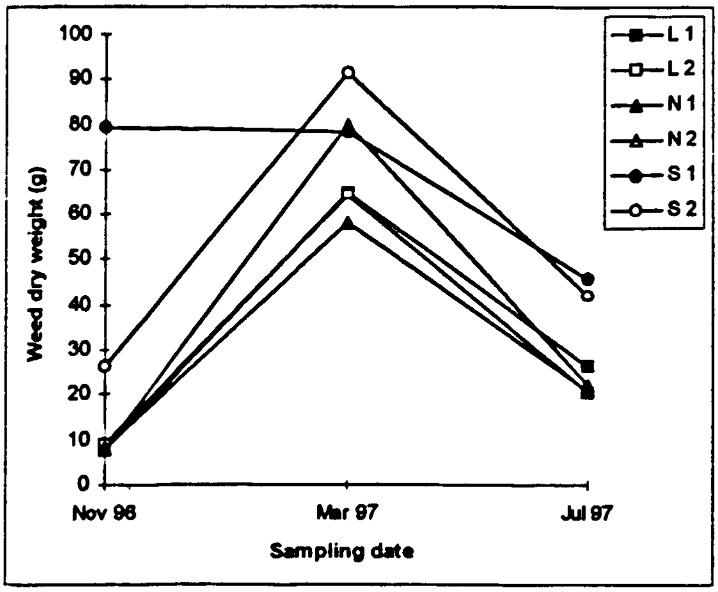


Figure 3.5 Changes in dry weed biomass over time in each high weeding plot (dry weights, in grams, of all weed growth-forms in a total sampled area of 6 m^2 per plot). 'L', 'N' and 'S' represent the large, normal and small soil volume plots respectively; '1' and '2' denote block number. November 1996, March 1997 and July 1997 correspond to 11, 15 and 19 months after planting the rubber trees.

3.3.1.3 Rubber tree growth

Effect of weeding and soil volume treatments on rubber tree growth

There was no significant effect of weeding on rubber tree height, at any of the six measurement occasions. Rubber tree diameter and the calculated variable 'trunk volume' (height multiplied by the square of the diameter) were significantly greater in the high weeding treatments than in the low weeding treatments ($p<0.05$, two-way ANOVA), at the measurements conducted at 18 and 21 months after planting (Figure 3.3). These measurement times coincided with the extended El Nino dry season of 1997 (Section 2.1.1).

The effect of the soil volume treatments was not significant for any rubber tree growth parameter, at any of the measurement times. The interaction between soil volume and weeding treatments was also not significant.

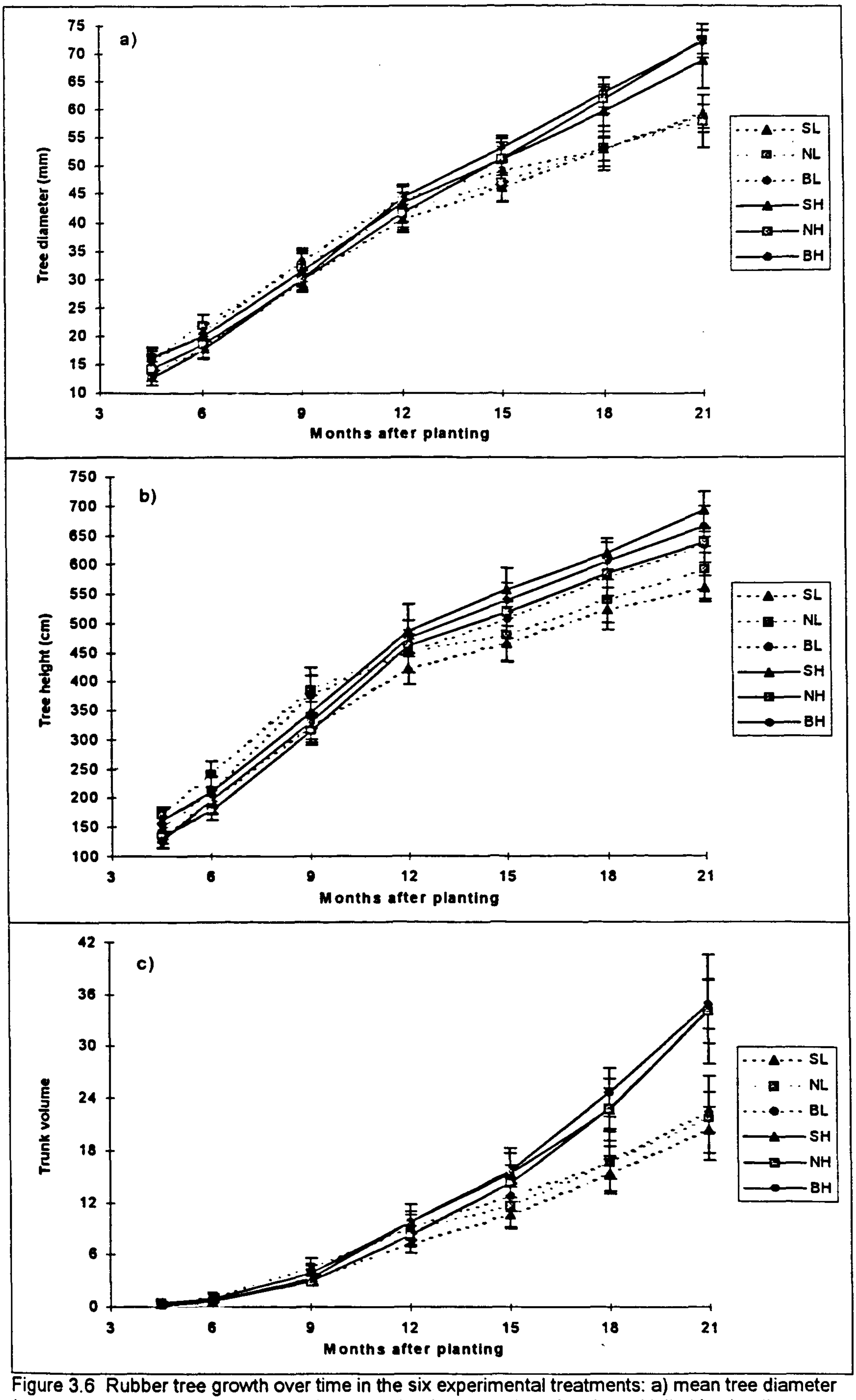


Figure 3.6 Rubber tree growth over time in the six experimental treatments: a) mean tree diameter (mm), b) mean tree height (cm), and c) mean trunk volume (tree height multiplied by the diameter square, divided by 100 000). 'S', 'N' and 'B' are 'small', 'normal' and 'large' soil volumes; 'L' and 'H' are 'low' and 'high' weeding treatments. Error bars denote the standard error of the mean.

Effect of N-fertilisation on rubber tree size, 21 months after planting

One-way analysis of variance[21] on rubber tree size (21 months after planting) in the small soil volume plots was conducted to assess the effect of weeding and the addition of N fertiliser on tree growth in these plots where the available below-ground resources had been most restricted. The three treatments used in the comparison were high weeding, low weeding, and low weeding plus N. Treatment effects were significant for tree height and trunk volume ($p<0.05$), but not significant for tree diameter (Figure 3.7).

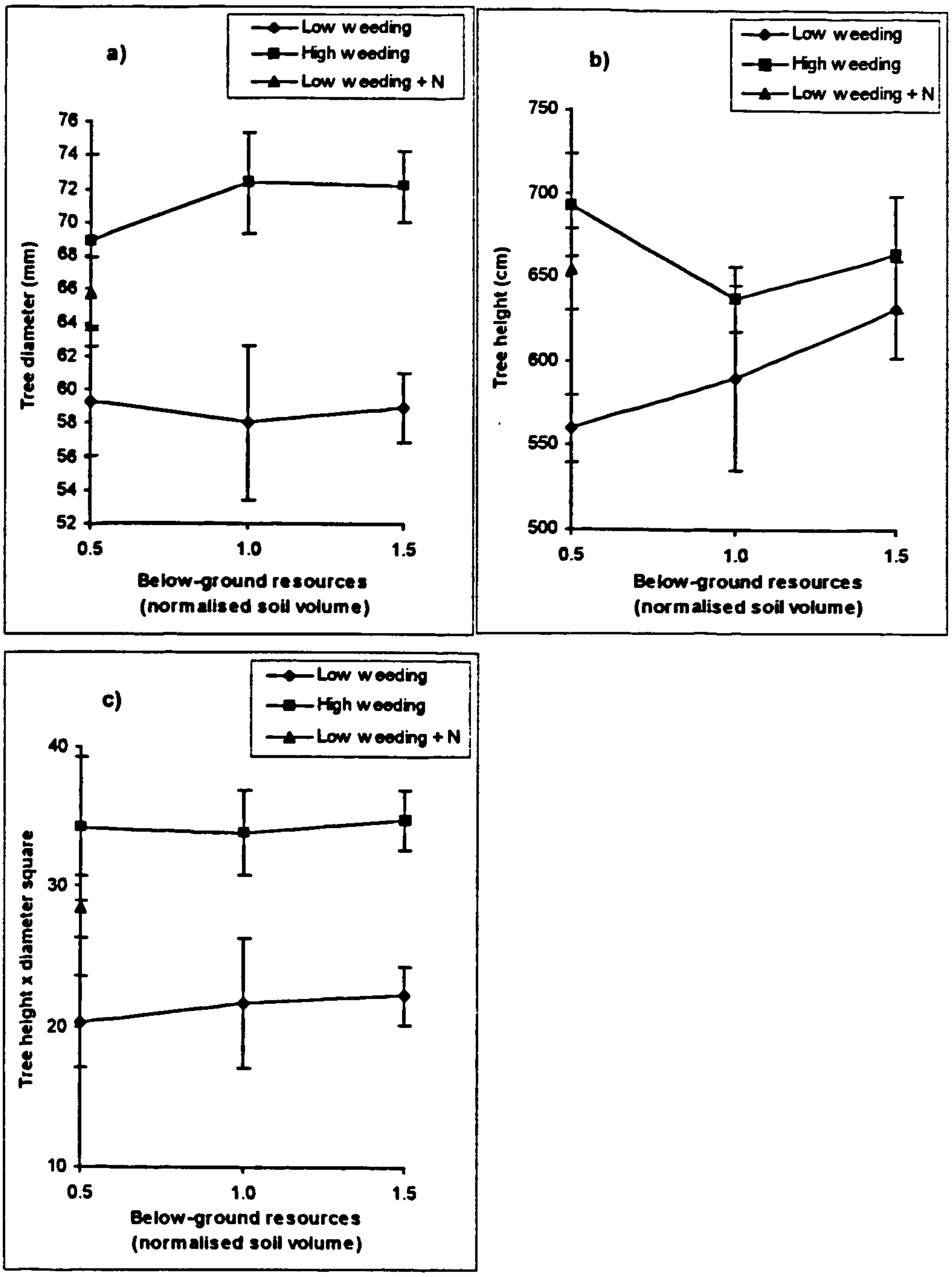


Figure 3.7 Rubber tree size (21 months after planting) in relation to below-ground resources (soil volume) and weeding treatments: a) tree diameter (mm), b) tree height (cm), and c) trunk volume (tree height multiplied by the square of tree diameter, divided by 100 000). Error bars denote the standard error of the mean.

[21] ANOVA on plot means, with no block structure as between-block differences were not significant

For tree height and trunk volume, the means of the low weeding plus N treatments were significantly greater than the low weeding, no N treatments ($LSD_{0.05}$), but not significantly different from the high weeding treatments. Thus addition of nitrogen resulted in significantly greater rubber tree height and trunk volume of low-weeded trees relative to unfertilised low-weeded trees, reaching levels comparable with high-weeded trees (at least for the six trees per treatment in this experiment).

Figure 3.7 also shows that for tree height, weeding had a much bigger effect in the small soil volume plots than in the other soil volumes, although this was not the case for tree diameter (at 21 months after planting).

3.3.1.4 Effects of experimental treatments on below-ground resources

Soil nitrate- and ammonium-nitrogen status (21 months after planting)

The effect of weeding on soil nitrate-nitrogen was significant ($p<0.01$; two-way ANOVA), with lower concentrations in the low weeding treatments (Figure 3.8), probably due to greater nitrogen uptake by weeds in these plots. The effect of soil volume on soil nitrate-nitrogen, however, was not significant, and neither was the interaction between the two treatments.

There were no significant differences between weeding treatments, or between soil volume treatments for soil ammonium-nitrate concentrations, nor was the interaction significant (two-way ANOVA). This may have been due to the greater buffering of ammonium-nitrogen in the soil, compared with the more mobile nitrate form (PPI, 1995).

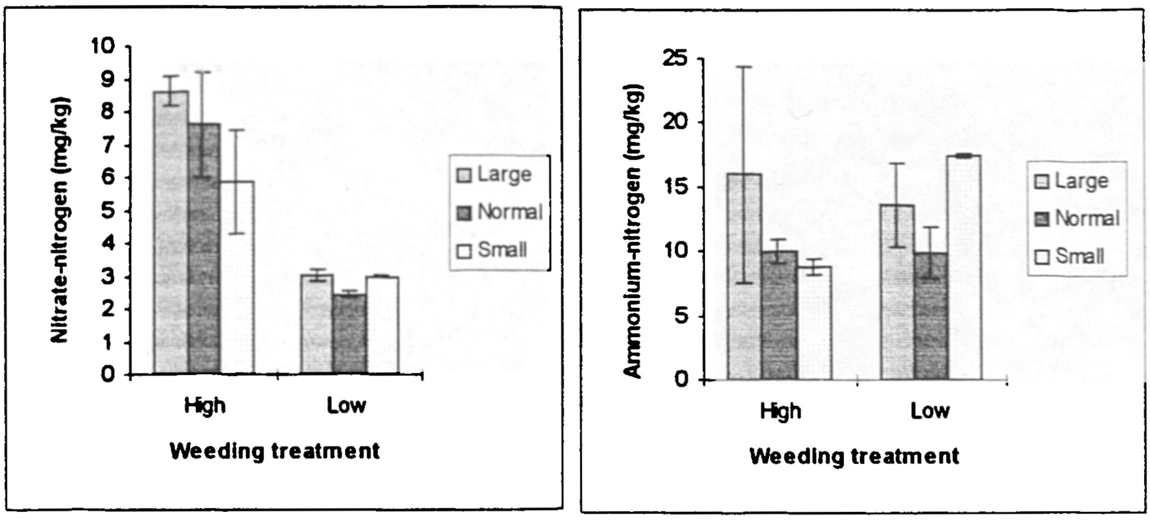


Figure 3.8 Soil nitrogen concentrations in weeding and soil volume treatments, 21 months after planting: a) nitrate-nitrogen (mg kg^{-1}) and b) ammonium-nitrogen (mg kg^{-1}). Means of two replicate plots per treatment, and standard errors of the means are displayed.

Soil bulk density (21 months after planting)

The range of values obtained for soil bulk density was considerable (between 0.8 and 1.3 g cm^{-3}), however, these values are unlikely to be a major limitation to rubber growth (Watson, 1989a). Bulk density was significantly higher ($p<0.01$) at the lower soil depth (Figure 3.9).

There were no clear trends of individual experimental treatments on bulk density, as seen by the significant interaction between soil volume and weeding ($p<0.05$). Bulk density was higher in the high weeding treatments for the large and small soil volumes (but not for the normal sized soil volume). In the low weeding treatments, bulk density decreased through the large, normal and small soil volumes, in contrast to the high weeding treatments where bulk density was highest in the large volumes, lowest in normal-sized volumes, and intermediate in the small soil volume treatment.

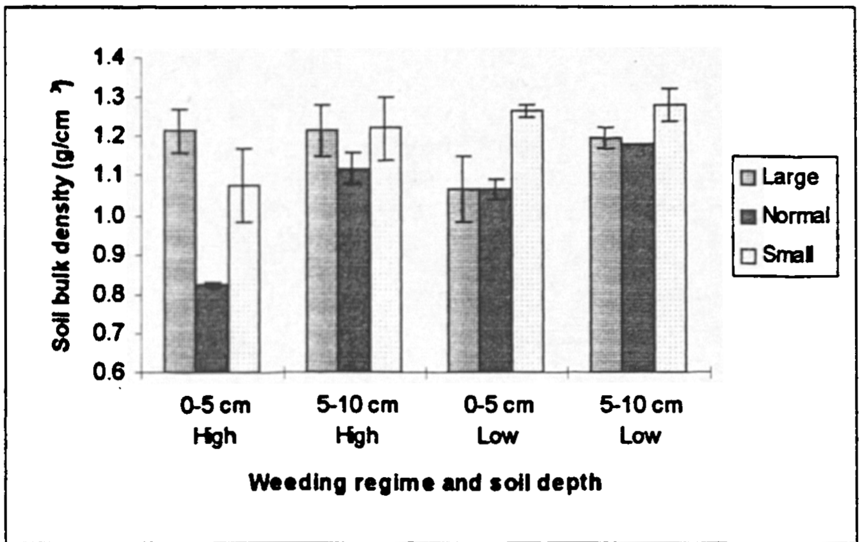


Figure 3.9 Soil bulk density in g cm^{-3} at 0-5 cm and 5-10 cm depths, for weeding and soil volume treatments, 21 months after planting. Means of two replicate plots per treatment, and standard errors of the means are presented.

Soil water content (21 months after planting)

There were no significant differences between soil water contents in the different soil volume treatments. Soil water content was significantly higher ($p<0.01$) at the lower soil depth than in the upper layer (Figure 3.10), possibly due to evaporation from surface layers, or to uptake by shallow roots of weeds and/or rubber trees. Support for the former explanation is provided by the fact that significantly higher ($p<0.01$) soil water contents were observed in the low weeding treatments than in the high weeding treatments. This could be due to lower evaporation rates where soil temperatures were reduced as a result of shading from weeds (see Section 4.3.2.3).

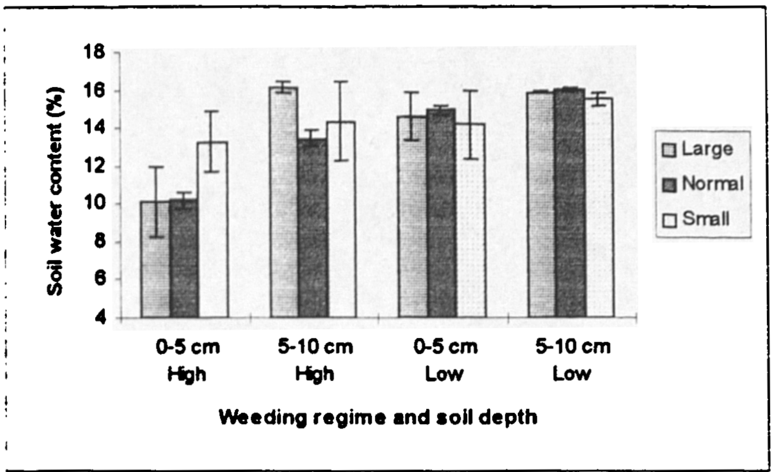


Figure 3.10 Soil water content (%) in relation to weeding and soil volume treatments, for two soil depths (0-5 cm and 5-10 cm). Means of two replicate plots per treatment , and standard errors of the means are presented.

3.3.1.5 Effect of experimental treatments on foliar nutrient and water contents of rubber trees and weeds (21 months after planting)

Rubber tree foliar water contents

No statistical analyses were conducted on rubber tree foliar water concentrations due to an error in sampling, where leaf samples were not collected from the small soil volume/high weeding treatment combination, but inspection of Figure 3.11 shows no obvious differences which could be attributed to the soil volume treatments, or to the weeding treatments.

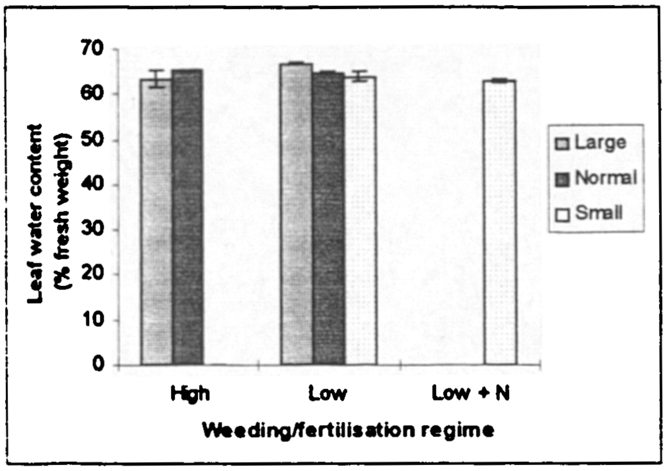


Figure 3.11 Rubber tree leaf water content (% of fresh weight), for soil volume, weeding and fertilisation treatments, 21 months after planting. Means and standard errors of two replicate plots per treatment are presented.

Rubber tree foliar nutrient contents

Analysis of variance on foliar nutrient concentrations was not conducted (as above). Results of the foliar nutrient analyses are presented in Figure 3.12. A trend was observed where foliar concentrations of N and P in the low weeding treatment were higher in the large soil volume treatment than in the two smaller soil volumes (which had lower total below-ground resources), but this has not been proved to be statistically significant. The addition of N fertiliser to trees in the additional small soil volume, low weeding plots did not appear to have increased foliar N concentration relative to any of the other treatments.

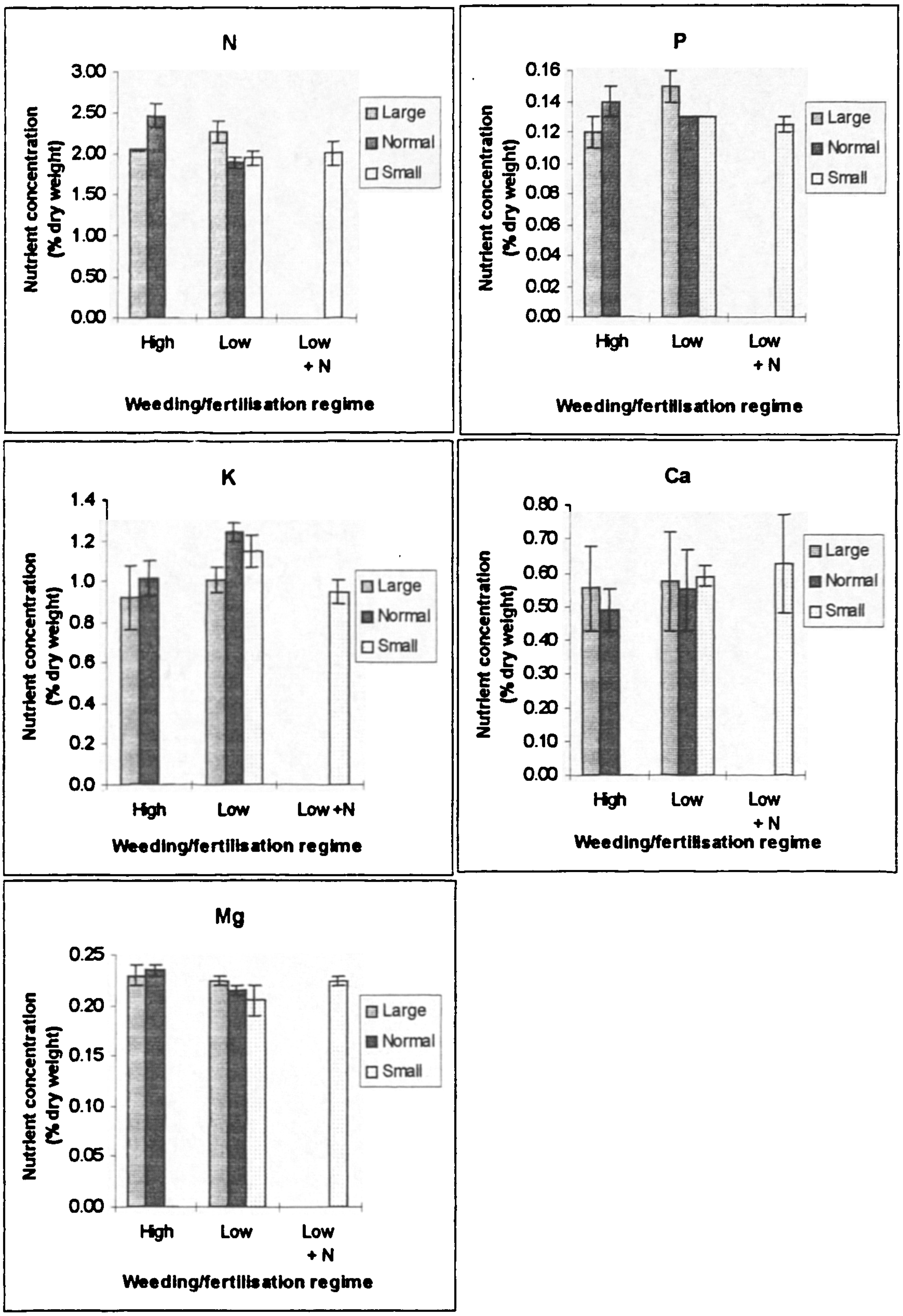


Figure 3.12 Foliar nutrient concentrations in rubber tree leaves (expressed as percentage dry weights), for high and low weeding treatments, and nitrogen fertiliser treatment (mean and standard errors of two replicate plots per treatment are presented).

Weed water contents

The results of ANOVA showed that there were no significant differences between soil volume treatments, or between weed type (plant parts), in terms of the water contents of weeds (Figure 3.13). The soil volume x weed type interaction was also not significant.

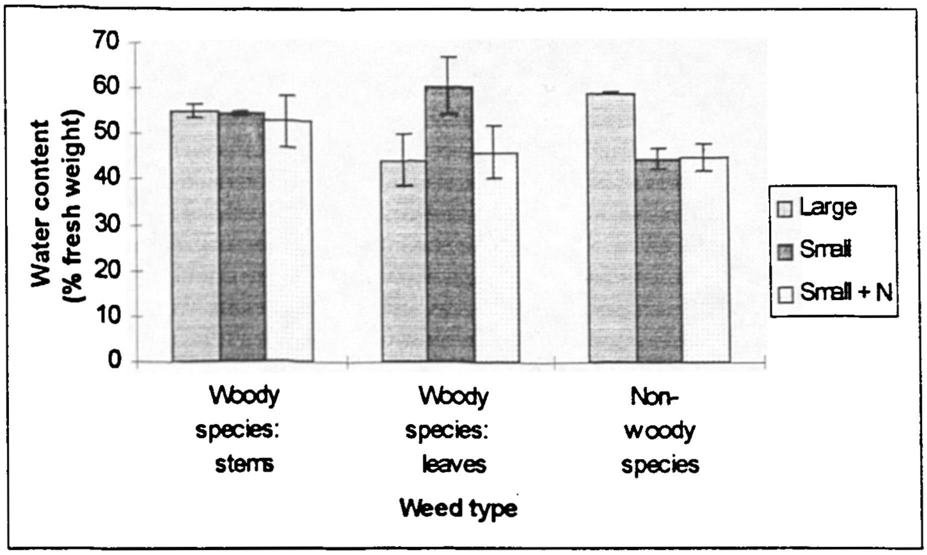


Figure 3.13 Water contents (% of fresh weight), of weed types: woody perennials (stems and leaves) and non-woody species (whole plants), in different soil volume treatments. Water contents were determined for composite samples of weeds harvested from 3 randomly placed quadrats per plot, and the figures presented here are the means and standard errors of values for two plots (one from each replicate block), for the low weeding treatments only.

Weed nutrient contents

ANOVA results showed no significant differences between soil volume treatments, for any of the nutrients (Figure 3.14). However, significant differences were found between weed types (plant parts) for N ($p<0.01$), P ($p<0.01$), Ca ($p<0.05$) and Mg ($p<0.05$); in all cases the leaves of the woody species had significantly higher concentrations of these nutrients than both the stems of the woody species, and the non-woody species (whole plants). In no case was the interaction between soil volume and weed type significant.

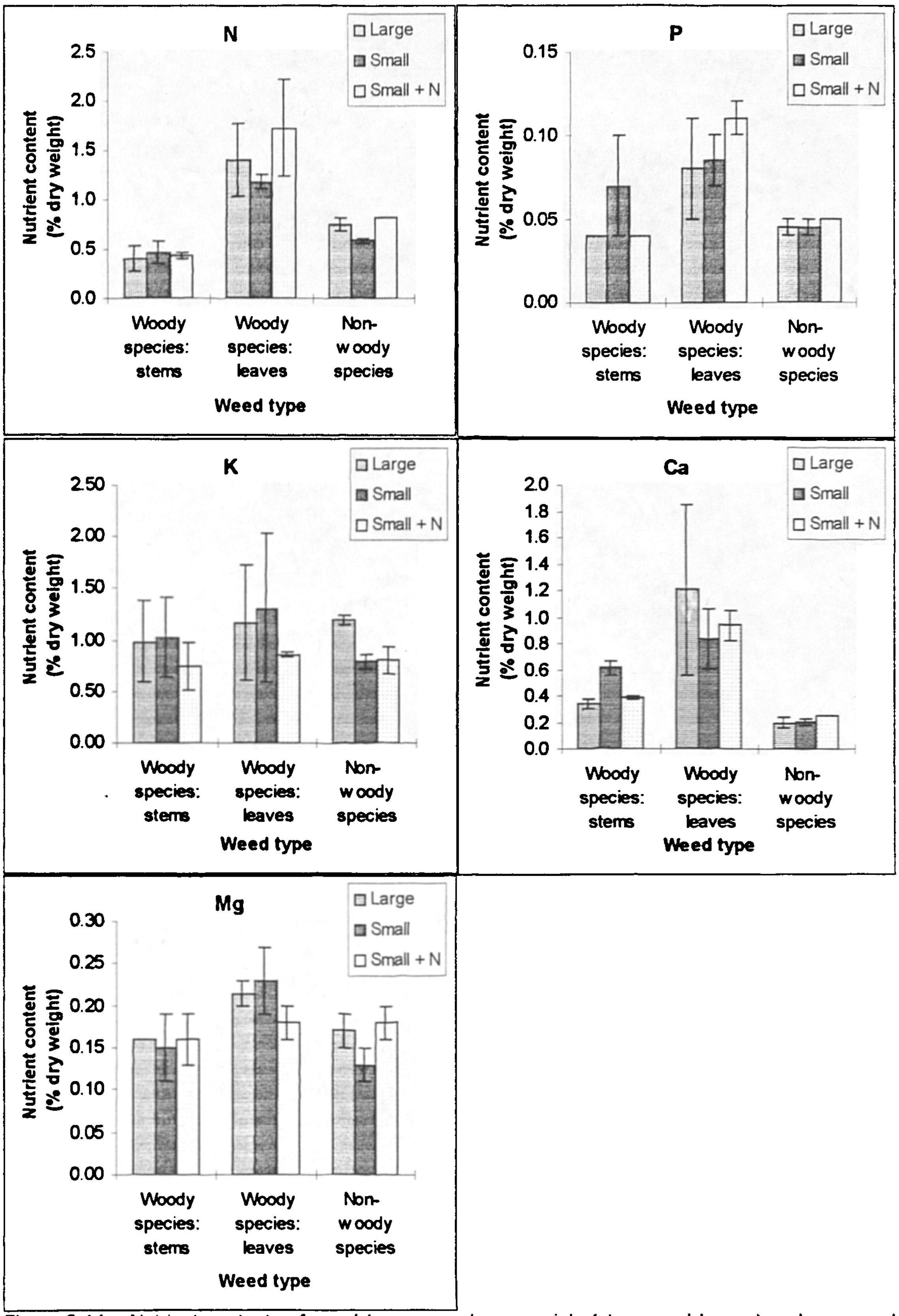


Figure 3.14 Nutrient contents of weed types: woody perennials (stems and leaves) and non-woody species (whole plants), expressed as percentages of dry weights. Nutrient analyses were conducted on composite samples of weeds harvested from 3 randomly placed quadrats per plot, and the figures presented here are the means and standard errors of values for two plots (one from each replicate block), for the low weeding treatments only.

3.3.2 Allocation to shoot and root growth within rubber trees

3.3.2.1 Root fractal branching study

The basic assumptions of the fractal branching model (van Noordwijk *et al.*, 1994; van Noordwijk and Spek, 1994) were found to be satisfied. Firstly, length of links between root branching points were found to be independent of root diameter, as regression analyses showed that there were no significant relationships between root diameter and link length, or between root diameter and the log of link length (adjusted r^2 values of 0.010 and 0.011 respectively). Secondly, the proportionality factor 'alpha' (Section 3.2.2.1) was also found to be independent of root diameter, regression analyses showing no significant relationships between root diameter and alpha or log-alpha (adjusted r^2 values of 0.001 and 0.007 respectively).

3.3.2.2 Proximal root study

There was considerable variation between trees in both numbers and cross-sectional areas of horizontally- and vertically-oriented roots (Figure 3.15). The number of horizontal roots was always greater than the number of vertical roots, except for the low-weeding, large soil volume treatment in Block 1. Total 'cross-sectional area' (CSA[22]) of vertical roots was usually greater than the cross-sectional area of horizontal roots, although the high-weeding large soil volume treatment in both blocks was an exception to this.

The effects of weeding and soil volume treatments on allocation to root growth were analysed with two-way ANOVA, and the results are presented in Table 3.6. Discussed first are the variables observed directly in the field: numbers and CSAs of horizontal and vertical roots. Secondly, calculated variables such as the percentage of horizontal roots and shoot:root ratio were considered in relation to the experimental treatments.

<u>Numbers of horizontal and vertical roots</u>

There were no significant differences in numbers of horizontal roots for either weeding or soil volume treatments (Table 3.6, Figure 3.16a). However, the numbers of vertical roots were significantly higher in the large than in the small soil volume plots ($p<0.05$).

<u>Total cross-sectional area of horizontal and vertical roots</u>

The total root cross-sectional area of horizontal roots was greater in the high weeding than the low weeding treatment ($p<0.01$, Table 3.6, Figure 3.16b). The interaction term was also significant ($p<0.05$), because with high weeding, total CSA of horizontal roots was greater in

[22] CSA calculated as the square of root diameter (D^2).

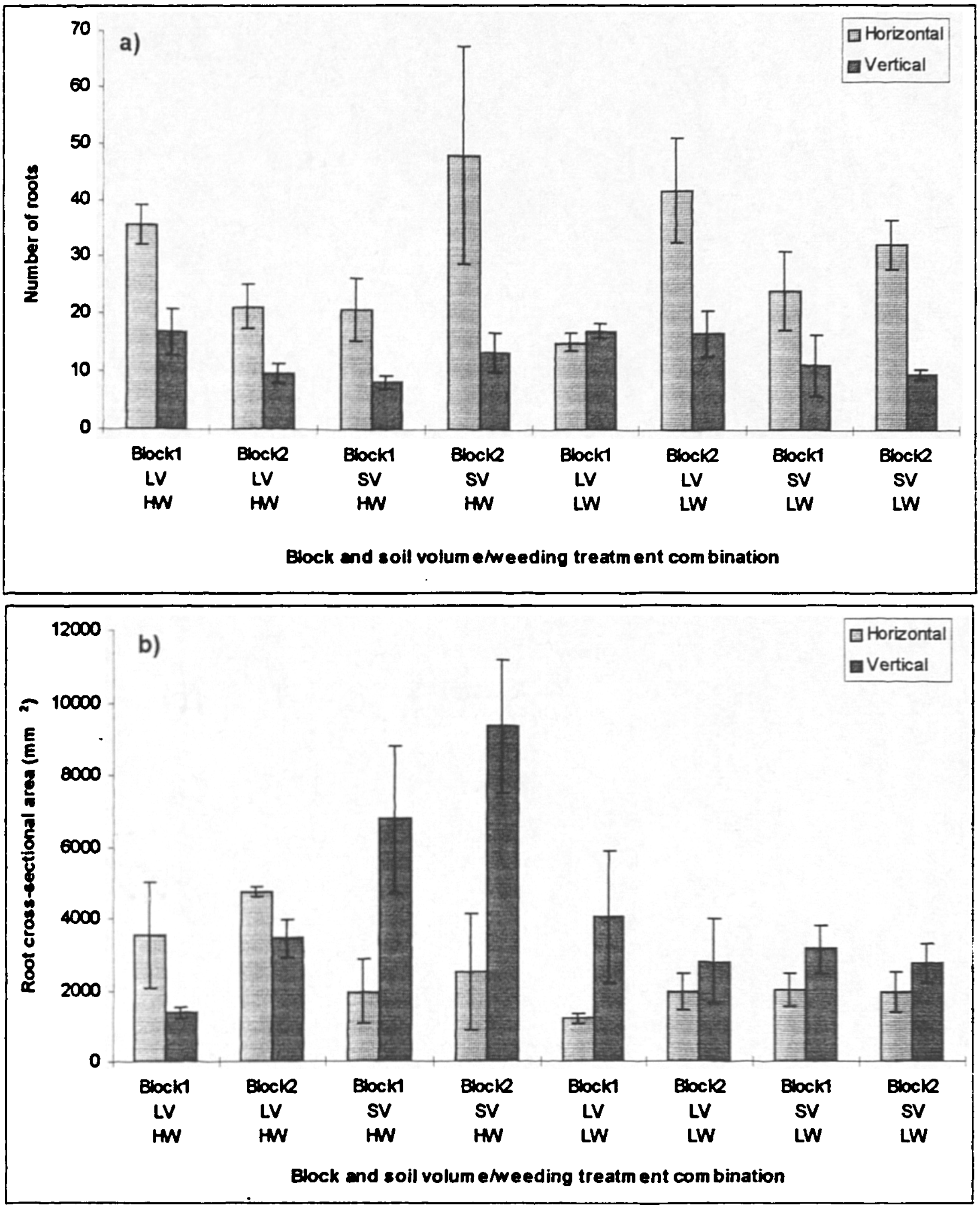


Figure 3.15 Variation between treatment plots in horizontally- and vertically-oriented proximal roots: a) root number, and b) total cross-sectional area of proximal roots. 'LV' and 'SV' are large and small soil volumes respectively; 'HW' and 'LW' are high weeding and low weeding treatments. Means of three trees per treatment plot are presented (except Block 1-LV-HW and Block 2-SV-HW: mean of two trees); error bars represent the standard error of the mean values per plot.
NB Cross-sectional area calculated as the square of root diameter (D^2).

Table 3.6 Root and stem characteristics of rubber trees planted in large and small soil volumes, with high and low weeding regimes, 21 months after planting. For each treatment combination, the mean of two replicate plots (one from each experimental block) are presented, with the standard error of this mean in parentheses.

Treatment	No. Horiz. Roots	No. Vert. Roots	CSA[1] Horiz. Roots (mm²)	CSA Vert. Roots (mm²)	%Horiz. Roots (Root No.)	%Horiz. Roots[2] (Root CSA)	Stem CSA (mm²)	Shoot Root Ratio (CSA)[3]
High weeding, large soil volume	28.4 (7.08)	13.3 (3.67)	4154.5 (596.50)	2396.2 (1029.17)	68.2 (0.17)	63.9 (5.29)	4094.5 (332.50)	0.64 (0.09)
High weeding, small soil volume	34.5 (13.50)	10.9 (2.58)	2207.1 (266.42)	8032.4 (1291.08)	73.5 (3.57)	21.3 (2.72)	3830.0 (298.00)	0.42 (0.03)
Low weeding, large soil volume	28.7 (13.33)	17.2 (0.17)	1557.2 (371.83)	3385.0 (612.00)	58.2 (11.39)	37.2 (7.03)	2737.8 (55.5)	0.63 (0.01)
Low weeding, small soil volume	28.3 (4.00)	10.5 (0.83)	1956.3 (34.33)	2905.8 (197.83)	72.4 (4.03)	40.2 (0.46)	2804.8 (276.33)	0.58 (0.03)
F-prob. (Weeding treatment differences)	NS	NS	0.005	0.034	NS	NS	0.004	NS
F-prob. (Soil volume differences)	NS	0.047	NS	0.015	0.048	0.01	NS	NS
F-Prob. Treatment interaction	NS	NS	0.015	0.005	NS	0.004	NS	NS
S.E.D.[4]	5.74	2.12	446.3	1873.6	4.87	6.53	379.6	0.068

[1] 'Cross-sectional area' (CSA) $= D^2$

[2] Percent Horizontal Root CSA $= 100 * \sum D_{hor}^2 / (\sum D_{hor}^2 + \sum D_{ver}^2)$

[3] Shoot/Root Ratio (on CSA basis) $= \sum D_{stem}^2 / (\sum D_{hor}^2 + \sum D_{ver}^2)$

[4] S.E.D. = standard error of differences between means

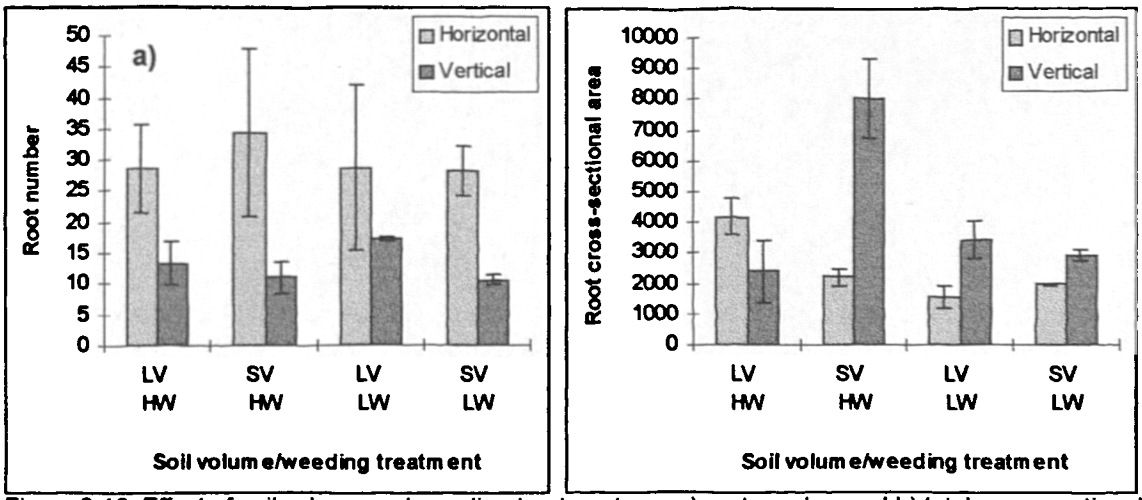


Figure 3.16 Effect of soil volume and weeding treatments on a) root number and b) total cross-sectional area of proximal roots. 'LV' and 'SV' are large and small soil volumes respectively; 'HW' and 'LW' high weeding and low weeding treatments. Means of two replicate plot means are presented; error bars represent the standard error of the mean.

the large soil volumes, whereas with low weeding it was greater in the small soil volume plots.

For total CSA of vertical roots, both weeding and soil volume treatments had significant effects, and the interaction term was also significant (Table 3.6). Due to the very high value in the small, high weeding treatment combination (more than double that of any other treatment, Figure 3.16b), there was a major positive interaction between the effect of high weeding and small soil volume on total CSA of vertical roots, and this largely accounts for the overall significantly higher total CSA in the small than the large volume treatment and high than low weeding treatment.

Relative numbers of horizontal and vertical roots

It was hypothesised (Section 3.1.2.1) that the proportion of horizontally-oriented roots would be lower in trees experiencing competition from weeds (low weeding treatment) than in frequently weeded trees (high weeding treatment). It was also expected that lower proportions of horizontally-oriented roots would be observed in the small soil volume plots than in large volume plots. In reality, however, the number of horizontal roots (expressed as a percentage of the total number of roots) was significantly ($p<0.05$) higher in the small soil volume treatment than in the large volume treatment (Table 3.6, Figure 3.17). The weeding treatments did not have a statistically significant effect on the relative numbers of horizontally and vertically-oriented roots.

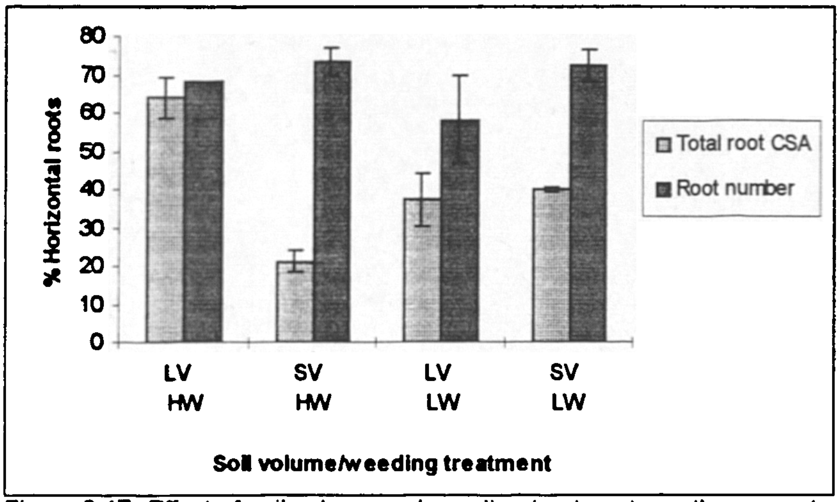


Figure 3.17 Effect of soil volume and weeding treatments on the percentage of proximal roots that are horizontally-oriented : a) root number and b) cross-sectional area (CSA) of proximal roots. 'LV' and 'SV' are large and small soil volumes respectively; 'HW' and 'LW' are high weeding and low weeding treatments. Means of two replicate plot means are presented; error bars represent the standard error of the mean.

Relative cross-sectional areas of horizontal and vertical roots

The effect of soil volume on the percentage of total root CSA accounted for by horizontally-oriented roots was significant ($p=0.01$), as was the interaction term ($p<0.01$), due to the great differences between the large and small soil volume treatments for the high weeding, but not the low weeding treatment (Table 3.6, Figure 3.17). The effect of weeding on CSA of horizontally-oriented roots (expressed as a percentage of total root CSA) was not significant.

Shoot:root ratios (CSA)

Contrary to expectation (Section 3.1.2.1), there were no statistically significant differences in tree shoot:root total cross-sectional area ratios (based on stem CSA and the total CSA of horizontal and vertical roots) for either weeding or soil volume treatments (Table 3.6, Figure 3.18). When considering the components of the ratio individually, stem CSA was significantly greater in the high weeding treatment than in the low weeding treatment ($p<0.01$), but there were no significant differences for soil volume (see also Section 3.3.1.2). The same results were found for total root CSA (data not shown), with significantly greater root CSA in the high weeding treatment ($p<0.01$), which is probably related to the larger size of these trees above ground.

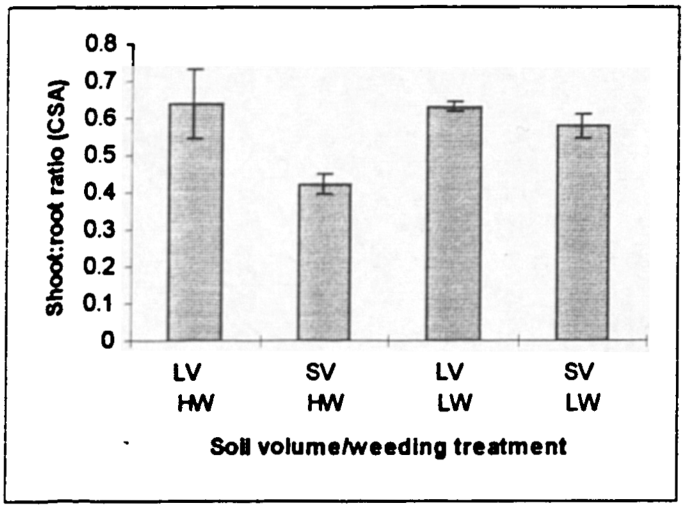


Figure 3.18 Effect of soil volume and weeding treatments on shoot:root total cross-sectional area ratio. 'LV' and 'SV' are large and small soil volumes respectively; 'HW' and 'LW' high weeding and low weeding treatments. Means of two replicate plot means are presented; error bars represent the standard error of the mean.

3.3.3 Root ingrowth core study

3.3.3.1 Treatment effects on biomass of rubber and weed roots

Rubber roots

There was no significant effect of any nutrient enrichment treatment on the biomass of rubber roots (mg cm^{-3}) that had grown into the experimental soil cores (Table 3.7). Thus, there was no significant difference between any of the nutrients and the unfertilised control. The interaction between nutrient and soil volume treatments was significant ($p<0.001$, Table 3.7). This was probably due to the greater root biomass in the added Ca and Mg treatment (dolomite) in the small soil volume plots, than in the large soil volume (Figure 3.19a and 3.19b), whereas added K caused a greater root biomass in the large volume plots than the small volume plots (Figure 3.19a and 3.19b).

Table 3.7 Results of ANOVA on dry weight (mg cm^{-3}) of rubber and weed roots at different soil depths within ingrowth cores treated with various nutrients, located in plots of different soil volumes.

	Rubber root dry weight (cm cm^{-3})	Weed root dry weight (cm cm^{-3})
Main effects		
Size	p<0.001	n.s.
Nutrient	n.s.	n.s.
Depth	p<0.01	p<0.001
Interactions		
Size.nutrient	p<0.001	n.s.
Size.depth	p<0.01	p<0.05
Nutrient.depth	n.s.	n.s.
Size.nutrient.depth	n.s.	n.s.

The effect of plot size was highly significant (Table 3.7), and its interaction with soil depth was also significant ($p<0.01$). This was due to the greater magnitude of root ingrowth in cores in the small soil volume plots compared with the large volume plots in the upper 20 cm of the soil, and the fact that in the 20-30 cm level, this trend was reversed (Figures 3.19a and 3.19b). There was thus a positive interaction between large soil vclume and greater soil depth. Comparing the means of the soil volume treatments for all samples (n=108), root biomass in the small volume plots was almost twice that in the large volume plots (0.1604 and 0.0924 respectively), which may be an indicator of generally higher biomass of rubber root per unit soil volume in the small plots as a result of the trenching treatment. There was also a significant overall decline in rubber root biomass with soil depth.

Weed roots

As for rubber, there were no significant effects of the nutrient enrichment of soil cores on the biomass of ingrown weed roots (Table 3.7). The effect of soil depth was significant, with weed root biomass decreasing down the profile. The significant interaction between soil volume and depth was explained by biomass being greatest in the 10-20 cm layer in the small soil volume plots (Figures 3.19c and 3.19d).

Over all samples (n=216), correlation of the dry weight of rubber roots with the dry weight of weed roots showed a non-significant negative relationship ($r^2 = 0.1901$), which indicated that the presence of weed roots did not affect the biomass of rubber roots in a sample.

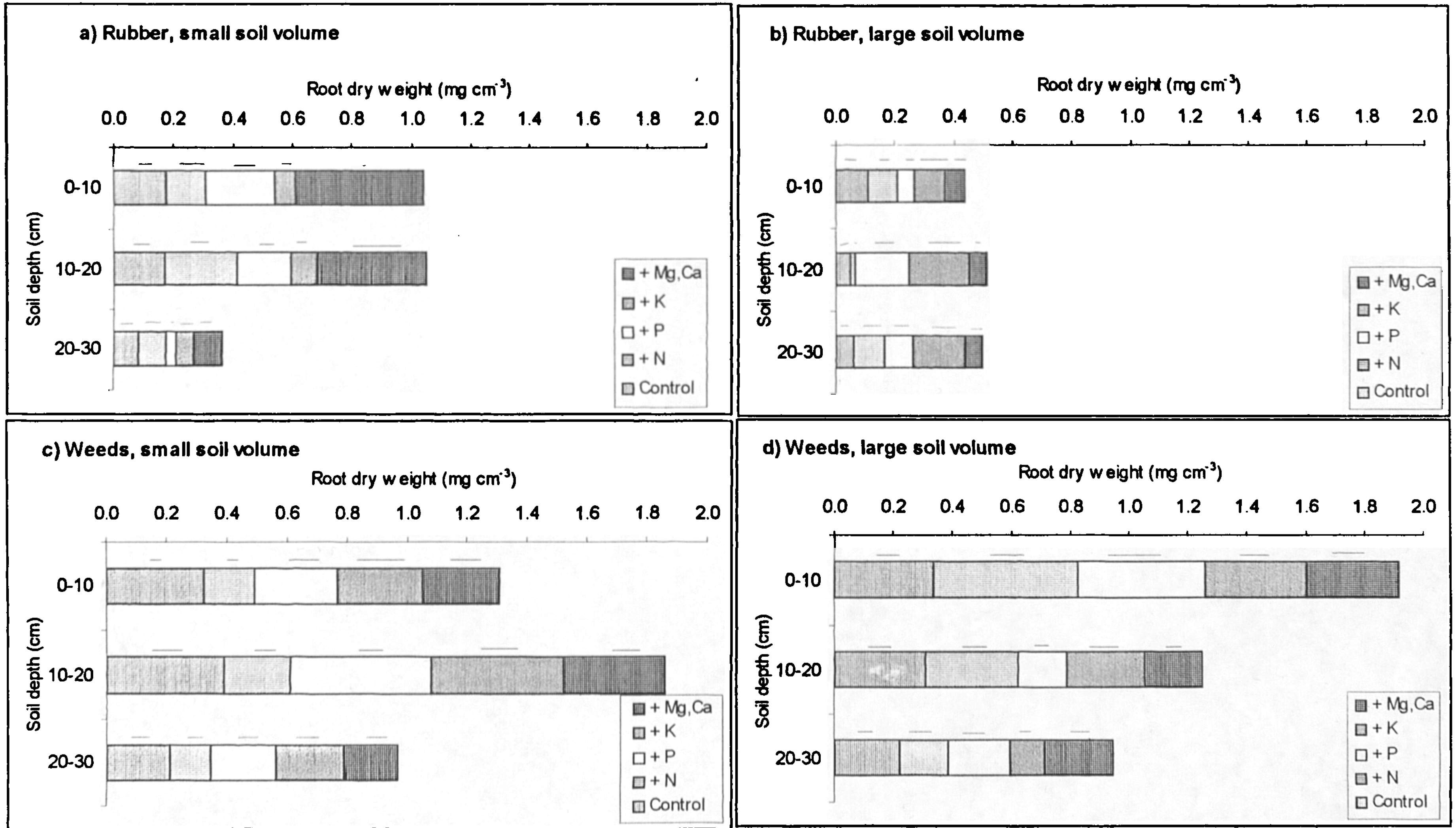


Figure 3.19 Mean dry weight of roots (mg cm^{-3}) per soil depth within ingrowth cores enriched with various nutrients: rubber tree roots in a) small and b) large soil volume plots (low weeding treatment); weed roots in c) small and b) large soil volume plots (low weeding treatment). Means and standard errors (represented by the single lines positioned above the bars) are shown for 6 samples per treatment combination, except the control (12 samples).

3.3.3.2 Estimation of weed root length density from weed root biomass measurements

Weed root length density was estimated from the dry weight of each sample. The estimates were based on a linear relationship between measured root length (using a line-intersect method; Tennant, 1975) and dry weight, in five samples:

$$y = 9.510\,x \qquad (p<0.001, \text{ adjusted } r^2 = 0.7262)$$

Where y is weed root length density (cm cm^{-3})
x is weed root dry weight (mg cm^{-3})
s.e. of regression slope is 0.4094

Means per treatment of the estimated values obtained are presented in Table 3.8.

Table 3.8 Estimated weed root length density (cm cm^{-3}) in different soil depths within ingrowth cores, enriched with various nutrients, for both small and large soil volume plots. Means and standard errors are shown for three samples per treatment combination, except the control (six samples per treatment combination).

			Nutrient enrichment treatment				
Soil volume	**Core depth (cm)**		**Control**	**+N**	**+P**	**+K**	**+ Mg,Ca**
Small	0-10	Mean	3.0799	1.6104	2.6497	2.6806	2.3933
		SE	1.0994	0.8132	1.9736	3.4652	2.0877
	10-20	Mean	3.7231	2.1124	4.4116	4.2604	3.1879
		SE	2.9811	1.6492	1.9220	2.7785	1.7866
	20-30	Mean	2.0088	1.3070	2.0443	2.1584	1.7270
		SE	1.7587	1.1046	1.5877	1.7112	1.5783
Large	0-10	Mean	3.1885	4.6949	4.0724	3.2702	2.9940
		SE	2.1721	2.6570	4.1337	2.3960	2.6014
	10-20	Mean	2.9277	3.0088	1.6063	2.4986	1.8223
		SE	1.9142	2.0000	0.9996	2.3428	1.1871
	20-30	Mean	2.1208	1.6016	1.9856	1.1144	2.1986
		SE	1.7390	1.7332	1.7011	0.9185	1.5318

3.3.3.3 Treatment effects on measured root length density of rubber

In contrast to weed root length (which was estimated from dry weights), rubber root length was measured directly, for <u>every</u> sample, using a line-intersect method (Tennant, 1975).

There were no significant differences between the nutrient enrichment treatments in terms of the root length density of rubber roots that had grown into the soil cores (Table 3.9), which is consistent with the results for rubber root biomass. The only other term found to be significant in the ANOVA was the plot size x nutrient interaction. As for root biomass, this was probably due to the greater root length density in the added Mg and Ca treatment (dolomite) in the small soil volume plots, than in the large soil volume plots (Figure 3.20), whereas added K caused greater root length density in the large plots than the small (Figure 3.20).

Table 3.9 Results of ANOVA on rubber root length density (cm cm^{-3}) at different soil depths within ingrowth cores treated with various nutrients.

	Measured rubber root length density (cm cm^{-3})
Main effects	
Size	n.s.
Nutrient	n.s.
Depth	n.s.
Interactions	
Size.nutrient	$p<0.01$
Size.depth	n.s.
Nutrient.depth	n.s.
Size.nutrient.depth	n.s.

As weed root length density was estimated from the corresponding root dry weight, the results of ANOVA were the same as those in Table 3.7. The mean of all weed root length density estimates (2.653 cm cm^{-3}, n=216) was over sixteen times that of rubber root length density (0.1634 cm cm^{-3}, n=216).

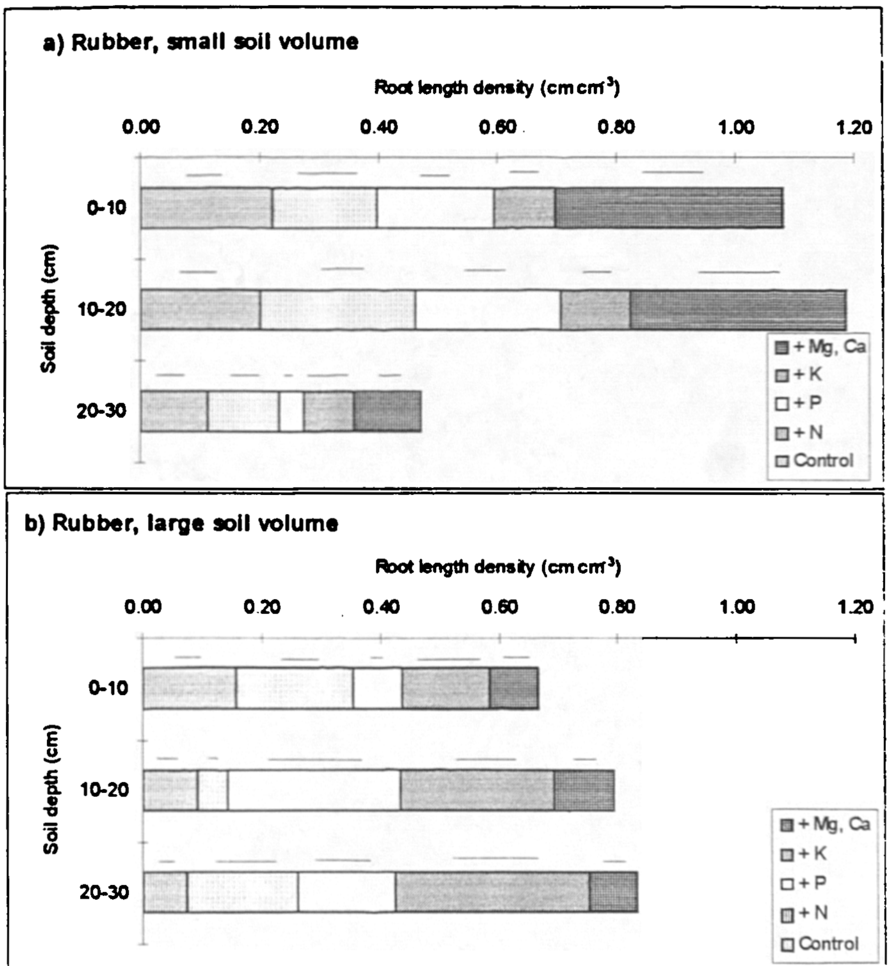


Figure 3.20 Mean rubber root length density (cm cm^{-3}) per soil depth within ingrowth cores enriched with various nutrients in a) small and b) large soil volume plots (low weeding treatment). Means and standard errors (represented by the single lines positioned above the bars) are shown for six samples per treatment combination, except the control (twelve samples).

3.4 DISCUSSION

3.4.1 Trenching experiment

3.4.1.1 Effect of experimental manipulation of below-ground resources on above-ground growth of rubber trees

Effect of soil volume on rubber tree growth

Hypothesis 1. Above-ground rubber tree growth will be less in smaller soil volumes, due to quicker exhaustion of limited resources.

The results from this study provided no evidence that the initial growth of rubber trees in this agronomic system was limited by the quantity of below-ground resources available to the trees, as the soil volume treatments used in the experiment did not show any statistically significant effects on rubber growth.

There are two possible explanations for this fact. The first is that roots may have penetrated the root barriers and thus were not confined to each soil volume treatment. This was checked by excavation of surface roots at the barriers in the field, and it was found that surface roots were deflected by the barrier and grew parallel to it, or turned inwards toward the centre of the plot (Plate 3.2a). However, in some cases, some branches did grow down the barriers (and presumably under them), although no quantitative data was collected on this.

One piece of evidence that would discount this explanation is the significant difference between weeding treatments observed in the experiment. If roots were foraging freely, for example growing out of 'high below-ground competition[23]' low-weeded plots into neighbouring 'low below-ground competition' clean weeded plots, then in theory, the differences between tree growth in the different weeding treatments would not be as clear cut as was observed in reality. The trees in the low weeding treatment would not have been so much at a competitive disadvantage from weeds if they were able to obtain resources from outside the plot, and also trees in high weeded treatments would have less of an advantage if they were competing directly with roots that had invaded their soil volume from neighbouring plots.

The second, more plausible, explanation is that the soil volumes have not yet been fully exploited by the developing root systems, and so below-ground resources in the plots are still not limiting, *i.e.* up until now, even the small soil volume treatment is not sufficiently limiting to affect tree growth. In this case, the clear effect of weeding may be due to interactions at the level of the individual roots, as there is evidence from mini-rhizotron photographs (data not

[23] Due to the low stature of the weed cover that regenerated in this experiment, above-ground competition was assumed to be negligible

presented) that weed roots are intimately associated with rubber roots, especially in the upper soil layers. Thus uptake of nutrients/water in the micro-environment around each rubber root is likely to be affected by the presence of roots of other species well before total below-ground resources are fully exploited and become limiting.

This process will of course depend on the specific resource for which there is competition, as zones of influence around each root differ for different nutrients. For example, for mobile ions such as nitrate, the zone of influence is relatively large, whereas for P, which is relatively immobile, roots have to be very close together before there are significant competitive effects (Barber, 1984).

Effect of weeding on rubber tree growth

Hypothesis 2. Weeding significantly increases rubber-tree above-ground growth, due to reduced competition for limited resources.

This hypothesis was accepted, with respect to rubber tree diameter and trunk volume. The effect of weeds on above-ground rubber growth was significant 18 and 21 months after planting the rubber trees.

The effect of weeding being statistically significant for rubber tree diameter and trunk volume but not for tree height is consistent with the rubber literature (Paardekooper, 1989), where diameter is used in preference to height as the most reliable indicator of tree growth. The effect of weeding was also seen in the significantly lower soil nitrate-nitrogen concentrations in the low weeding treatment. This provides evidence that weeds have obtained a proportion of the available pool of N that would otherwise have been utilised solely by the rubber, and this may be a reason for the reduced rubber tree growth in this treatment, relative to trees in the high weeding treatments.

Hypothesis 3. Soil volume and weed competition will interact, resulting in a greater increase in rubber-tree above-ground growth with weeding, in a small soil volume, than in a larger soil volume.

This hypothesis was rejected, as the interaction term was not significant.

Hypothesis 4. Rubber tree growth in small volume, unweeded + N fertiliser plots will be higher than in small, unweeded plots with no fertiliser addition, due to alleviation of competition for nitrogen between trees and secondary forest regrowth.

Effect of N fertiliser addition

A very interesting result is that in the treatment with added N fertiliser (small soil volume, low weeding), tree growth was much greater than growth of trees in the corresponding plots with no added fertiliser. This growth was even comparable with the high weeding plots, where there was negligible competition from weeds.

Although these results agreed with the finding of Mainstone (1963, 1969), that addition of nitrogen in the form of fertiliser may offset the competition resulting from a high weed density, this study was conducted on a very small scale. If further studies at a larger scale and a range of sites confirmed the effect of N fertiliser, then the practical implications would be a reduction in labour necessary for weeding an RAS 1-type system, and a greater potential to allow the regeneration of secondary vegetation (with the benefits associated with this as perceived by the farmers, and also a higher level of biodiversity) without it resulting in a reduction in rubber growth. However, results from a larger trial (two hectares in area) in the Smallholder Rubber Agroforestry Project (SRAP), showed no significant effects of N-fertilisation on rubber tree growth, up to 18 months after planting (Akiefnawati and van Noordwijk, in press). It is likely that response to N addition will depend on soil fertility, and will be greater on more infertile soils (Watson, 1964a).

3.4.1.2 Effect of experimental treatments on below-ground resources, and on foliar nutrient and water contents of rubber and weeds

Hypothesis 5. After 22 months, below-ground resources of nitrate- and ammonium-nitrogen will be greater in clean-weeded than in unweeded plots, and greater in larger soil volumes than in smaller soil volumes. Soil bulk density will be lower in clean-weeded than unweeded plots.

The hypothesis of greater soil nitrogen concentrations in clean-weeded than in unweeded plots was accepted for nitrate-nitrogen, but not for ammonium-nitrogen. There was no effect of soil volume treatments, and the hypothesis for bulk density was also rejected.

Hypothesis 6. After 22 months, rubber tree foliar nutrient and water contents will be greater in clean-weeded than in unweeded plots (due to reduced resource competition from secondary forest regrowth) and will also be higher in trees growing in larger soil volumes than in smaller soil volumes (due to a greater quantity of below-ground resources per tree). Nutrient and water contents of secondary forest regrowth will follow the same pattern.

The hypothesis regarding nutrient and water contents of rubber tree leaves could not be tested statistically due to missing data for one treatment combination. The hypothesis regarding weed nutrient and water contents was rejected, as there was no significant difference between large and small soil volumes.

The results of this study provided no conclusive evidence that competition for water played a major role in the interactions between rubber and weeds. The fact that there were no apparent differences in foliar water contents for either rubber or weeds amongst the experimental treatments, and also that soil water contents were greater in the low weeding as opposed to the high weeding treatments, implies that there was sufficient water for both components, and this was not a major limiting factor. However, the surface drying of the upper soil layers could have an effect on nutrient mineralisation and uptake processes.

The mean foliar N concentrations for trees in the high and low weeding and low weeding +N treatments (2.216, 2.043 and 2.010 % respectively), did not appear to be very different from each other, and all three fell into Pushparajah and Tan's (1972) classification of 'low' nitrogen status ('well below optimum, tending to visual deficiency'). These authors predicted that a growth response to N fertiliser would occur for trees with foliar N concentrations of 3.2 % and below. There was indeed a positive growth response to N fertiliser (Section 3.4.1.1). All other foliar nutrient concentrations (P, K, Ca and Mg) were below the 'optimum' levels quoted by Adiwiganda (1992), and, except for K, lower than levels observed for 22 month old trees in the intercropping experiment in Sembawa (Wibawa and Thomas, 1997).

3.4.2 Effect of experimental treatments on allocation within the rubber tree

Hypothesis 1. Rubber shoot:root ratios will be increased by weeding, due to greater resource allocation to root growth where there is competition from secondary forest regrowth that is predominantly below-ground.

This hypothesis was rejected on the basis of the results from this study. There was no significant effect of reducing weed competition (by weeding) on rubber tree shoot:root cross sectional area ratio. There is no evidence that the presence of weeds results in a proportionately greater allocation of biomass to roots than in situations when there is negligible competition from weeds. This was in direct contrast to the results from my similar study in the STD III intercropping experiment in Sembawa (Williams *et al.*, in press; Appendix 3.1) where rubber tree shoot:root ratios were significantly lower for trees planted with intercrops than for clean-weeded trees.

Hypothesis 2. Rubber shoot:root ratio will be lower in trees growing in a smaller soil volume than in a large soil volume, due to greater resource allocation to root growth in conditions where total available below-ground resources are reduced.

This hypothesis was also rejected. Soil volume had no effect on rubber shoot:root ratio. This is consistent with the fact that the soil volume treatments had no significant effect on above-ground rubber growth (Sections 3.3.1.2, 3.4.1).

Hypothesis 3. Ratios of the number and cross-sectional area of vertically and horizontally oriented roots will be higher where there is competition from weeds, i.e. there will be a greater allocation to vertically oriented roots.

This hypothesis was rejected for both numbers and cross-sectional areas of roots. Again, this is not consistent with the results obtained in the Sembawa study (Williams *et al.*, in press; Appendix 3.1), where the percentage of horizontal root CSA was significantly lower in rubber trees intercropped with pineapple, and in the presence of the weed *Imperata cylindrica* than in clean-weeded trees.

Hypothesis 4. Ratios of the number and cross-sectional area of vertically and horizontally oriented roots will be higher in rubber trees growing in a small soil volume than in a larger soil volume, i.e. there will be a greater allocation to vertically-oriented roots.

This hypothesis was also rejected, and, in reality, the opposite was true for root number, as allocation to horizontally-oriented roots was greatest in the small volume plots. In terms of horizontal root CSA, the interaction between the treatments was significant, and the results followed no clear pattern. In fact, significant interaction terms were also observed for vertical root number and CSA, and were not easily explained in terms of biological phenomena.

It is clear that the trend of decreasing shoot:root ratio and proportion of horizontal roots with increasing inter-specific competition is not universal, as seen by the contrasting results of this study and the previous one in Sembawa Rubber Research Station. It is possible that there are important differences in environmental conditions between the two sites where the investigations of proximal roots were conducted. Firstly, annual rainfall in Sembawa is 1550 mm (average for 1994-1996), which is just over half that of Rantau Pandan (Chapter 2). From detailed studies on soil moisture content, nutrient status and evapo-transpiration, Wibawa and Thomas (1997) concluded that water was the most limiting factor for rubber growth in the intercropping systems at Sembawa. However, Dr Wibawa (pers. comm., 1997) did not expect the same situation to occur in Rantau Pandan, due to the higher annual rainfall there. Therefore, in the Sembawa study it is possible that competition for water had a relatively large effect on trees in the treatments studied in the proximal root investigation, and this could explain the significant differences in allocation observed in shoot:root ratios, and percentages of horizontal roots. Chemical soil properties in the Sembawa trial at 0 - 20 cm depth were comparable with those in the trenching experiment (Wibawa and Thomas, 1997).

It is also possible that there was a greater magnitude of competition exerted by the pineapple and *Imperata cylindrica* treatments in Sembawa than by the regenerating weeds in the present trenching experiment, and this could explain the conflicting results in the two trials. Biomass of *Imperata* shoots (average of 12 measurements) at Sembawa was 435 g m^{-2} (Wibawa and Thomas, 1997), whereas in the trenching experiment, weed biomass was approximately 195 g m^{-2} in the low weeding treatment. There were no data available on total biomass of pineapple plants in the Sembawa trial, although when harvest data was scaled according to plot size, approximately 750 g of fruit was harvested per m^2. This too indicates a considerably greater biomass of vegetation competing with rubber trees than the weeds in the present trenching experiment.

3.4.3 Root ingrowth core study

Hypothesis 1. N is the most limiting nutrient for rubber growth in this soil, when there is competition from weeds, as indicated by greater root proliferation (fine root biomass and root length density) in N-enriched soil cores, than in soil cores enriched with other nutrients.

This hypothesis was rejected on the basis of the results of the root ingrowth core study, as there was no significant main effect of the nutrient treatments on either rubber root biomass or root length density.

Hypothesis 2. Rubber trees growing in smaller volumes of soil will show a greater response of fine-root proliferation (fine root biomass and root length density) to nutrient enrichment than those growing in larger soil volumes.

The soil volume x nutrient interaction was significant for both rubber root biomass and root length density. This appeared to be due to the greater root ingrowth in the added Mg/Ca treatment in the small soil volumes than in the large volumes, and also due to the greater root ingrowth in the added K treatment in the large plots than in the small plots. Thus the effect of adding Ca and Mg (dolomite) tends to support the above hypothesis, but the converse was true for added K.

In general, density of in-grown rubber tree roots was twice as great in the small soil volume plots than in the large soil volume plots, indicating greater potential for encountering weed roots, and a greater probability that the nutrient depletion zones around rubber and weed roots would overlap. It was therefore surprising that the main effect of nutrient treatment was not significant. Possible reasons for this are discussed below.

1. Rubber tree roots do not proliferate in response to nutrient-rich microsites

This is unlikely, as a study by the Rubber Research Institute of Malaya (1958) specifically mentioned that in a four-year old plantation, fine roots were evenly distributed across the inter-row area, except where the roots had branched prolifically on entering a patch of particularly well-aerated, moist or nutrient-rich soil. Another mechanism cited in general ecological literature which could explain the lack of proliferation in this experiment would be enhanced uptake capacity by a specific length of existing root, as opposed to production of new fine roots (Cui and Caldwell, 1997), however no evidence could be found in the rubber literature regarding this phenomenon. In contrast, more evidence for increased rubber root length density in response to nutrient addition was provided by Watson *et al.*'s (1964) study, which found that rubber root length densities in the surface 7.5 cm of soil were higher in fertilised than in non-fertilised areas.

2. Variation in the distribution of rubber roots throughout the experimental plots

It is possible that the distribution of rubber roots throughout the experimental plots was not uniform, and that this masked any potential nutrient treatment effects. The area of the ingrowth cores was very small in relation to the total area of the plot; the 18 cores per plot comprising only 0.34 and 0.11% of the surface area of the small and large-sized plots respectively. Although this proportion is comparable with previous ingrowth core studies (Table 3.1), these other studies were conducted in environments with mature trees (tropical forest, or plantations over 11 years old), or with grasses or annual crops, where the density of fine roots would be expected to be much higher. Thus there would be a greater probability of a more uniform initial root distribution on which to impose the cores.

However, the experiment had been designed to maximise the potential number of in-growing roots by placing cores in the zones of maximum root density reported by Samarappuli *et al.* (1996) for one year old trees (within 1.2 m from the base of the tree, and in the upper 30 cm of the soil where 95% of the fine roots were found. To allow for variation in root distribution, a greater number of replicate cores per treatment could have been installed throughout the inter-row area, although this would have required a much greater investment of time and labour.

3. El Nino drought

The El Nino effect led to a severe and extended dry season in 1997 which coincided unfortunately with the incubation period of the root ingrowth core study. During this period, rainfall measured in the raingauge at the experimental site was very low (215 mm in total over the 20-week study, and there were only 15 days when rain fell) (Figure 2.3). It is possible that rubber roots simply could not detect the nutrient-enriched cores, due to the low soil moisture content. Dryness of the soil could have reduced soil-root contact (Drew, 1987), and also reduced the transport of nutrient ions in the soil solution to the roots (Lake, 1987), due to a decrease in the diffusion coefficient (Jungk, 1991). Thus nutrient uptake would have been impaired, and a subsequent response (rubber root proliferation) would have been less likely.

Although the lack of response by rubber roots to the nutrient-enriched cores could be explained by variation in root density (above), the case of weed roots is different, as they were present in all samples/cores, at over twice the density (on average) of rubber roots (Figure 3.18). As weed roots also did not show any response to the nutrient treatments, then it is likely that soil dryness was indeed a factor which contributed to the experimental results presented here.

CHAPTER 4

PERFORMANCE OF CLONAL AND SEEDLING RUBBER PLANTING MATERIALS IN A MULTISTRATA AGROFORESTRY SYSTEM:

A RESEARCHER-MANAGED, ON-FARM WEEDING TRIAL

4.1 INTRODUCTION

The dominant land-use in the study area of Rantau Pandan is jungle rubber (Section 1.2.2), and this provides the main source of household income for the majority of farmers (Section 2.1.5). This system is based on rubber 'seedlings', grown from unselected seed that was first introduced to Sumatra in the first decade of the twentieth century (Dijkman, 1951). Farmers plant rubber seedlings at high densities (Section 1.4.5.2) in fields which have been slashed and burned, then allow secondary forest to regenerate around the trees, with little subsequent weeding management (Sections 1.2.2.3 and 2.1.7.1).

This introductory section considers issues pertinent to sloping land, previous studies on management of secondary forest regrowth in rubber plantations, and the differences between rubber 'seedlings' and bud-grafted 'clones'. In addition, farmers' indigenous knowledge about the establishment of jungle rubber gardens will be presented in Section 4.1.4.

4.1.1 Issues regarding rubber planting on sloping land

The landscape of the study area is hilly, being located in the foothills of the Barisan mountains (Section 2.1). This area is representative of the piedmont zone of Sumatra, where clonal rubber planting is rare compared with the peneplain zone. This is because many privately-owned and government clonal rubber plantations have been established in the peneplain, where there are more favourable conditions (flat land and better infrastructure in terms of roads and factories). Therefore, when considering the introduction of clonal rubber to the piedmont area, any potential system must be tested on slopes.

Standard plantation practice when planting clonal rubber on slopes of more than 8% is the construction of terraces, using tractors (Webster, 1989a). However, this is impractical for individual smallholders. Manual terracing is labour-intensive, and generally not practiced in the Rantau Pandan area (pers. obs.). Slopes of 20-35% and over 35% are classified as presenting 'severe' and 'very severe' limitations to clonal rubber growth (Sys, 1975, cited in

Watson, 1989a). In the study area, however, seedling rubber is widely planted on slopes which are much steeper than those quoted above. Farmers' observations on the growth and yield of seedlings on slopes is further considered in Section 4.1.4.4.

In hilly areas, the importance of ground cover to protect the soil in rubber plantations has long been recognised (van Gelder, 1950; Dijkman, 1951). The multistrata agroforestry system being tested in this research programme was expected to be particularly effective on sloping land, in terms of soil conservation. This is because rubber trees are planted in rows along the contours of the hills, with regular weeding carried out only 1 m either side of the trees. Between rubber rows, bands of deep-rooted and dense secondary vegetation are allowed to regenerate; this type of layout is similar to many contour hedgerow intercropping systems (Garrity, 1996), which have been designed specifically for soil conservation purposes.

4.1.2 Secondary forest regrowth in rubber plantations

The advantages of using naturally regenerated vegetation as a ground cover in rubber plantations were recognised as long ago as the 1930s (Haines, 1934). This study specifically mentions benefits such as reduced soil erosion and run-off, increased percolation, reduced soil temperature, and increased soil organic matter as a result of the decay of litter from the vegetation.

Following Haines' (1934) characterisation of spontaneous vegetation, as desirable, tolerable and undesirable, this study classified the majority of woody species occurring in Rantau Pandan as desirable or tolerable (Table 2.6), although the slashing of dense shrubs to a height of 1.5 m, every six months was recommended. Selected weeding of trees over 5 cm in diameter was also proposed, primarily to increase the rate of return of nutrients to the soil in litter and prunings (Haines, 1934). The class of weeds which were considered undesirable, however, included *Chromolaena odorata*,[24] *Lantana camara* and *Melastoma malabathricum*, which are shrubs common in early regenerating secondary forest in Rantau Pandan. Haines (1934) envisaged the ideal natural cover being managed as two layers of vegetation, the first consisting of woody plants with an erect, shrub-like habit (lower in height than the rubber trees), and the second comprising low-growing herbs and ferns near the soil surface.

In the 1940s and 1950s, however, the benefits of planting legumes as cover crops began to be recognised, and various trials were established to compare the effect of leguminous and 'natural' covers on the growth of rubber (Mainstone, 1963, 1969; Watson *et al.*, 1964a; Section 1.5.4.1). Results from these trials demonstrated significant advantages on both yield and growth of rubber trees due to legume cover crops (LCCs), and subsequently these were

[24] However, the advantages of this species have been discussed by Cairns (1994), specifically in its use in a bush-fallow agroforestry system in the Barisan mountains of Sumatra, and in general by Baxter (1995).

incorporated into standard plantation management practices, and their use is still continued (Watson, 1989b). However, even in intensive monoculture plantations, naturally regenerated vegetation is still recommended for steep, erosion-susceptible areas, in combination with 'heavy' dressings of nitrogen fertiliser (Watson, 1989b).

4.1.3 Clonal and seedling rubber

The clonal rubber planted in monoculture plantations, and the rubber seedlings used in the jungle rubber system are two distinct types of planting material, with inherent differences in origin, genotype, architecture and latex yield. The characteristics of each are described below, firstly with reference to the history of genetic improvement of *Hevea brasiliensis* and secondly with respect to biology and morphology.

4.1.3.1 Historical development of rubber planting material

In Indonesia, the first commercial plantings of *Hevea brasiliensis* occurred between 1895 and 1905. These consisted of seedlings which had been introduced, mainly from Malaysia (Baulkwill, 1989). The Malaysian material was derived from 22 seedlings imported from Kew Gardens in 1877, which had been produced from Wickham's collection of seeds from Brazil (Dijkman, 1951). The area of estate plantations planted with these unselected seedlings increased rapidly, and by 1914 consisted of 245 000 ha in Indonesia, whilst an additional 20,000 ha had been planted spontaneously by smallholders (8% of the total area of rubber) (Baulkwill, 1989).

The first primitive selection of trees practised by estates was collection of seeds from individual high-yielding trees in their plantations, known as 'mother trees'. Dijkman (1951) assessed that the majority of new plantings of 'so-called unselected seedlings' after 1916, actually consisted of these selected mother-tree seedlings. By 1929, the area of seedling rubber (unselected and mother-tree seedlings) planted by Indonesian estates had reached 546 000 ha, and the area planted by smallholders was even greater: 727 000 ha, or 57% of the total area planted (Baulkwill, 1989).

From the 1920s onwards, research on vegetative propagation increased, and bud-grafting produced 'clones' which were more successful in terms of growth and yield than even the most rigorously-selected and well-managed mother-tree seedlings (Dijkman, 1951). An intensive breeding programme followed, managed by various research stations, and second and third generation clones were produced (Simmonds, 1989). Characters selected for were primarily high yield and growth vigour, although 'secondary characters' such as wind-fastness, disease resistance, bark morphology (especially with respect to its regeneration after tapping), and latex vessel plugging (Section 1.4.4) were also important (Simmonds, 1982; 1989). The greater yields of clones, as compared with other types of planting material can be seen in Table 4.1.

Table 4.1 Yields per hectare (at maturity) of various types of rubber planting material

Planting material	Latex yield[1] (kg/ha)	Date
Unselected seedlings	330-648 (average 496)	Before 1917
First mother-tree seedlings	505-710 (average 639)	1917-1918
Higher class, selected mother-tree seedlings	704 (average 704)	1919-1922
First generation of clones (TJIR 1-type)	1350-1400	1930
Second generation of clones (PR 107-type)	1500-1700	1950-1960
Third generation of clones (PB 260[2]-type)	1700-2000	1980

Sources: Maas, 1948 (cited in Dijkman, 1951) for seedlings; Penot, 1997b for clones
[1] 100% dry rubber content (d.r.c.)
[2] PB 260, the clone used in this specific experiment is one of the more robust third generation clones (Penot and Aswar, 1994).

Widescale adoption of clones by estates occurred from 1945 (Simmonds, 1989), and today, no Indonesian plantations plant seedlings for latex production (E. Penot, pers. comm.). In contrast, the majority of non-project farmers[25] still use seedlings, especially in the jungle rubber system. This material is likely to be a mixture of unselected, mother-tree and clonal seedlings, given the rapid increase in the areas planted by smallholders (above), and the associated demand for seed (from any available source). This is a possible explanation for the growth and yield of seedlings in jungle rubber being very variable (Penot, 1997b). It also may contribute to the lower yields per hectare in jungle rubber than in clonal plantations: seedlings in jungle rubber represent only the very first steps in the process of genetic improvement of rubber.

4.1.3.2 Propagation and biology

Seedlings are propagated directly from seed and then cut back. They are transported easily to the field and planted as 'stumped seedlings' (Figure 4.1b). Traditional methods of the propagation and planting of seedlings in jungle rubber are described in Section 4.1.4. A 'bud-grafted clone' (Figure 4.1a) is propagated by grafting a high yielding bud onto a rootstock (usually a clonal seedling, aged 5-6 months) at approximately 5 cm above ground level, by a technique known as 'green budding' (Webster, 1989b). Approximately three weeks later, the stem of the rootstock is cut back at 5 cm above the bud patch, and then it can be uprooted and planted in the field directly as a bare-root stump, or planted in a polybag in a nursery and then transplanted to the field. Issues regarding production of bud-grafted clones by farmers, budwood gardens and clonal purity are discussed by Penot *et al.* (1998) and Komardiwan and Penot (in press).

[25] Farmers outside the large monoculture rubber development projects (Section 1.2.3.1)

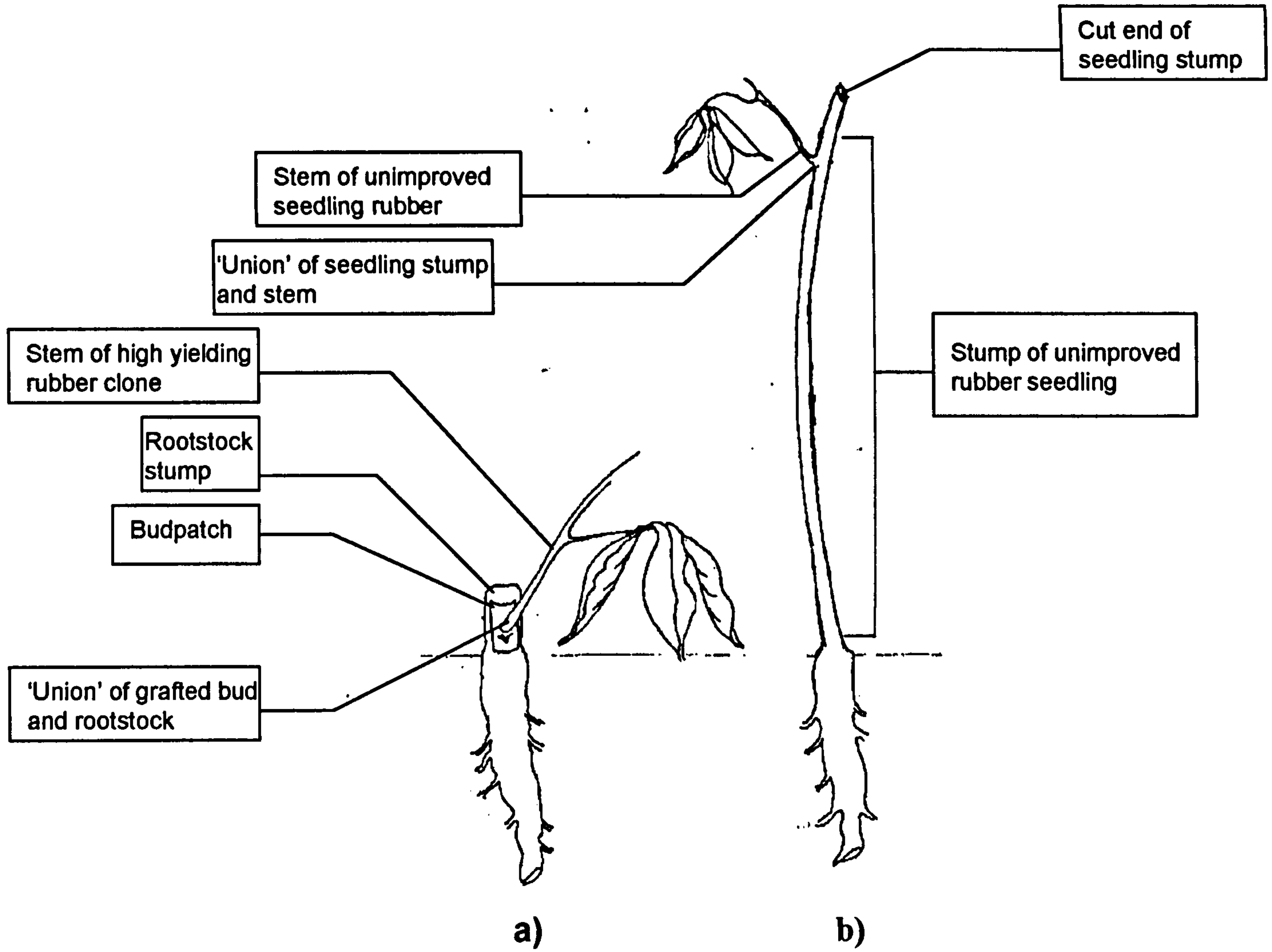


Figure 4.1 Illustration of two types of rubber planting material a) bud-grafted clone and b) seedling ('stumped seedling').

Seedling populations are inherently variable, and this leads to large differences between trees in terms of both growth and yield (Section 2.1.7.6; Appendix 2.1). Dijkman (1951) states that in some cases, 70% of the yield of a seedling-origin plantation could be accounted for by only 30% of trees, and Whitby (1919) reported a study where 28% of the total yield was produced by 9.6% of the trees. Whatever the exact proportions may be, the management implications are that there will be a low efficiency in use of inputs with seedling trees, as the costs and labour involved will effectively be wasted on a large proportion of the trees, because their production is limited mainly by genetic factors. In contrast, the growth and yield of clonal material is more uniform, and therefore use of inputs is more efficient (Penot, 1997b). The main differences between seedling and clonal planting material are summarised in Table 4.2.

Table 4.2 Summary of differences between seedling and clonal planting material

Characteristic	Seedling planting material	Clonal planting material
Latex yield	Low (350-500 kg/ha in jungle rubber)	High (1500-2000 kg/ha, depending on the clone)
Growth vigour	Good	Good to very good
Variation in growth and yield between trees	Very variable	Relatively uniform
Trunk form (mature tree)	Conical	Cylindrical
Bark thickness	Thick	Thinner
Disease resistance	Low	High
Suitability for jungle rubber conditions	Good	Unknown
Availability of planting material to smallholders	High (collected from mature rubber agroforests)	Low

4.1.4 Traditional methods of establishing seedlings in jungle rubber agroforests

Indigenous knowledge regarding the traditional methods of obtaining and planting rubber seedlings in the jungle rubber system was elicited from a group interview with seven men from the village of Muara Buat in December 1995, all of whom had experience of establishing their own jungle rubber agroforests.

4.1.4.1 Collection and preparation of seedlings

Local 'unimproved' rubber tree seeds and seedlings are collected from mature rubber agroforests. Usually these are planted in a nursery close to the farmer's house and protected by a fence from domestic animals. Seeds and seedlings are very rarely planted in polybags. After two months in the nursery, (if resources are available) fertiliser is added in the form of animal dung, urea and/or triple super phosphate (TSP). When they reach a diameter of approximately 2 cm (at around two years of age), they are uprooted, the roots are trimmed and the shoot is cut back to a height of 1.5 m (sometimes this process is carried out on seedlings of this size that have been uprooted directly from a mature rubber agroforest).[26] The roots of the seedlings are then soaked in the river for around two weeks. When the roots and shoots have begun to resprout, they are planted in the field in holes made quickly with a sharpened stake.

4.1.4.2 Planting

The reason given by farmers for planting seedlings of this large size was that it reduced the risk of loss resulting from damage by pigs. Although there would still be a risk of crown damage from 'simpai' (red monkeys, *Presbytis melalophos nobilis*) for the first four to five years after planting, pigs are a much greater problem as they dig up the tree roots, or break the stem at a very low height, and the whole tree can be lost.

In Muara Buat, rubber is usually planted in January, February and even in March (the end of the rainy season). However, the later in the rainy season, the greater is the susceptibility to drought of bare-rooted seedlings which have been transplanted from the nursery (via soaking in the river), as the root system is small. If the seedlings were planted in polybags, the farmers thought there would be no problem, as the root system would already be well developed. The ideal time for planting was thought to be on an overcast day, when there had been at least two days of rain in the preceding week.

Farmers usually plant trees in a 3 m x 4 m pattern, or even closer (a higher density than recommended in plantations). This gives greater protection from wind and also, if there is some mortality, there are still sufficient numbers of trees to make tapping worthwhile. In addition, farmers mentioned that with this high density the canopy closes quickly and the shade provided reduces the abundance of weeds.

4.1.4.3 Mortality

Mortality rates were quoted by the group as being typically about 10%. The causes mentioned were termites, which attacked tree roots, and fungal infection. However, these farmers believed that local seedlings were much more resistant to the latter than the 'improved' planting material supplied by government estates (PTP) and the Department of Agriculture.[27] Farmers said that if a young tree dies it can be replaced (although only if the farmer has the time).

---

[26] This method of cutting back seedlings in the nursery was standard practice in plantations in the early 20th century, (before the development of clones) when seedlings were planted extensively (Dijkman, 1951). The rationale was that by allowing some time for recovery after 'stumping', growth processes in the plant would become more active, therefore assuring successful establishment in the field after transplanting (Dijkman, 1951).

[27] On the contrary, certain clones have been bred to be resistant to specific leaf diseases (Johnston, 1989; Penot and Aswar, 1994). It is possible that the farmers' perceptions stemmed from the fact that,

4.1.4.4 Factors affecting seedling growth

Farmers believed that topography influenced the growth of seedling rubber. They said that trees planted at the tops of hills were slower growing than those at the bottom, because hilltops are 'less fertile', whereas the bottom is 'fertile'. Also, the trees at the top of the hill give less latex, as the soil is drier. Trees planted on flat land grow better, however there is very little flat land available for rubber in the area. None of the farmers was able to say whether the aspect of a slope had any effect on growth or yield.

In addition to differences in soil fertility, variation in tree growth within a field was thought to be due to differences between the seedlings themselves: some grew very quickly, some very slowly.[28] The third factor mentioned was competition from 'belukar', secondary forest regrowth. Farmers' weeding practices, in response to this factor, are presented in Section 2.1.7.1.

4.1.5 Experimental objectives

Considering the issues discussed above, I designed an experiment with the general aims of testing clonal rubber in a prototype multistrata agroforestry system[29] similar to jungle rubber, and of comparing its performance with the farmers' traditional planting material. The trial was conducted in a farmer's field, on sloping land, and thus was representative of conditions experienced by farmers in the study area. The experiment was conducted at the scale of a whole field, and was researcher-managed to ensure control over all implementation of treatments.

The specific issues identified as requiring research can be formulated as a series of questions:

1. Can clonal rubber be established and grow successfully on sloping land, in a multistrata agroforestry system similar to the conditions found in jungle rubber, with only a very low level of weeding in the rubber row?

2. Is clonal rubber survival and growth significantly greater when a more intensive level of weeding in the rubber tree row is implemented?

---

historically, mistakes had been made by government extension services, in recommending a number of susceptible clones for areas where fungal leaf disease was actually prevalent.

28 Seedling populations are known to be highly variable in terms of vigour (and yield) (Dijkman, 1951; Webster, 1989b).

29 Section 1.2.3.3

3. How does the performance of clonal rubber compare with the rubber seedlings used in the traditional system? Is there an interaction between weeding and the type of rubber planting material?

4. What are the other factors, besides weeding, that affect growth of clonal rubber under smallholders' conditions, and what are the effects of these?

5. What are the practical issues involved in the implementation of a multistrata agroforestry system of this type? How could the system be refined in light of this?

4.2 MATERIALS AND METHODS

4.2.1 Trial context

This experiment was designed to complement the network of on-farm trials set up by the ICRAF/CIRAD/GAPKINDO Smallholder Rubber Agroforestry Project (SRAP), (Penot *et al.*, 1994). SRAP provided technical advice, the clonal rubber planting material, fertiliser and other inputs. The author provided the rubber seedlings, and The Leverhulme Trust paid for fence construction and all other labour costs. All work involved in the establishment and maintenance of the experiment was done by myself, my field assistant (Mbak Yusnidar), and a team of women from the village of Muara Buat.

4.2.2 Site description

The experiment was conducted in a field located 0.2 km from the village of Muara Buat, along the road to Rantau Pandan (Figure 2.2), at an altitude of 235 m asl, and at grid reference 1°40'55" S, 101°52'83" E. The total area of the field was approximately 0.75 ha. The arrangement made with the field owner was that I could borrow the field for two years, and in return, the trees I planted would subsequently belong to the owner.

4.2.2.1 Previous land use

At the start of this experiment, vegetation in the field was six-year old secondary forest regrowth, with a high density of trees (dominated by *Macaranga* spp., *Mallotus* spp. and *Trema* spp.). The height of the stand was approximately 5-6 m, and tree diameters ranged from 3 to 15 cm. There was a sparse understorey of tree seedlings, grasses and ferns.

The field had previously been cleared in 1989, from mature rubber agroforest, then burned and planted with upland rice and seedling rubber. However, due to unforeseen circumstances, the field was abandoned shortly after planting.

4.2.2.2 Topography

The field comprised two large spurs (hereafter referred to as 'hills'), running parallel to each other, and separated by a very small stream (Plates 4.1a and 4.1b). The field was surrounded on three sides by mature rubber agroforest, and on the fourth by flat land which had previously been used for irrigated rice, but was abandoned throughout the duration of this experiment and was dominated by the fern *Stenochloaena palustris.*

4.2.3 Split-plot experimental design

Each hill was sub-divided into three blocks, taking into account the topography of the field (Table 4.3, Figure 4.2) and the potential differences in rubber growth due to slope and aspect. Thus, for each hill, one block was situated on the top of the hill, one on the lower slope on the left side of the hill (when observing from the end of the spur), and one on the lower right side of the hill.

Table 4.3 Physical characteristics of the two hills, and six blocks within the experimental field.

	Hill 1			Hill 2		
Characteristic	**Block 2**	**Block 1**	**Block 3**	**Block 5**	**Block 4**	**Block 6**
Position	Lower slope, left	Ridge	Lower slope, right	Lower slope, left	Ridge	Lower slope, right
Aspect	40° (NE)	305° (NW)	220° (SW)	40° (NE)	305° (NW)	220° (SW)
Average slope (°)	18	4	25	20	9	23

Each block was further sub-divided into two main plots. One of two weeding treatments was assigned to each at random. The choice of weeding as a main plot treatment was logistical: to facilitate easier implementation of the weeding treatments. Supervising workers and ensuring the correct plots were weeded was difficult, because of the topography and because the plot layout was quite complex. The main plots were further divided into two sub-plots, and one of two types of rubber planting material (seedling or bud-grafted clone) randomly allocated to each (Figure 4.2). On the smaller hill (Hill 1), each sub-plot contained nine trees (at least), and on the larger hill (Hill 2) there were at least eighteen trees per sub-plot.

4.2.4 Field preparation and planting

4.2.4.1 Chronology

The field was cleared in September 1995, by hand, using machetes. A broadcast burn was conducted in October 1995, and the remaining large branches cut and pile-burned in November 1995. Logs left after the broadcast burn were used to make a fence, which consisted of six logs at the base (flush with the ground, to prevent pigs getting under), and also two rows of barbed wire at the top, to deter cattle.

a

b

Plate 4.1 a) Hill 1 showing weeded rows of clonal rubber trees and inter-row of regenerating secondary forest species; b) Hill 2, (three months after planting rubber trees).

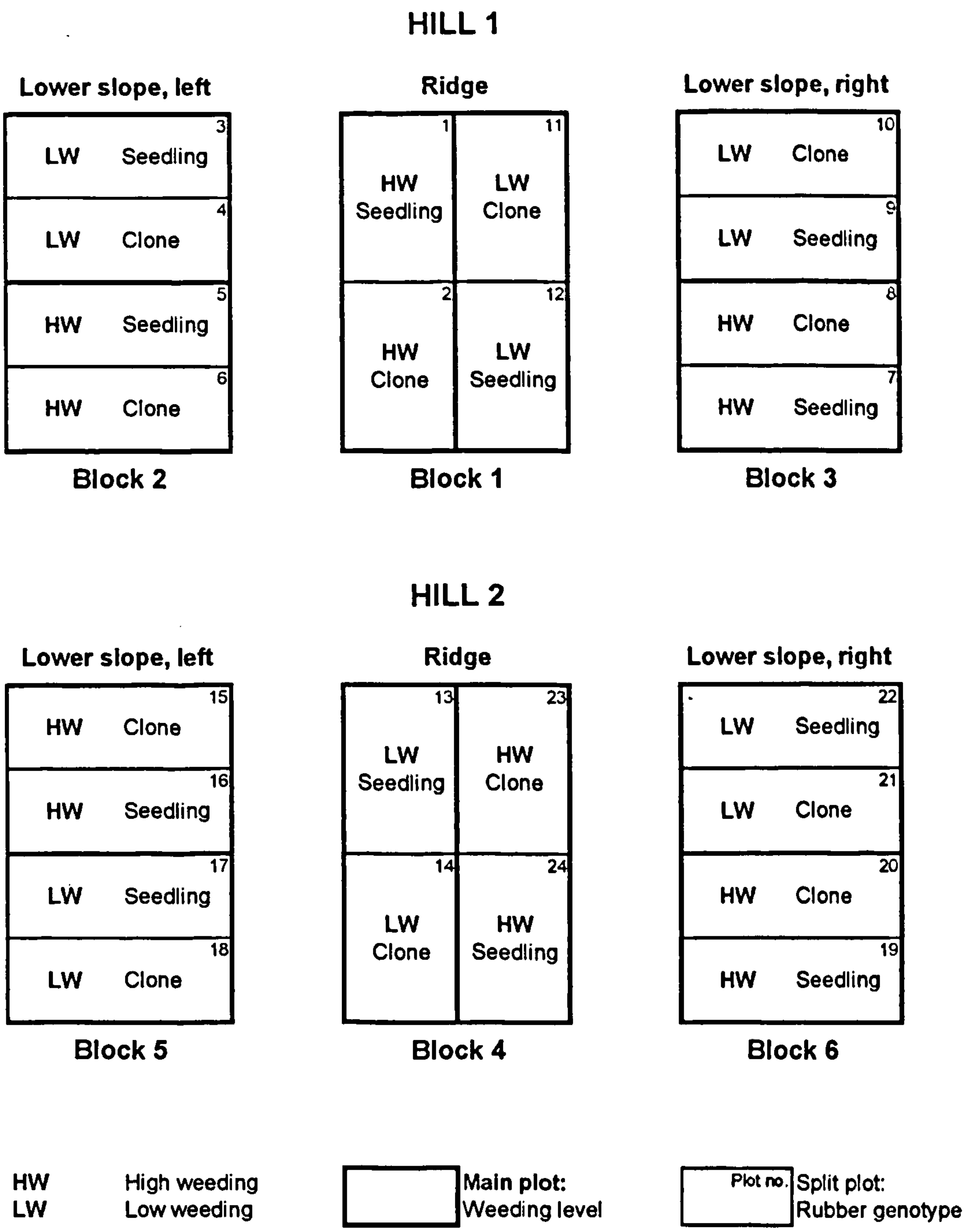


Figure 4.2 Experimental layout, showing the six experimental blocks on the two hills. Each block was divided into two main plots, with one weeding treatment ('High' or 'Low' weeding) assigned randomly to each. Main plots were further subdivided into two split plots, with one rubber planting material treatment (seedling or bud-grafted clone) assigned randomly to each.

Contour staking and digging of planting holes, and plot marking (Section 2.2.1.2) was carried out in November and December 1995. To facilitate planting, in December 1996, weeds were cleared within a 1 m radius of each planting hole, then rubber trees were planted using the methods and fertiliser described in Section 2.2.1.1, on an overcast day, after three previous days of rain (Section 4.1.4.2).

4.2.4.2 Planting material

Clonal rubber planting material

The clonal rubber planting material (bare-root bud-grafted stumps) arrived in November 1995, and we planted these in polybags and prepared a nursery. In December, the very low survival rates of these budded stumps necessitated the purchase of an alternative source of planting material: bud-grafted stumps in polybags. The clone used was PB 260, which exhibits vigorous growth (attaining tappable size around five years after planting, under plantation conditions), and which produces high yields of latex (Penot and Aswar, 1994).

Seedling rubber planting material

The seedling rubber planting material was bought from a farmer in Muara Buat, and had been produced according to traditional practice (Section 4.1.4), and subsequently prepared for planting (i.e. uprooted and cut back to produce stumped seedlings, Figure 4.1b) according to farmers' practices.

4.2.5 Experimental weeding treatments

The experimental weeding treatments consisted of two frequencies of weeding within the row of planted rubber trees, 1 m on either side of the trees, in a strip along the length of the rubber-tree row. The treatments were started three months after planting, in March 1996, and corresponded to the highest and lowest weeding frequencies chosen by farmers in the experiment in Chapter 5.

High weeding treatment: three times per year (every 4 months) (Plate 4.2a)
Low weeding treatment: nine times per year (every 40 days) (Plate 4.2b)

Weeding was carried out with machetes, and the weeds were cut to ground level. After the first weeding, we had to mark out each the strip which had to be weeded, using pegs and string, as workers tended to weed further than 1 m from the rubber trees.

Inter-row vegetation: for both treatments, the inter-row vegetation was lopped to a height of 1.5 m, once only, one year after planting the rubber trees (December 1996), using machetes.

a

b

Plate 4.2 a) High weeded-plot, six weeks since previous weeding; b) Low-weeded plot, four months since previous weeding (twelve months after planting rubber trees).

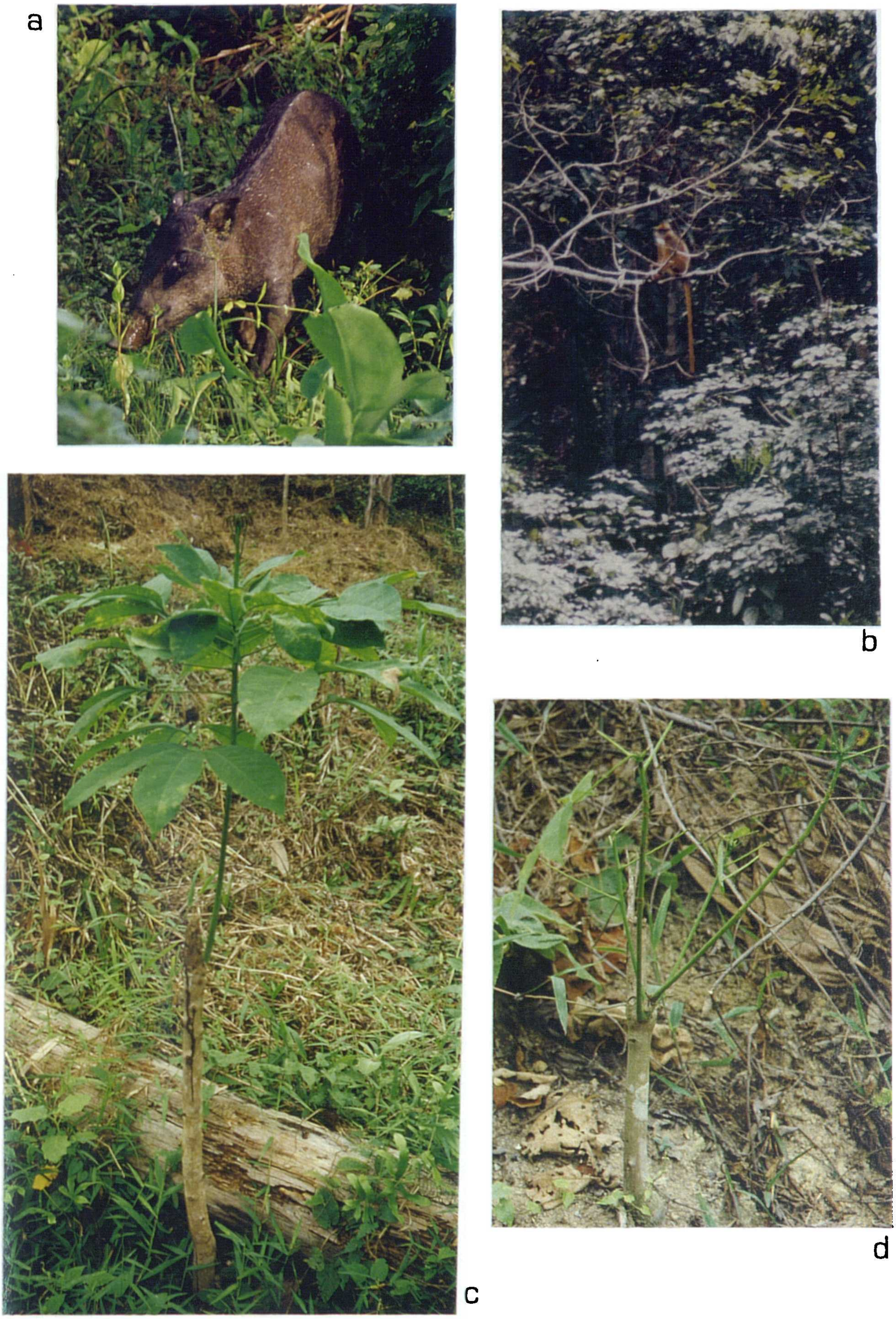


Plate 4.3 a) Vertebrate pest *Sus barbatus* (feral pig); b) Vertebrate pest *Presbytis melalophos nobilis* (Banded leaf monkey); c) damaged rubber tree showing broken stem and new shoot; d) damaged rubber tree showing broken stem and four new shoots which have also been damaged.

4.2.8 Data collection

4.2.8.1 Rubber tree growth

Measurements of rubber tree size were made every three months, starting in March 1996 (three months after planting) and continued until September 1997 (21 months after planting). In addition, vertebrate pest damage (the number of times that each tree's main stem was completely severed) and tree survival was recorded at each measurement occasion.

<u>Clonal rubber trees</u>
Clonal tree height was measured from the basal graft (Figure 4.1a) to the top of the stem (the union of the bud graft and rootstock is approximately 5 cm above ground level). Diameter was measured at 10 cm above the basal graft, using calipers.

<u>Seedling rubber trees</u>
The stem height of the 'stumped seedlings' (Section 4.1.3.2) was measured from the union of stem and the planted stump (Figure 4.1b) to the top of the stem. Diameter was measured 10 cm above this union. As the original stems often died after transplanting, and new ones were produced (some of which subsequently died), each stem was 'labelled' with colour-coded plastic thread, which ensured continuity of the data collected at every three-monthly measurement. Once one stem had become dominant, the others were pruned, as was the case with clones (Section 2.2.1.3). The height above the ground at which the stem was initiated from the stump was also measured, to assess whether weeding treatment had any effect on this.

Thus, for both types of planting material, the shoot ('stem') arising from the stump was used as the most comparable indicator of growth after planting in the field.

4.2.8.2 Soil analyses

Initial soil conditions were assessed in July 1996, six months after planting the rubber trees. Using a hand auger, six samples (0-15 cm) were taken at random positions within the rubber tree rows in each plot. A further six samples were taken from the inter-row areas. The samples were pooled for each position within the plot (row and inter-row), giving two samples per plot for analysis. The soil was air-dried on drying racks and sieved with a 2 mm sieve, then 100 g samples were bagged, labelled and sent away for commercial analysis at the Rubber Research Institute of Sembawa, Palembang, South Sumatra. Samples were analysed for pH, C_{org}, total N, $P_{Bray\ II}$, exchangeable K, Ca, Mg, Na, Al and H^+, and cation exchange capacity (CEC).

In addition, to investigate potential differences in the physical and chemical properties of the soil due to the effect of slope, twenty samples were taken at each of three positions (top, middle and bottom) on each of the two hills. These were pooled, giving six samples in total, which were analysed for chemical properties (as described above), and also for texture.

4.2.8.3 Vegetation monitoring

Rubber-tree row

Weeds were recorded by growth-form: trees, shrubs, herbs, grasses, ferns and climbers (Table 2.6). Weed dominance was assessed within the rubber-tree rows just before weeding was implemented, *i.e.* at the incidence of highest weed biomass. Weeds in the 'low weeding' treatment were assessed before every four-monthly weeding event, namely July 1996, November 1996, March 1997 and July 1997. These sampling occasions coincided with certain scheduled weedings in the 'high weeding' treatment, therefore weeds were characterised in the two treatments at the same time.

Six one-metre square quadrats per plot were used to record the percentage weed cover and average height of each growth-form. A stratified-random sampling method was used, with two samples taken at random positions within the upper, middle and lower row in each plot. This avoided any bias related to position on the slope (bias could have arisen with the use of a completely-randomised sampling design).

Inter-row

Inter-row vegetation was characterised every eight months, starting in June 1996, six months after planting the rubber trees. This gave three measurements in total. Six 1 m^2 samples were located in each plot, using a stratified-random sampling method (above), which gave a total of 72 samples per measurement.

The growth-form classification in Table 2.6 was used, although some were classes were further sub-divided. For example, the 'tree' category was divided into 'individual seedlings', and 'coppice shoots' (shoots growing from a cut stump), and the 'grass' and 'fern' categories were divided into 'self-supporting' (upright growth habit) and 'creeping', low-growing forms. Another category 'woody climber' was included, as these occurred in the inter-row vegetation but not in the vegetation in the rubber row. Certain forms had to be assessed by their density (number of individuals per m^2), not as percentage cover, as this was more suitable for the form of the vegetation. The average height of each growth form was also recorded.

Soil temperature under weed cover

Soil temperature under weed cover and bare soil on Hill 1, and under the mature rubber agroforest bordering the field, were measured once, in February 1996, to provide an indication of the shading effects of weed cover on the soil.[32] The soil temperature was measured at 5 cm intervals, between 0 and 40 cm depths; measurements were taken around midday, under clear skies.

4.2.8.4 Foliar nutrient analyses

Foliar nutrient and water contents were analysed in October 1997 (22 months after planting) as described in Chapter 3. In this experiment six trees from each plot (Figure 4.2) were sampled, then the leaves composited to give one sample per plot for analysis (24 samples in total).

4.2.9 Data analysis

All statistical analyses were conducted using Genstat 5.32 for Windows, and when ANOVA was used, data was checked for homogeneity of variance and normality by analysis of residuals. Results were taken as being 'non-significant' if they were not significant at the 5% level or below.

4.2.9.1 Rubber tree growth

The effect of weeding and rubber planting material on the height and diameter of undamaged trees (21 months after planting) was analysed for plot means with ANOVA. A split-plot design was used, with weeding at the main plot level, and rubber planting material ('genotype') at the sub-plot level (Table 4.4).

Table 4.4. Split-plot ANOVA structure

Source of variation	**Degrees of freedom (d.f.)**
Block stratum	5
Block x Weeding stratum	
Weeding	1
Residual	5
Block x Weeding x Genotype stratum	
Genotype	1
Weedings x Genotype	1
Residual	10
Total	23

Absolute growth rates (AGR) of stem diameter and height were calculated as the increment between two consecutive three-monthly measurements. The difference between treatments was examined graphically, using the mean AGR for each treatment.

[32] This was a one-off measurement, part of an ASB (Alternatives to Slash and Burn) greenhouse gas study by Dr Y. Husin, in which I participated.

Relative growth rates of stems (RGR) were calculated (after Hunt, 1990), for diameter (mm mm^{-1} in a time period of three months) as:

$$\log_e D_2 - \log_e D_1$$

Where D_1 and D_2 are stem diameters at measurement times 1 and 2, three months apart

Likewise, RGR was calculated for stem height (cm cm^{-1} in a time period of three months) as:

$$\log_e H_2 - \log_e H_1$$

Where H_1 and H_2 are stem heights at measurement times 1 and 2, three months apart

The difference between treatments was examined graphically, using the mean RGR for each treatment, at successive measurement intervals.

4.2.9.2 Relative growth rates of trees in each pest-damage class

Over each measurement interval, mean RGR was calculated for trees in each pest-damage class, excluding any trees that had been damaged during that particular interval.

This was done using a database (Microsoft Access). For each measurement time, all the trees that had not been damaged in the three months since the previous measurement, were identified, and isolated as a sub-set of the data. These trees were grouped according to rubber planting material and weeding treatment. Trees in each group were then classified, according to their previous history of damage, i.e. undamaged trees were put into damage class 0, trees which had sustained one previous stem break were put into damage class 1, and so forth.

The RGR of each tree was calculated as described above, using the data from its previous three-monthly measurement. The mean RGR (and S.E.) was then calculated for trees in each damage class. These values were then plotted as a bar chart, and inspected for differences in growth rate among damage classes for clones and seedlings under the two weeding treatments.

4.2.9.3 Plot-level analysis of tree growth in relation to pest damage

The index of pest damage was calculated per plot, as the total number of stem breaks sustained by trees within the plot, divided by the number of trees per plot. This was regressed against the mean stem diameter per plot.

4.2.9.4 Soil analyses

<u>All plots</u>

Firstly, ANOVA was conducted to see if there was a significant difference between the row and inter-row samples. There was no difference, so these two values were averaged to give one value per plot. A second ANOVA was then conducted on these values.

<u>Slope position</u>

One-way ANOVA (for randomised blocks) was conducted, with 'hill' as the blocking factor, giving 2 d.f. for the treatment term (position on slope), 3 d.f. for the error term, and 5 d.f. in total.

4.2.9.5 Vegetation characterisation

For the rubber-tree row data, values of percentage cover of each growth form were averaged to give a mean value per m^2, for each of the two weeding treatments, at each sampling occasion. For the inter-row vegetation, values of percentage cover or density of each growth were averaged to give a mean value per m^2 at each sampling occasion. Trends over time were examined graphically.

4.2.9.6 Foliar water and nutrient analyses

Nutrient and water contents of rubber tree leaves were analysed in a split-plot ANOVA, with the same structure as that described in Section 4.2.9.1.

4.3 RESULTS

4.3.1 Characterisation of physical and chemical soil properties

Six months after planting, no significant differences were found for soil texture among the positions at the top, middle or bottom of the slopes of the two hills (one-way ANOVA), Table 4.5. The mean values for sand, silt and clay content over the both hills correspond to a USDA textural classification of sandy clay loam.

Chemical soil properties (Table 4.5) did not vary significantly with slope position (one-way ANOVA), the only exception being K, where the bottom and mid-slope values were significantly greater than those at the top of the slope ($LSD_{0.05} = 0.026$).

Table 4.5 Physical and chemical characteristics of soil at different slope positions on the two experimental hills.

HILL	SLOPE POSITION	SAND %	SILT %	CLAY %	pH (H_2O)	C %	N %	P (Bray)	K	Ca	Mg	CEC	Al	H+
									(me/100 g)					
1	Top	66	18	19	4.36	1.89	0.18	8	0.22	0.12	0.24	5.17	0.70	0.01
2	Top	65	17	18	4.39	2.25	0.16	5	0.24	0.33	0.27	3.47	0.42	0.01
1	Middle	51	20	29	4.38	2.87	0.16	8	0.36	0.45	0.53	5.83	0.61	0.01
2	Middle	64	12	24	4.37	1.88	0.20	4	0.36	0.33	0.32	6.32	0.42	0.04
1	Bottom	66	17	17	4.37	2.00	0.16	5	0.33	0.34	0.37	5.45	0.58	0.02
2	Bottom	62	15	23	4.44	1.70	0.14	3	0.33	0.43	0.47	6.82	0.47	0.06
Mean		62.3	16.5	21.7	4.39	2.10	0.17	5.5	0.31	0.33	0.37	5.51	0.53	0.03
S.E.		2.35	1.12	1.86	0.01	0.17	0.01	0.85	0.02	0.05	0.05	0.47	0.05	0.01

Results of chemical soil analyses (Table 4.6) showed that there was no significant difference between the row and inter-row areas for any soil property. Therefore, the mean of these two values per plot was calculated, and this was used in a subsequent ANOVA to assess differences between experimental plots and blocks.

Results from this second ANOVA showed that there was no significant difference between plots under the high and low weeding treatments, for any of the soil nutrients. Therefore, it is reasonable to conclude that there was no underlying variation in soil properties which may have influenced the effects of the weeding treatments.

4.3.2 Characterisation of weeds and secondary forest regrowth

4.3.2.1 Regeneration of inter-row vegetation

The density of tree seedlings (plants m^{-2}) declined over time, probably due to competition processes within the inter-row area (self-thinning), which resulted in a small number of individuals becoming dominant. The lower mean height of trees observed in February 1997 (Figure 4.3b) was a result of the deliberate lopping of the tallest individuals to a height of 1.5 m, in December 1996 (one year after planting) as described in the experimental protocol. Subsequently, tree height growth had recovered by October 1997, giving an average height of 142 cm; the maximum height recorded was 350 cm (*Trema orientalis:* see Plates 4.4a and4.4b).

The abundance of other woody growth-forms did not change dramatically over time, in contrast to the 'herb' morphotype which had completely disappeared by October 1997 (Figure 4.3c). There was also a marked decrease in the percentage cover of low-growing grasses (indicated by the high cover of dead grass observed in Figure 4.3b). However, there was an increase in fern numbers with time. The trends exhibited by these non-woody morphotypes were probably caused by the increased shade cast by the woody growth-forms.

Table 4.6 Chemical characteristics of surface soil in each of the 24 experimental plots (composite sample from six points in the rubber tree row (R), and six points in the inter-row area (IR), at depth 0-15 cm).

HILL	BLOCK	PLOT	R/IR[1]	WEED[2]	pH (H_2O)	C %	N %	P (Bray)	K	Ca	Mg	CEC	Al	H+
											(me/100 g)			
1	1	1	R	H	4.43	2.49	0.15	8	0.22	0.24	0.36	4.97	0.52	0.02
1	1	1	IR	H	4.29	2.01	0.13	7	0.30	0.17	0.31	5.66	0.72	0.04
1	1	2	R	H	4.54	2.26	0.14	8	0.39	0.52	0.44	7.39	0.79	0.01
1	1	2	IR	H	4.30	2.26	0.16	5	0.28	0.25	0.34	7.46	1.18	0.03
1	2	3	R	L	4.51	2.11	0.16	7	0.29	0.37	0.40	8.22	0.58	0.06
1	2	3	IR	L	4.48	2.01	0.10	5	0.28	0.31	0.37	5.28	0.54	0.07
1	2	4	R	L	4.53	2.25	0.14	4	0.18	0.46	0.37	6.16	0.53	0.20
1	2	4	IR	L	4.44	2.13	0.15	3	0.24	0.31	0.32	6.20	0.84	0.03
1	2	5	R	H	4.46	1.37	0.12	5	0.25	0.34	0.42	5.97	0.47	0.05
1	2	5	IR	H	4.37	1.64	0.10	4	0.25	0.35	0.39	5.40	0.45	0.07
1	2	6	R	H	4.35	1.64	0.12	5	0.34	0.38	0.46	5.85	0.70	0.07
1	2	6	IR	H	4.44	1.83	0.13	5	0.29	0.41	0.46	4.48	0.66	0.06
1	3	7	R	H	4.29	2.01	0.12	4	0.28	0.24	0.32	4.98	0.84	0.03
1	3	7	IR	H	4.37	2.01	0.09	4	0.24	0.25	0.41	5.22	0.96	0.02
1	3	8	R	H	4.11	1.77	0.12	3	0.21	0.38	0.39	5.37	0.54	0.01
1	3	8	IR	H	4.35	1.52	0.12	4	0.21	0.36	0.37	5.10	0.78	0.07
1	3	9	R	L	4.30	1.64	0.14	6	0.31	0.31	0.25	5.56	0.63	0.03
1	3	9	IR	L	4.35	1.64	0.14	4	0.32	0.37	0.39	5.80	0.63	0.01
1	3	10	R	L	4.30	1.76	0.14	4	0.22	0.28	0.29	4.19	0.54	0.01
1	3	10	IR	L	4.40	2.00	0.10	3	0.23	0.07	0.34	4.23	0.57	0.02
1	1	11	R	L	4.30	1.27	0.13	5	0.17	0.10	0.19	3.89	0.82	0.02
1	1	11	IR	L	4.36	1.82	0.12	8	0.22	0.13	0.19	4.05	0.72	0.13
1	1	12	R	L	4.30	1.89	0.12	6	0.22	0.25	0.27	5.03	0.80	0.05
1	1	12	IR	L	4.50	2.14	0.15	5	0.19	0.63	0.36	4.78	0.44	0.03
2	4	13	R	L	4.47	1.63	0.12	4	0.30	0.46	0.25	4.80	0.59	0.03
2	4	13	IR	L	4.53	1.88	0.12	5	0.36	0.62	0.34	5.10	0.40	0.05
2	4	14	R	L	4.39	2.13	0.16	3	0.34	0.75	0.39	5.01	0.21	0.08
2	4	14	IR	L	4.40	2.01	0.14	5	0.24	0.65	0.46	5.04	0.28	0.05
2	5	15	R	H	4.65	1.27	0.11	4	0.40	0.93	0.52	3.98	0.17	0.07
2	5	15	IR	H	4.47	2.48	0.15	5	0.36	1.13	0.59	4.75	0.02	0.05
2	5	16	R	H	4.33	1.88	0.18	3	0.54	0.63	0.54	4.00	0.24	0.02
2	5	16	IR	H	4.46	2.49	0.19	5	0.68	0.64	0.48	4.81	0.22	0.04
2	5	17	R	L	4.65	2.23	0.14	4	0.26	0.34	0.36	4.99	0.67	0.02
2	5	17	IR	L	4.50	2.38	0.16	5	0.44	0.41	0.37	4.95	0.39	0.03
2	5	18	R	L	4.36	1.54	0.14	4	0.34	0.35	0.29	4.89	0.66	0.04
2	5	18	IR	L	4.40	1.15	0.22	7	0.33	0.62	0.49	4.75	0.39	0.08
2	6	19	R	H	4.30	1.27	0.13	5	0.32	0.22	0.24	3.74	0.64	0.05
2	6	19	IR	H	4.49	1.40	0.14	3	0.23	0.36	0.25	4.82	0.49	0.03
2	6	20	R	H	4.58	2.35	0.15	4	0.34	0.43	0.30	3.75	0.17	0.09
2	6	20	IR	H	4.91	3.58	0.17	4	0.38	0.59	0.32	4.93	0.23	0.03
2	6	21	R	L	4.57	1.57	0.16	3	0.47	0.51	0.42	3.95	0.23	0.01
2	6	21	IR	L	4.60	1.27	0.12	4	0.34	0.55	0.47	5.04	0.14	0.01
2	6	22	R	L	4.00	1.03	0.13	4	0.28	0.73	0.46	4.37	0.03	0.07
2	6	22	IR	L	4.24	1.57	0.13	4	0.40	1.06	0.67	4.08	0.02	0.05
2	4	23	R	H	4.35	1.64	0.13	4	0.36	0.54	0.29	5.39	0.52	0.03
2	4	23	IR	H	4.42	1.03	0.16	5	0.19	0.35	0.19	5.07	0.89	0.02
2	4	24	R	H	4.55	1.89	0.14	3	0.44	0.53	0.31	3.56	0.37	0.03
2	4	24	IR	H	4.47	1.82	0.12	7	0.20	0.26	0.20	5.56	0.91	0.02
Grand mean					4.42	1.853	0.14	4.7	0.306	0.44	0.37	5.054	0.524	0.045
S.E.					0.638	0.268	0.020	0.680	0.044	0.064	0.053	0.729	0.076	0.006

[1] Position within each plot. R: Rubber tree row, IR: Inter-row area.
[2] Experimental weeding treatment. H: High weeding, L: Low weeding.

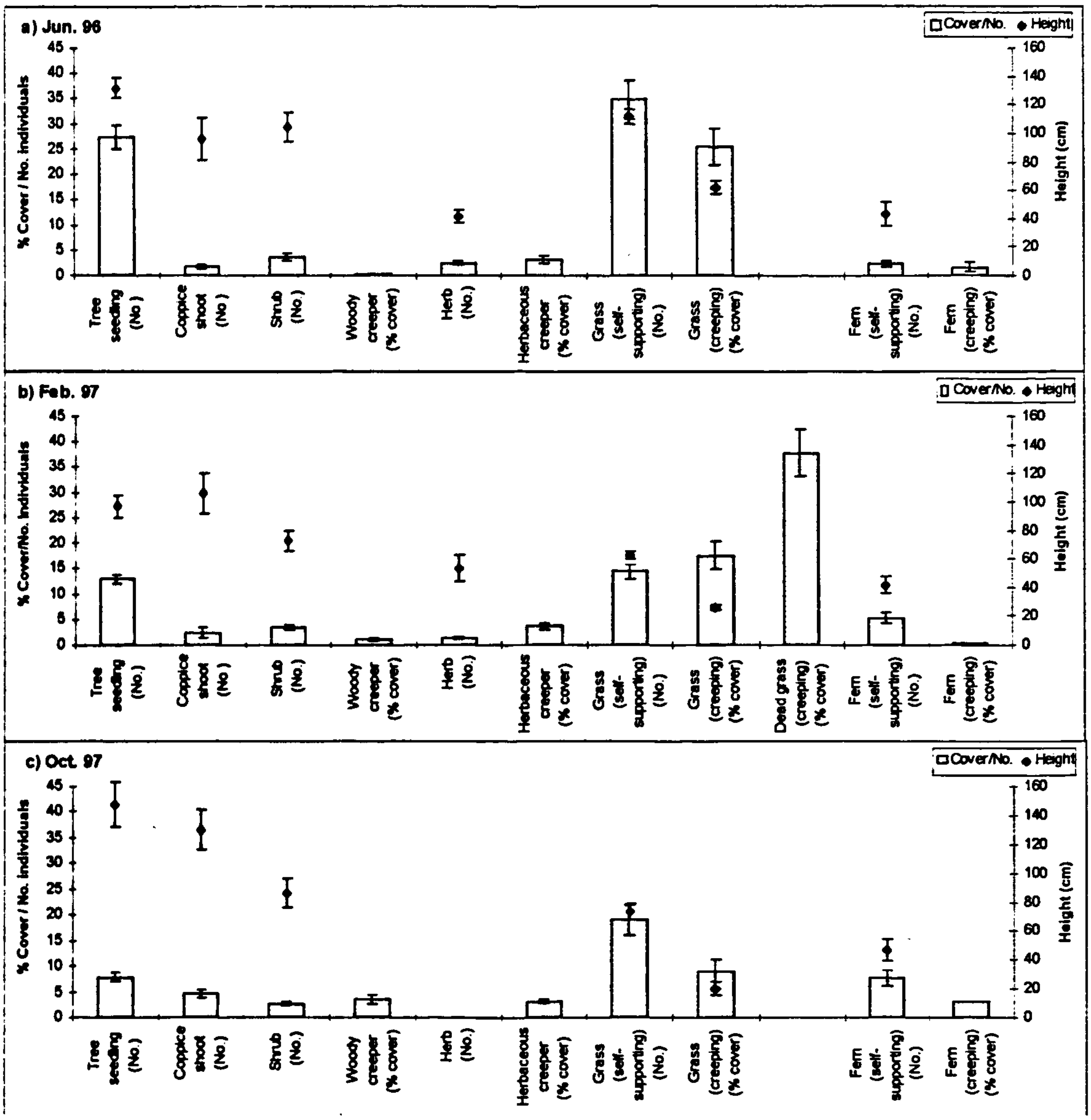


Figure 4.3 Composition and average height of secondary vegetation in the inter-row area, at three eight-monthly intervals: a) June 1996 (eight months after burning the field, and six months after planting rubber); b) February 1997 (sixteen months after burning the field, and fourteen months after planting rubber) and c) October 1997 (twenty-four months after burning the field, and twenty-two months after planting rubber). For each growth form, the mean of 72 replicate 1 m^2 quadrats and the standard error of this mean are presented for each sampling date, for either percentage cover or the number of individuals per m^2 (according to the growth habit of each morphotype), and for mean height (cm).

a

b

Plate 4.4 a) Hill 1: Rubber trees and secondary forest regrowth (twenty one months after planting rubber trees); b) Hill 2: Clonal rubber trees in weeded row and secondary forest regrowth in inter-row area (twenty one months after planting rubber trees).

4.3.2.2 Weed regeneration in rubber tree rows, in response to weeding treatments

There were clear differences between the high and low weeding treatments in terms of weed percentage cover (Figure 4.4a and 4.4c; note the different scales on the axes). In general, the composition of the weed community did not change dramatically with time, although in the high weeding treatment there was a decrease in the percentage cover of herbaceous growth forms, and a very slight decrease in the abundance of both tree and fern forms. The same trend was observed in the low weeding treatment plots for herbs and ferns. However, by contrast, the percentage cover of trees was fairly constant over time. A consistent increase in the cover of climbers (mainly *Mikania* spp.) was observed in the low weeding treatment (Figure 4.4c), although grasses remained the dominant growth form. The mean height of each growth form also indicates the difference between high and low weeding treatments (Figures 4.4b and d). After November 1996, weeds only attained heights of 5-10 cm in the high weeding treatment, whereas in the low weeding plots, mean weed height was between 15 and 30 cm.

4.3.2.3. Soil temperature under weed cover

Soil temperature was lower under weed cover than under bare soil, between 5 and 40 cm depth (Figure 4.5), to a level approaching that of mature rubber agroforest. However, these data provide only limited evidence, as only one sample was taken for each vegetation type. Watson *et al.* (1964a) state that the lower soil temperatures found under cover plants than under bare soil demonstrate the beneficial effect of cover plants in protecting the soil from insolation, and also in reducing the high rates of mineralisation of soil organic matter observed under bare soil.

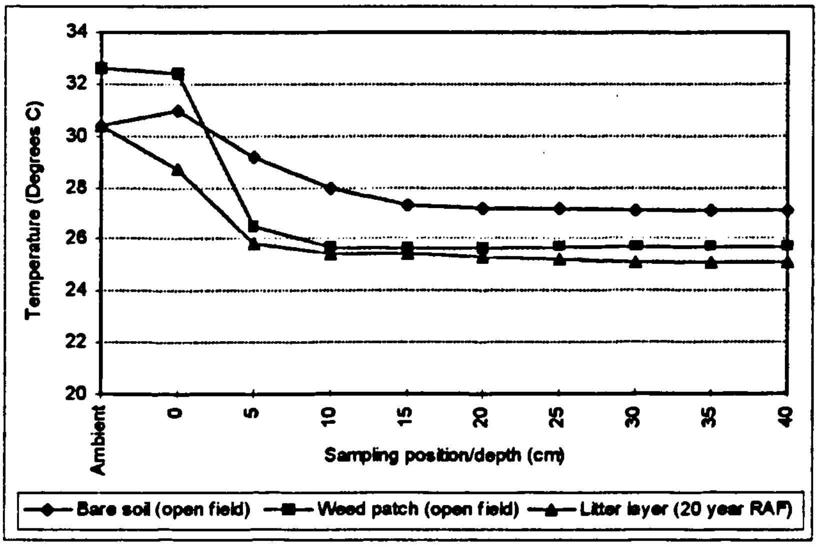


Figure 4.5 Soil temperatures (°C) down the profile under bare soil, a weed patch and under 20 year old rubber agroforest. Ambient temperature taken at 10 cm above the soil surface, and temperature at soil surface corresponds to depth 0 cm. Time of sampling: bare soil, 11.00; agroforest, 12.00; weed patch, 12.10.

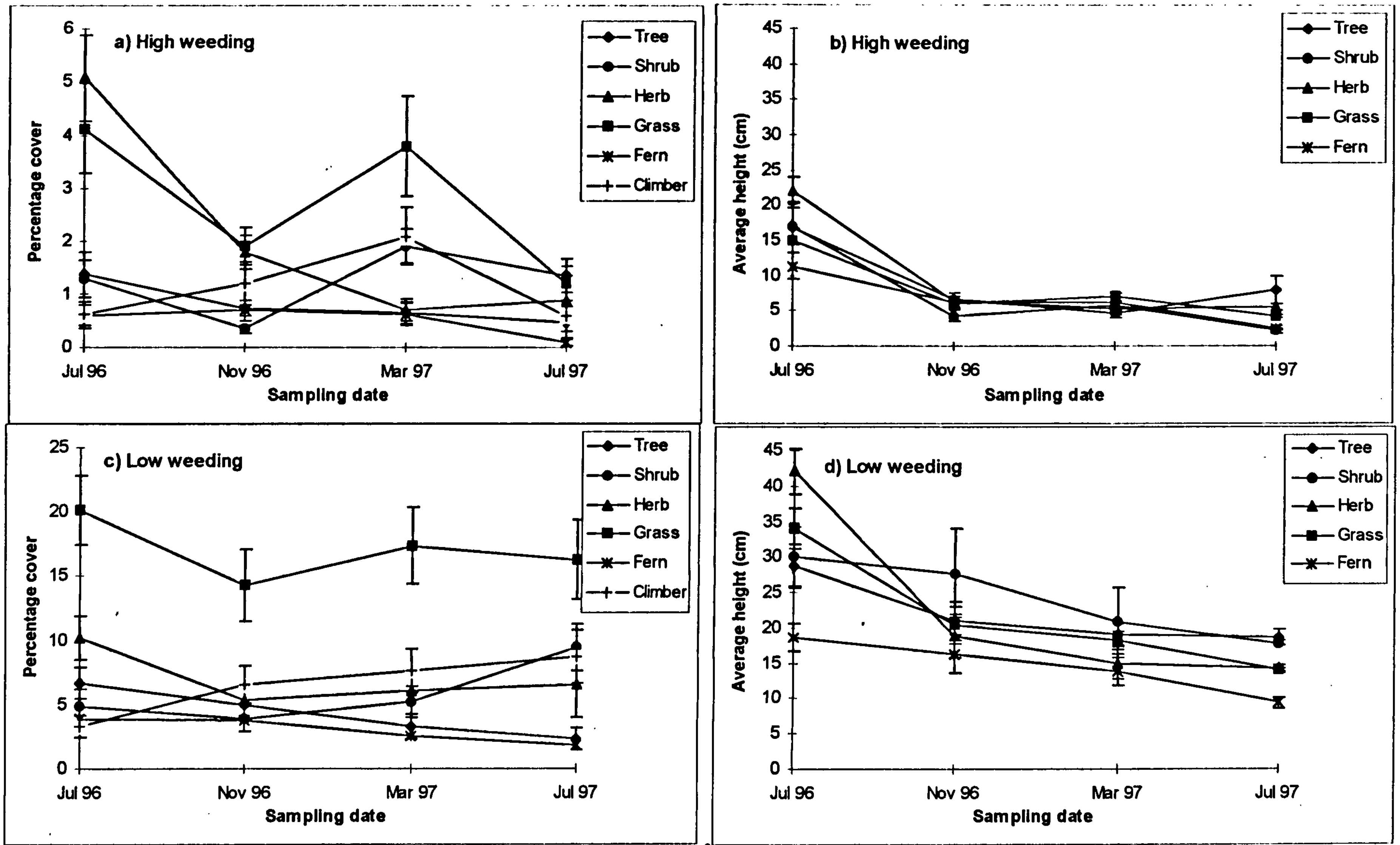


Figure 4.4 Weed abundance and height over time, for each growth form, per m^2: a) percentage cover, high weeding treatment; b) average height (cm), high weeding treatment; c) percentage cover, low weeding treatments; d) average height (cm), low weeding treatment. Each treatment mean presented is the average of twelve plot means (these plot means derived from three 1 m^2 samples per plot); standard errors of treatment means also shown. Note the different scales on the y-axes for percentage cover.

4.3.3 Tree mortality: differences between clonal and seedling rubber

Clonal rubber trees

Only three clonal trees died and had to be replaced, and this was due to a minor landslide in Block 6. New trees were planted in the original positions in June 1996, and these trees established successfully.

In addition, after severe damage caused by pigs in June 1996, a number of trees in Block 5 were replaced with new trees. The subsequent growth of these trees, and the growth of the replacements planted in Block 6 was monitored and the results are presented separately (Section 4.3.4).

Seedling rubber trees

Mortality of seedling trees was very high (35.3 % of the 173 original seedling trees that were planted in January 1996) (Table 4.7). The majority of the seedling tree deaths occurred within six months of planting (Table 4.7), and there were no obvious differences in mortality between trees in the high and low weeding treatments.

Table 4.7 Mortality of the seedling rubber trees which were planted in January 1996 (n=173): numbers of trees that had died in the three months preceding each measurement occasion, in the high and low weeding treatments.

Measurement date (months after planting)	Mar.96 (3)	Jun.96 (6)	Sep.96 (9)	Dec.96 (12)	Mar.97 (15)	Jun.97 (18)	Sep.97 (21)
High weeding	12	16	3	0	0	0	0
Low weeding	11	14	2	2	0	1	0
Total	23	30	5	2	0	1	0
(Percentage of original trees)	(13.3)	(17.3)	(2.9)	(1.2)	(0)	(0.6)	(0)

The trees that died were replaced, and the mortality rate of these replacement trees was slightly lower than the rates observed for the original trees, being 20% in the high weeding treatment (7 trees died from a total of 39 replacements), and 14% in the low weeding treatment (5 of the 35 replacement trees) (Table 4.8). The highest mortality rate was observed for replacement trees that had been planted at the beginning of the dry season (the three months leading up to June 1996), and the highest rate of mortality was during the height of the dry season (the three months leading up to September 1996). All replacement trees planted after September 1996 survived until the end of the experiment (September 1997).

Table 4.8 Mortality of replacement seedling trees over the course of the experiment: numbers of trees replanted before each measurement occasion and which subsequently died (as well as the measurement interval in which these died), for the high and low weeding treatments

	Measurement date (months after planting)	Mar.96 (3)	Jun.96 (6)	Sep.96 (9)	Dec.96 (12)	Mar.97 (15)	Jun.97 (18)	Sep.97 (21)
High weeding	No. of replanted trees / No. of trees that subsequently died	14	18	4	0	1	2	0
	Jun.96 (6)	1						
	Sep.96 (9)	-	3					
	Dec.96 (12)	-	1	1				
	Mar.97 (15)	-	-	-	-			
	Jun.97 (18)	-	1	-	-	-		
	Sep.97 (21)	-	-	-	-	-	-	
	% replanted trees that subsequently died	7	28	25	0	0	0	0
Low weeding	No. of replanted trees / No. of trees that subsequently died	11	14	5	3	2	0	0
	Jun.96 (6)	-						
	Sep.96 (9)	2	3					
	Dec.96 (12)	-	-	-				
	Mar.97 (15)	-	-	-	-			
	Jun.97 (18)	-	-	-	-	-		
	Sep.97 (21)	-	-	-	-	-	-	
	% replanted trees that subsequently died	18	21	0	0	0	0	0

In addition to poor survival of seedlings, production of a viable shoot from the seedling stump was very slow. Often, the original shoot (or sprouting bud), that was present when the stump was transplanted, died. There was frequently a delay before another shoot was produced. At the first measurement, three months after planting, 56 of the original 173 seedlings (32 %) had not yet produced shoots (but were still alive). By the time of the next measurement, (six months after planting), 37 of these 56 trees had sprouted and survived until the end of the experiment. There were no trends observed in the speed of shoot production, in relation to weeding treatment. By contrast, the initial shoot produced by the clonal rubber trees always survived. This was because the clonal trees were transplanted from the nursery with one whorl of fully-expanded leaves (a standard recommendation for planting clonal planting material).

In conclusion, clonal rubber trees were established far more successfully than seedling rubber trees.

4.3.4 Performance of replacement rubber trees

<u>Clonal rubber trees</u>

Of the ten replacement trees that were planted in June 1996, all were subsequently damaged by pests in the following 15 months (Table 4.9). The two trees in damage class 1 were not damaged until 12 and 15 months after they were planted, and this was just top damage caused by monkeys (Figure 4.6, the two largest trees). These trees therefore attained sizes (diameter and height) comparable with those trees planted in December 1995, and can be considered to have established successfully.

The other eight replacement trees however, sustained repeated damage, and after 15 months, none had attained heights of over 1 m (Figure 4.6b). The six trees with the smallest diameter in Figure 4.6a were those that had been damaged three or more times, and they were located at the base of the hill where there was heavy shade from the inter-row vegetation. In addition to pest damage and shade, the fact that the replacement trees were planted in June, at the onset of the dry season is likely to have contributed to their low rate of successful establishment (20%).

Table 4.9 Number of stem-breaks (caused by pests) sustained by clonal rubber trees that were replanted in June 1996, in the following 15 months.

Damage class (number of stem-breaks per tree)	1	2	3	4	5
Number of trees	2	2	3	1	2

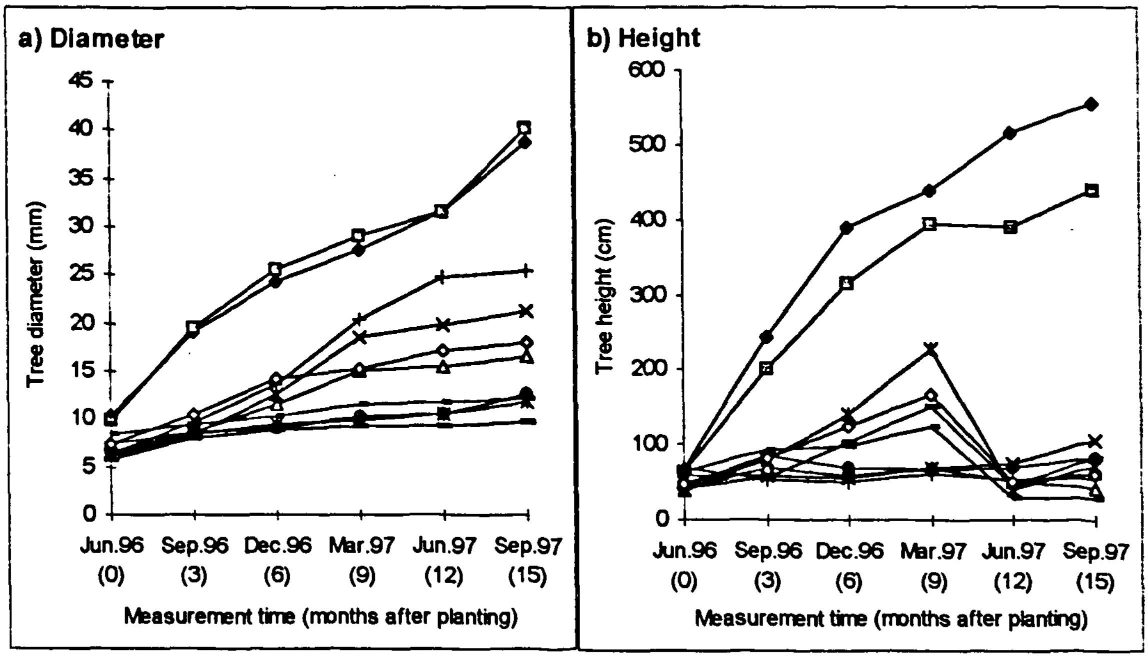


Figure 4.6 Growth of ten replacement clonal rubber trees that were planted in June 1996: a) stem diameter (mm), b) stem height (cm). Each tree is distinguished by a different symbol.

Seedling rubber trees

Replacement seedling trees also suffered from pest damage. Sometimes the shoot was broken off completely, as illustrated by the zero values seen for diameter and height in Figure 4.7. Occasionally the stump itself was broken, and so the entire new stem plus some of the original seedling was lost.

Replacement trees in the high weeding treatment appeared to fare slightly better than their counterparts in the low weeding treatment (Figure 4.7), with a few trees attaining diameters of over 30 mm, and heights of over 3 m. In the low weeding treatment, however, no replacement tree exceeded 10 mm in diameter or 1 m in height by the end of the experiment. On average, replacement clonal trees grew to larger sizes than replacement seedling trees (compare Figures 4.6 and 4.7).

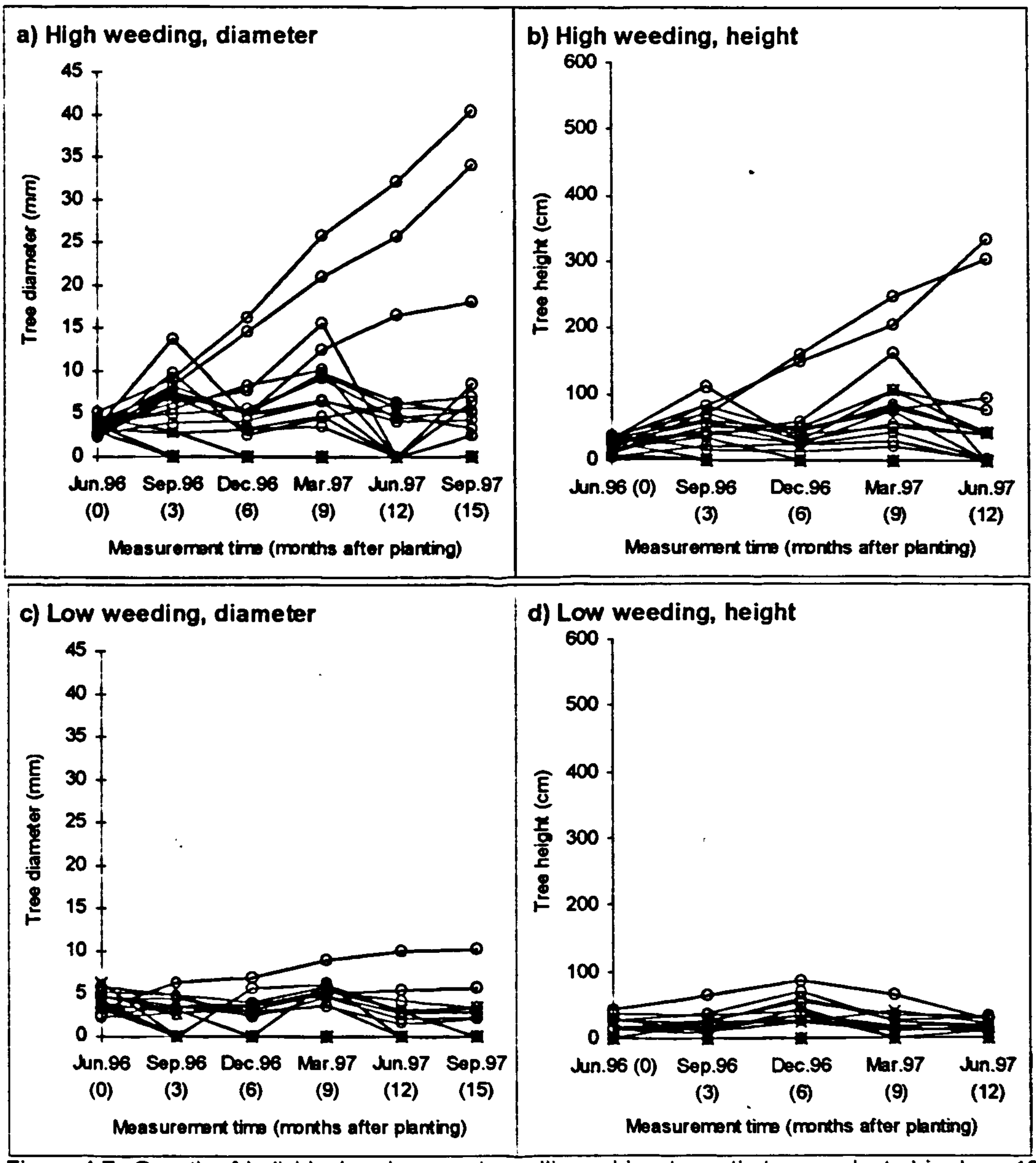


Figure 4.7 Growth of individual replacement seedling rubber trees that were planted in June 1996: a) stem diameter (mm), high weeding treatment (n=18); b) stem height (cm), high weeding treatment; c) stem diameter (mm), low weeding treatment (n=14); d) stem height (cm), low weeding treatment.

4.3.5 Incidence of pest damage on clonal and seedling rubber trees

Clonal rubber trees

As pest damage was seen to have a severe effect on tree growth in the case of replacement trees (Section 4.3.4), pest damage was quantified for all trees in the experiment (Figure 4.8). The numbers of undamaged trees declined with time, as more trees were damaged during the course of the experiment, and moved into other damage classes, and this trend was much stronger in the high than the low weeding treatment. Likewise, there were more trees in the higher damage classes (2-6) in the high weeding treatment, indicating a greater proportion of repeatedly damaged trees in this treatment. This may be due to the fact that in low weeding plots, rubber trees were less obvious to pigs and monkeys due to the greater ground cover of weeds. However, another reason may be that the plots adjacent to points in the fence where pigs repeatedly broke through (i.e. where the fence bordered a pig track through the surrounding mature agroforests) just happened to have been allocated the high weeding treatment.

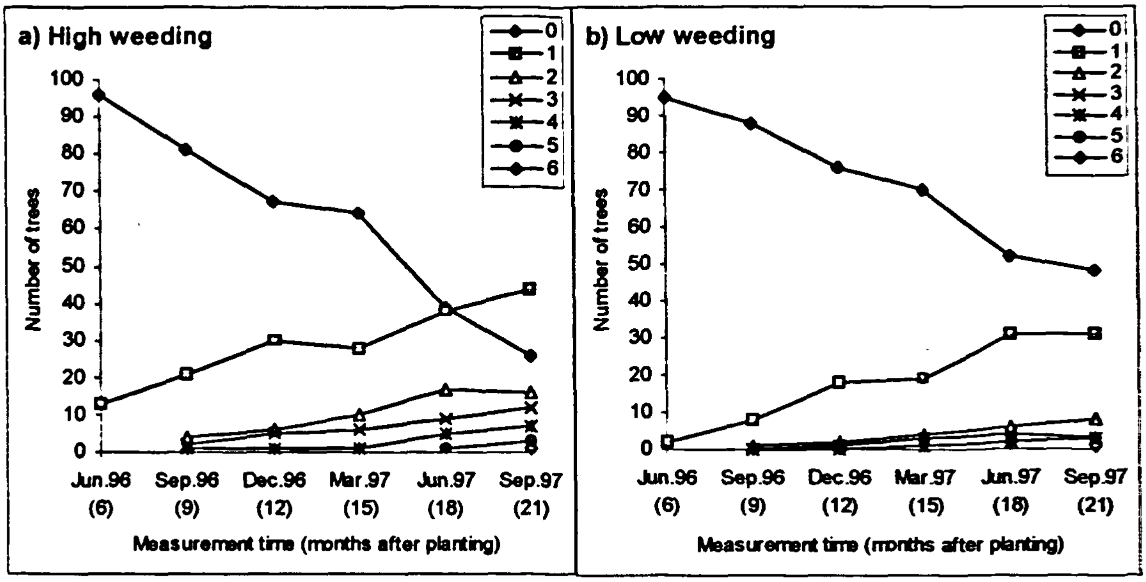


Figure 4.8 Incidence of pest damage on clonal rubber trees: numbers of trees falling into each damage class (of number of stem-breaks per tree) at each three-monthly measurement, for trees in a) the high weeding treatment, (n=109), and b) the low weeding treatment (n=97). Includes replacement trees.

Seedling rubber trees

For seedling rubber (unlike clonal rubber), there did not appear to be any differences in trends of pest-damage incidence between high and low weeding treatments (Figure 4.9). When comparing clonal and seedling trees (Figures 4.8 and 4.9), there does not appear to be much difference between the two types of planting material in terms of number of stem breaks per tree. However, this result is due to the use of stem-breaks per tree to quantify damage. As very few clones were replanted, damage occurred repeatedly on each individual, resulting in greater numbers of trees falling into the higher damage classes. Individual seedling trees, on the other hand, tended to die and be replanted, and were thus not in the field long enough to be repeatedly damaged, and to move into higher damage classes.

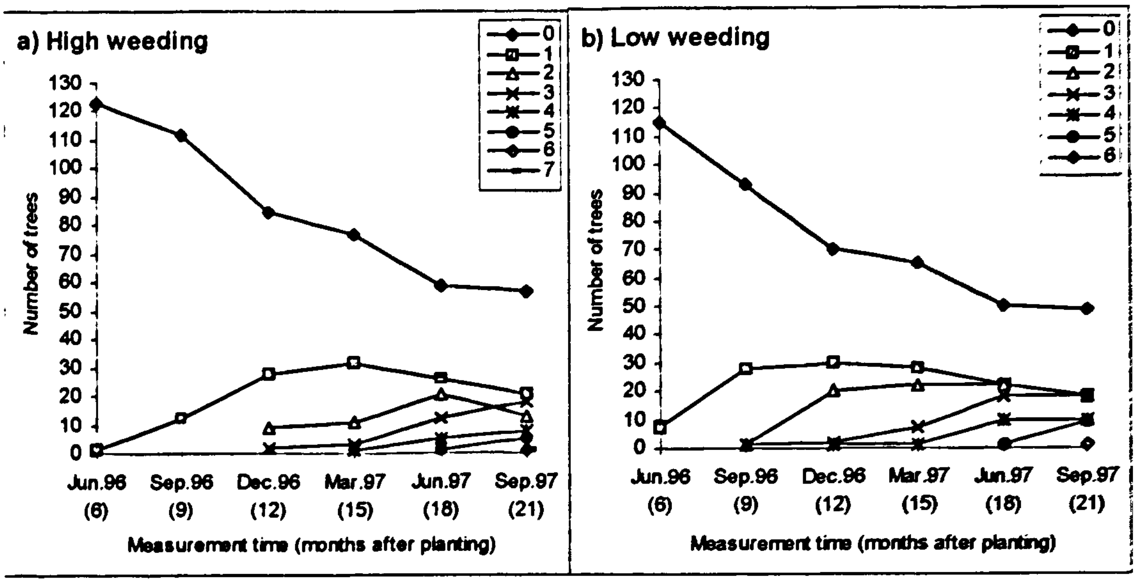


Figure 4.9 Incidence of pest damage on seedling rubber trees: numbers of trees falling into each damage class (of numbers of stem-breaks per tree) at each three-monthly measurement, for trees in a) the high weeding treatment, (n=124), and b) the low weeding treatment (n=123). Includes replacement trees.

Therefore, a different measure of pest damage was used to compare the two types of planting material, based on the planting position (hole), not individual trees. The cumulative number of stem breaks sustained by (successive) trees in each planting position shows a much greater impact of pest damage on seedling trees than on clonal trees (Table 4.10), and corresponds to observations in the field. Even greater damage on seedling trees than on clonal trees is seen when considering the number of times that a stem was completely destroyed, and a new stem was produced from scratch from the stump (Table 4.10).

Table 4.10 Incidence of pest damage on clonal and seedling rubber trees, per planting position: mean number of completely new stems produced in response to stem-breakage, and mean number of stem-breaks per planting position

		Clones		Seedlings	
		High weeding	Low weeding	High weeding	Low weeding
Number of planting positions		90	94	85	88
New shoots	Total number	9	4	87	104
	Mean per planting position	0.10	0.04	1.02	1.22
Stem breaks	Total number	161	89	177	213
	Mean per planting position	1.79	0.95	2.08	2.42

Because pest damage is such an important factor, and had a large impact on trees in the experiment, tree growth in relation to the experimental weeding treatments (the original subject of the experiment) must be considered separately for trees in different damage classes.

Firstly, the effect of weeding on the two types of planting material will be assessed, for undamaged trees, using the planned split-plot ANOVA (Section 4.2.7.1). Secondly, the growth rates of undamaged trees will be presented graphically, in order to a) compare tree growth over time in the two weeding regimes, and b) provide baseline information for a subsequent consideration of the effect of pest damage on tree growth rates. Thirdly, tree growth in relation to pest damage will be investigated, as this is obviously a factor which could affect growth of clonal rubber in a smallholder situation in this area. Finally, the effect of weeding on foliar nutrient and water contents of the rubber trees will be analysed.

4.3.6 Undamaged trees

4.3.6.1 Effect of weeding on tree size, 21 months after planting

<u>Clonal rubber trees</u>

The number of undamaged trees per plot varied between 1 and 14 (Table 4.11). There were a total of 13 trees undamaged in the high weeding treatment, and 44 undamaged in the low weeding treatment.

Table 4.11 Numbers and size of undamaged clonal trees per weeding treatment, 21 months after planting: stem diameter (mm) and height (cm). Means and standard errors per plot.

Hill	Block	Plot	Weeding	Number of trees	Stem diameter (mm) Mean	S.E.	Stem height (cm) Mean	S.E.
1	1	2	High	2	33.7	4.23	496	37.0
1	1	11	Low	5	36.6	2.46	483	34.3
1	2	6	High	2	43.8	7.37	463	53.0
1	2	4	Low	6	46.2	1.84	536	20.2
1	3	8	High	2	35.4	1.45	451	22.0
1	3	10	Low	4	33.7	1.43	422	20.8
2	4	23	High	2	39.7	3.60	492	2.5
2	4	14	Low	9	41.3	3.08	453	32.0
2	5	15	High	4	39.8	1.43	520	32.9
2	5	18	Low	14	39.7	1.31	466	22.1
2	6	20	High	1	43.3	-	523	-
2	6	21	Low	6	39.7	1.44	479	11.5

<u>Seedling rubber trees</u>

The number of undamaged trees per plot varied between 1 and 5 (Table 4.12). There were a total of 16 trees undamaged in the high weeding treatment, and 13 undamaged in the low weeding treatment.

The height at which the shoot was initiated on each seedling stump was assessed in relation to the weeding regime. The mean height was only slightly greater in the low weeding treatment (68.9 cm, S.E. 7.5) than in the high weeding treatment (72.8 cm, S.E. 8.0), and the difference was not significant (*t*-test).

Table 4.12 Numbers and size of undamaged seedling trees per weeding treatment, 21 months after planting: shoot diameter (mm) and height (cm). Means and standard errors per plot.

Hill	Block	Plot	Weeding	Number of trees	Stem diameter (mm) Mean	S.E.	Stem height (cm) Mean	S.E.
1	1	1	High	1	32.80	-	350	-
1	1	12	Low	3	27.58	1.94	315	34.03
1	2	5	High	3	33.18	2.00	308	25.24
1	2	3	Low	1	32.60	-	414	-
1	3	7	High	1	32.35	-	328	-
1	3	9	Low	5	31.91	3.78	397	20.02
2	4	24	High	5	29.69	0.92	345	5.00
2	4	13	Low	1	35.40	-	409	-
2	5	16	High	1	25.60	-	350	-
2	5	17	Low	2	27.10	0.05	330	20.00
2	6	19	High	5	34.98	3.34	429	34.09
2	6	22	Low	1	30.85	-	468	-

Effect of weeding on clonal and seedling rubber

The results of a split-plot ANOVA on plot means (Tables 4.11 and 4.12), showed that the effect of weeding was not significant for either stem diameter or stem height, and neither was the weeding x planting material interaction. However, clonal rubber trees grew significantly larger than seedling rubber trees in both stem diameter and height ($p<0.001$), Figure 4.10. This difference between clonal and seedling trees was quite clear, despite the fact that some of the plot means were based on very low numbers of trees.

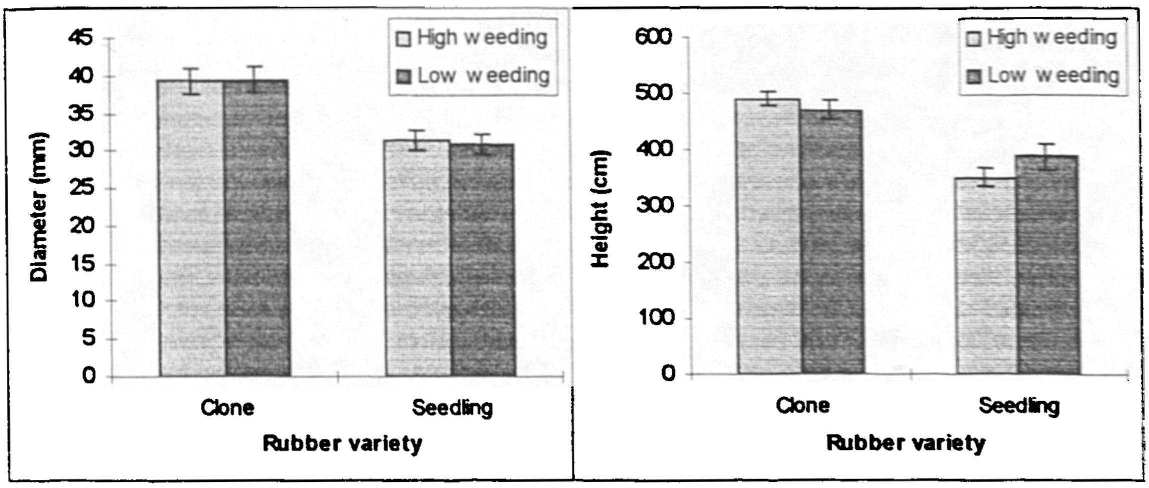


Figure 4.10 Effect of weeding on undamaged clonal and seedling rubber trees: a) stem diameter (mm), b) stem height (cm). Error bars denote the standard error of the mean.

4.3.6.2 Growth of undamaged trees over time (0-21 months after planting)

Clonal rubber trees

Stem diameter growth over time was very similar for undamaged trees in the high and the low weeding treatments (Figure 4.11a), throughout the full 21 month period of the experiment. Mean stem height in the high weeding treatment was generally greater than in the low weeding treatment, this difference becoming apparent six months after planting, at the end of the first dry season. However, by the time of the measurement at 21 months after planting, the difference had decreased, to a non-significant level (Section 4.3.6.1). The slight tailing off in height growth after March 1997 was probably due to production of branches (Webster, 1989b)[33].

Seedling rubber trees

For seedling rubber trees, there was no apparent difference in either stem diameter or height, between the two weeding treatments, throughout the first 21 months of growth (Figure 4.12).

4.3.6.3 Absolute growth rates of undamaged clonal and seedling rubber trees

Absolute growth rates are a measure frequently used in the rubber literature to compare performance of trees under different management regimes, so here, the increments per measurement interval of three months are presented, to enable comparison with other studies.

Clonal rubber trees

For stem height, the greatest growth increment was seen in the high weeding treatment initially, but from 15-21 months after planting, growth rates were higher in the low weeding treatment (Figure 4.13). For both stem diameter and height, differences in AGR between treatments were especially marked during the first dry season (June to September 1996).

Seedling rubber trees

Absolute growth rates of seedling rubber trees were much lower initially than those of clonal rubber trees (compare Figures 4.14 and 4.13). Differences between high and low weeding treatments for seedling trees were smaller in the first dry season than they were in clonal trees. However, for seedling stem diameter (Figure 4.14a), the growth rate in the second dry season (March to September 1997, an El Nino drought year), was considerably greater in the high weeding treatment than in the low weeding treatment.

[33] Previously, stem elongation was restricted to the main vertical axis, because lateral shoots were deliberately pruned (Section 2.2.1.4).

Growth of undamaged trees over time (0-21 months after planting)

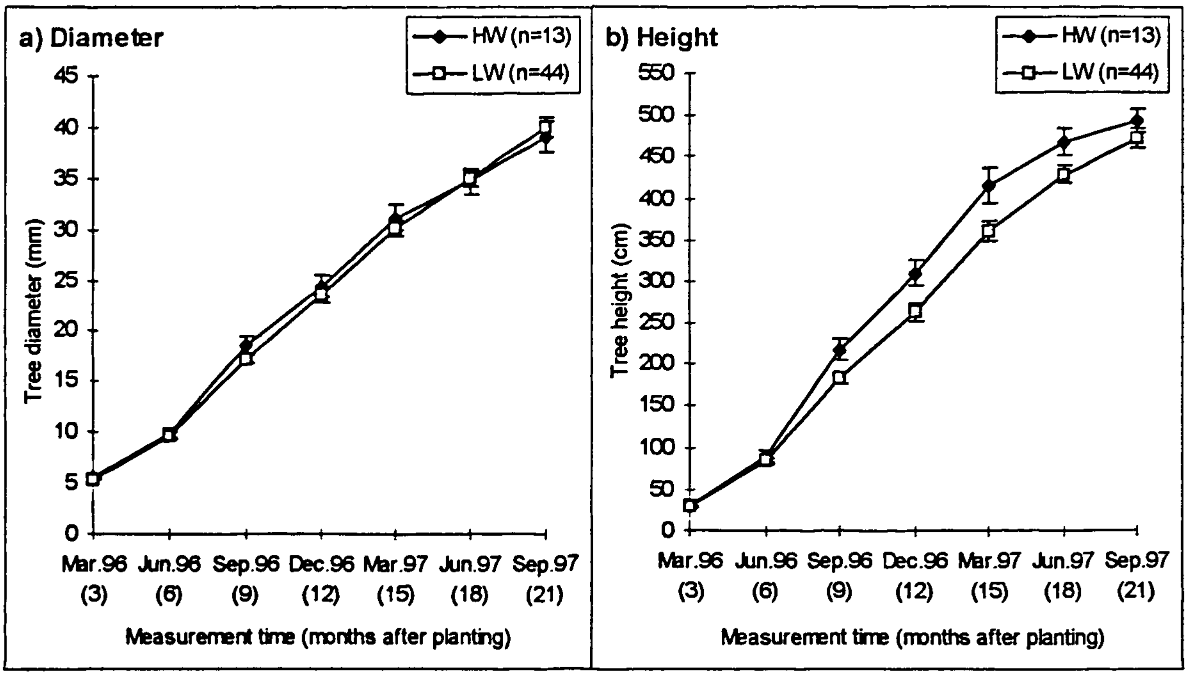


Figure 4.11 Stem growth of undamaged clonal rubber trees over time: a) mean diameter for high and low weeding treatments (mm), and b) mean height for high and low weeding treatments (cm). Error bars denote the standard error of the mean.

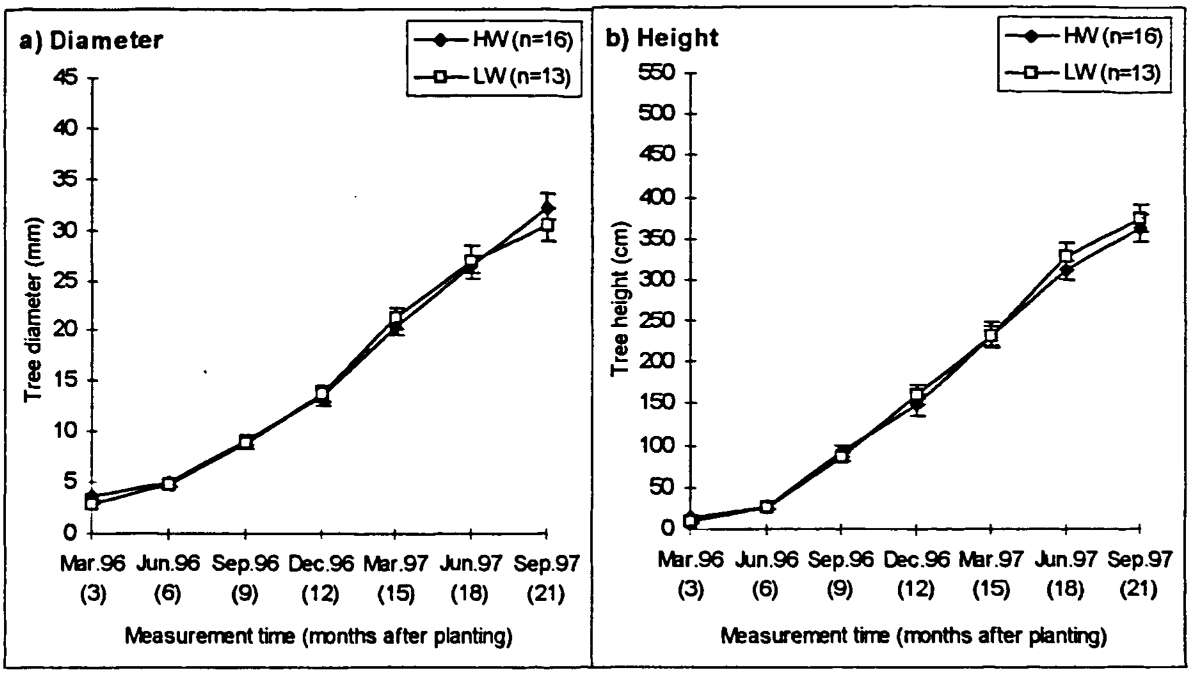


Figure 4.12 Stem growth of undamaged seedling trees over time: a) mean diameter for high and low weeding treatments (mm), and b) mean height for high and low weeding treatments (cm). Error bars denote the standard error of the mean.

Absolute growth rates of undamaged clonal and seedling rubber trees

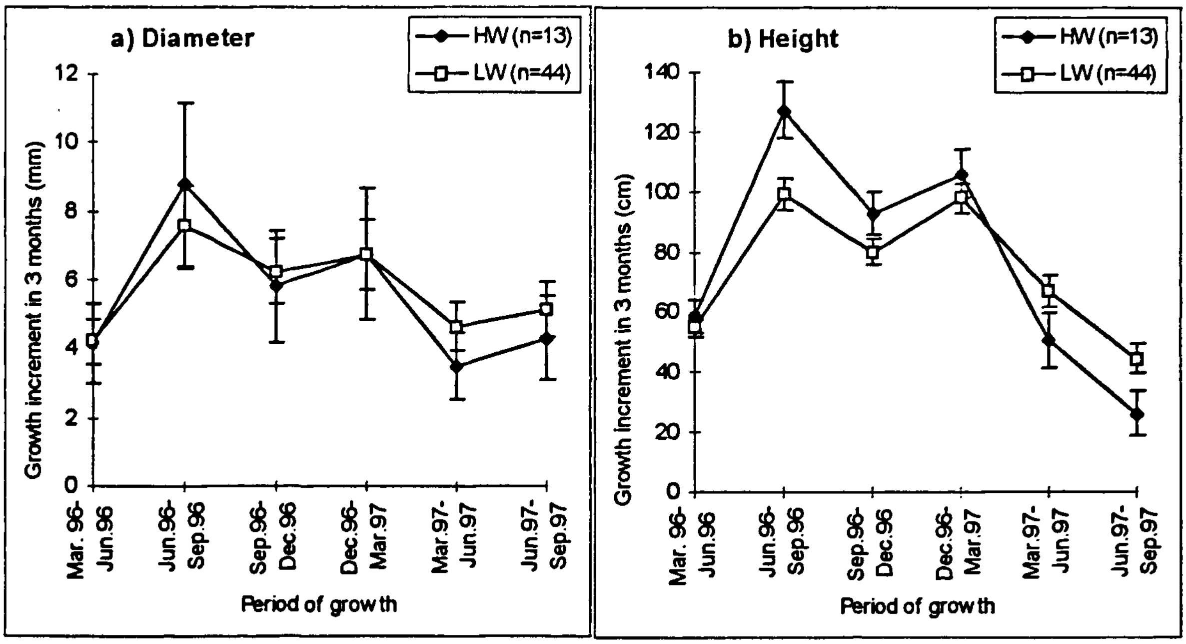


Figure 4.13 Absolute growth rate of undamaged clonal rubber trees in high and low weeding treatments: a) mean stem diameter increment (mm per three-monthly measurement interval), b) mean stem height increment (cm per three-monthly measurement interval). Error bars denote the standard error of the mean.

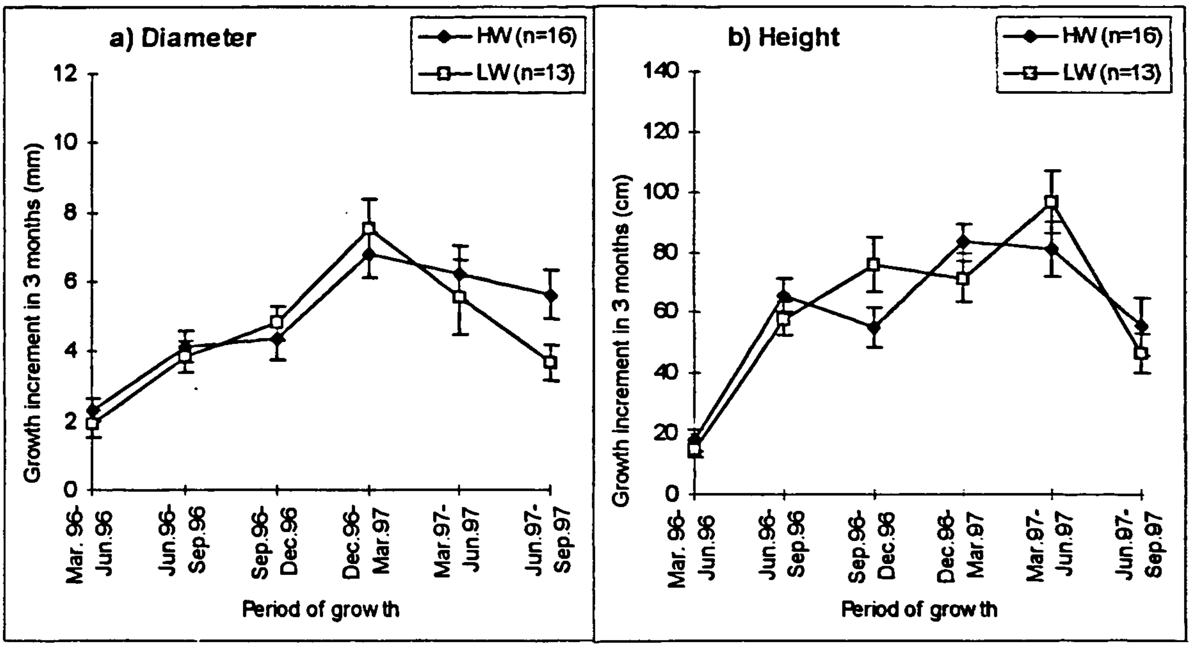


Figure 4.14 Absolute growth rate of undamaged seedling rubber trees under high and low weeding treatments: a) mean stem diameter increment (mm per three-monthly measurement interval), b) mean stem height increment (cm per three-monthly measurement interval). Error bars denote the standard error of the mean.

4.3.6.4 Relative growth rate of undamaged clonal and seedling rubber trees

The relative growth rate (RGR) of stems, over a period of three months, is presented here to provide a baseline for comparing the growth of damaged trees in the next Section (4.37).

Clonal rubber trees

In general, RGR decreases with time (Figure 4.15), however for diameter, RGR was greater for the period June to September 1996 (6-9 months after planting) than in March to June 1996 (3-6 months after planting). In the 6-9 month period, RGR in the high weeding treatment was greater than in the low weeding treatment. This trend was also seen for height, indicating that for the first dry season after planting, weeding may be beneficial, possibly by reducing competition for water.

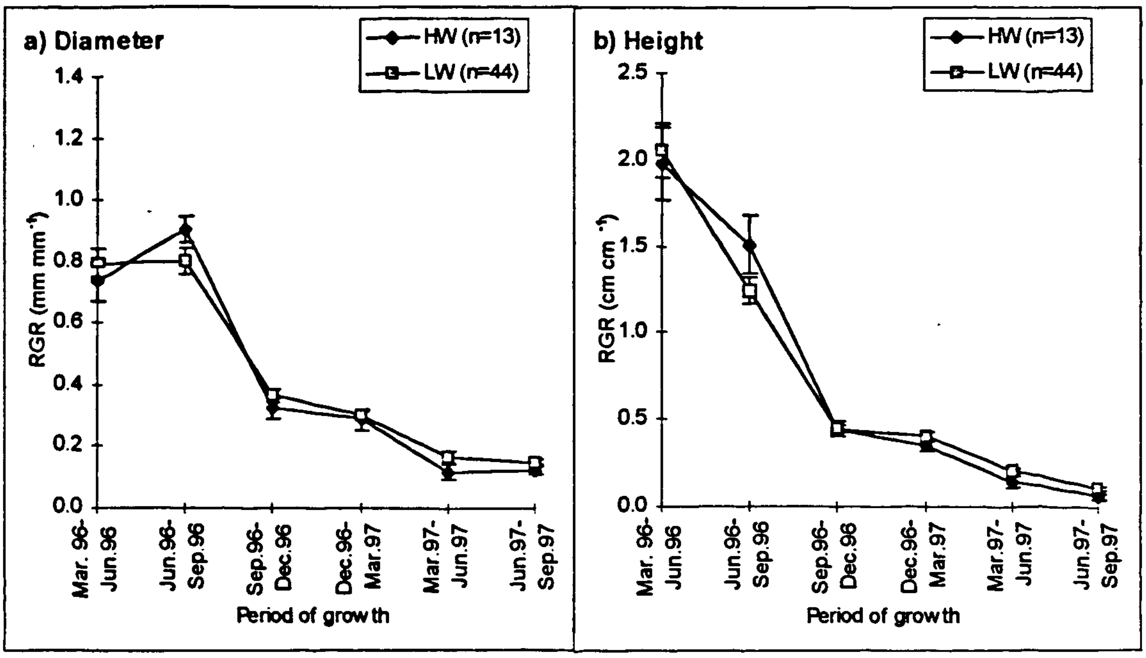


Figure 4.15 Relative growth rate (RGR) of undamaged clonal rubber trees under high and low weeding treatments: a) mean stem diameter increment[1] (mm mm^{-1} per three-monthly measurement interval), b) mean stem height increment[2] (cm cm^{-1} per three-monthly measurement interval). Error bars denote the standard error of the mean.

[1] RGR (mm mm^{-1} in a time period of three months) for stem diameter, calculated as: $\log_e D_2 - \log_e D_1$
Where D_1 and D_2 are stem diameters measured at 10 cm above the graft
[2] RGR (cm cm^{-1} in a time period of three months) for stem height, calculated as: $\log_e H_2 - \log_e H_1$
Where H_1 and H_2 are stem heights, measured from the graft to the top of the main stem.

Seedling rubber trees

For seedling stem diameter, RGRs followed the same pattern as those of clonal trees (compare Figures 4.16 and 4.15), although values were generally higher for seedling tree RGR. For seedling height, as for diameter, RGR peaked at 6 to 9 months after planting. RGR (height) of seedling trees was much lower than that of clonal trees in the first six months after planting.

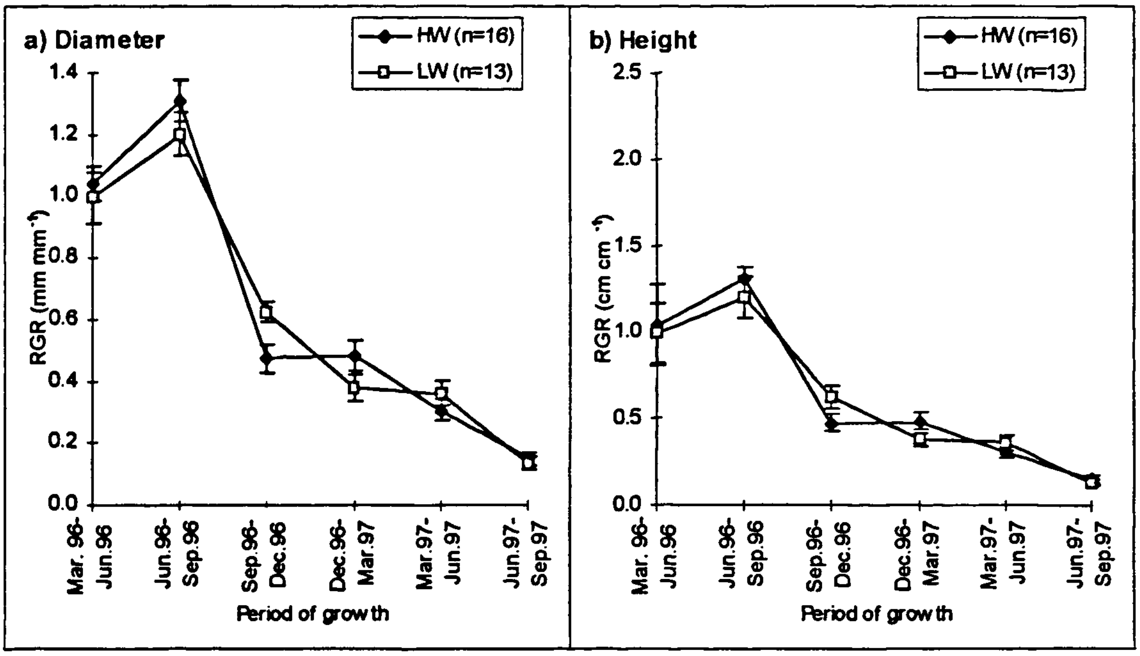


Figure 4.16 Relative growth rate (RGR) of undamaged seedling rubber trees under high and low weeding regimes: a) mean stem diameter increment[1] (mm mm^{-1} per three-monthly measurement interval), b) mean height increment[2] (cm cm^{-1} per three-monthly measurement interval). Error bars denote the standard error of the mean.

[1] RGR (mm mm^{-1} in a time period of three months) for stem diameter, calculated as: $\log_e D_2 - \log_e D_1$
Where D_1 and D_2 are stem diameters measured at 10 cm above the union of shoot and stump
[2] RGR (cm cm^{-1} in a time period of three months) for stem height, calculated as: $\log_e H_2 - \log_e H_1$
Where H_1 and H_2 are stem heights, measured from the union of the shoot and stump to the top of the main stem.

4.3.7 Growth of damaged trees

4.3.7.1 Relative growth rates of trees in each pest-damage class

Relative growth rate (RGR) is considered for diameter only, as tree height is, of course, directly affected by stem-breakage by pests. At each measurement occasion, trees were grouped according to damage class (number of stem-breaks per tree), and the mean RGR was calculated for each group of trees, for the three-month period leading up to that measurement occasion (Section 4.2.7.1). Mean RGR (and S.E.) was plotted for trees in each damage class, for each weeding treatment, and the numbers of trees in each group (from which the mean was calculated) are presented separately in a table, for both clonal and seedling trees.

Clonal rubber trees

Not all damage classes were represented at each measurement occasion (Table 4.13), and sometimes only one or two individuals fell into each damage class. In the case of one individual, no standard error is of course quoted, and in the case of two individuals, the standard error of the growth rate tends to be large (Table 4.13).

Table 4.13 Relative growth rates (RGRs, stem diameter) per measurement interval, for clonal rubber trees in different pest-damage classes, for a) trees in the high-weeding treatment plots and b) trees in low-weeding treatment plots. Mean RGRs for trees in each damage class are presented, with standard errors and numbers of trees.

		High weeding						Low weeding					
Damage class	RGR (mm mm^{-1})	Mar.96 - Jun.96	Jun.96 - Sep.96	Sep.96 - Dec.96	Dec.96 - Mar.97	Mar.97 - Jun.97	Jun.97 - Sep.97	Mar.96 - Jun.96	Jun.96 - Sep.96	Sep.96 - Dec.96	Dec.96 - Mar.97	Mar.97 - Jun.97	Jun.97 - Sep.97
0	Mean	0.514	0.616	0.296	0.217	0.112	0.108	0.515	0.549	0.294	0.266	0.129	0.128
	S.E.	0.025	0.020	0.013	0.014	0.013	0.013	0.022	0.019	0.010	0.011	0.012	0.008
	n	60	51	44	44	40	37	84	78	68	65	62	62
1	Mean		0.540	0.302	0.258	0.157	0.173		0.556	0.221	0.236	0.187	0.145
	S.E.		0.141	0.031	0.035	0.024	0.019		0.142	0.057	0.042	0.023	0.029
	n		4	12	15	12	13		2	5	12	10	12
2	Mean			0.293	0.349	0.078	0.155			0.084		0.326	0.279
	S.E.			0.020	0.029	0.001	0.128			-		-	0.185
	n			2	2	2	2			1	0	1	2
3	Mean			0.318	0.293		0.021				0.139		0.202
	S.E.				0.129		0.004				-		-
	n			1	2		2				1	0	1
4	Mean			0.119	0.140		0.039						0.037
	S.E.						0.009						-
	n			1	1		2						1
5	Mean												0.359
	S.E.												-
	n												1

For clonal trees, there was no clear evidence that stem growth rates either increased or decreased in relation to pest damage (Figure 4.17), as examples of both these trends were seen at different measurement intervals. This could of course be due to the low numbers of replicates in some classes. There also did not appear to be any consistent differences in RGR between high and low weeding treatments. Certainly RGR of clonal rubber trees decreased over time, but this was the general trend shown for undamaged trees (Figure 4.15).

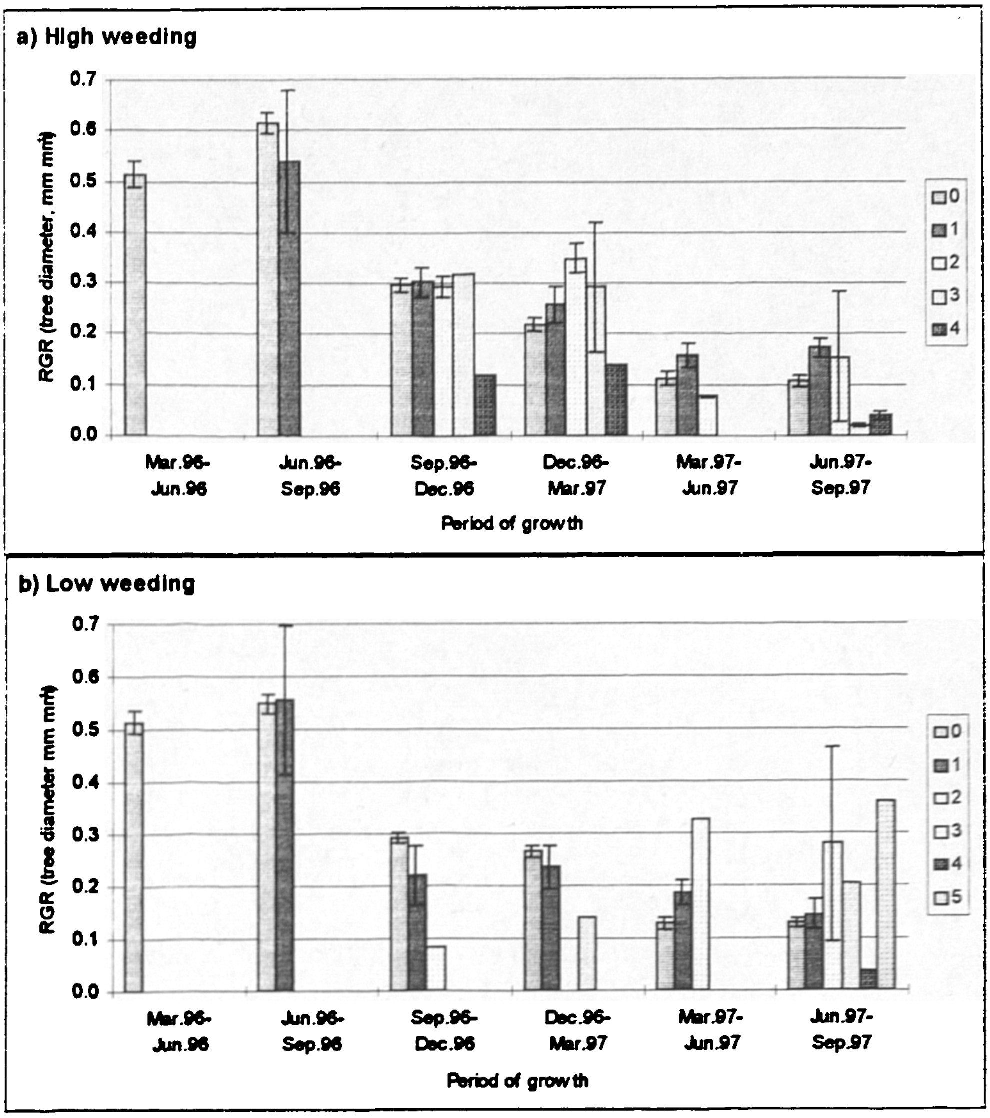


Figure 4.17 Relative growth rates per measurement interval, for clonal rubber trees in different pest-damage classes, for a) trees in the high-weeding treatment plots and b) trees in low-weeding treatment plots. Means and standard errors of trees in each damage class are presented; numbers of trees are displayed in Table 4.13.

Seedling rubber trees

As was the case with clones, not all damage classes were represented at each measurement occasion (Table 4.14), and as discussed previously (Section 4.3.5), the numbers of seedling trees falling into the higher damage classes was lower than for clonal trees. In the high weeding treatment, RGR of seedling rubber trees damaged once was consistently lower than the RGR of undamaged trees, but this trend was not seen in the low weeding treatment. However, given the small numbers of trees, this difference is unlikely to be of great consequence.

Table 4.14 Relative growth rates (RGRs, stem diameter) per measurement interval, for seedling rubber trees in different pest-damage classes: a) trees in the high-weeding treatment and b) trees in low-weeding treatment. Mean RGRs for trees in each damage class are presented, with standard errors and numbers of trees.

Damage class	RGR (mm mm^{-1})	High weeding Mar.96 - Jun.96	Jun.96 - Sep.96	Sep.96 - Dec.96	Dec.96 - Mar.97	Mar.97 - Jun.97	Jun.97 - Sep.97	Low weeding Mar.96 - Jun.96	Jun.96 - Sep.96	Sep.96 - Dec.96	Dec.96 - Mar.97	Mar.97 - Jun.97	Jun.97 - Sep.97
0	Mean	0.262	0.649	0.342	0.469	0.328	0.222	0.530	0.515	0.389	0.461	0.254	0.135
	S.E.	-	0.079	0.048	0.056	0.030	0.028	0.084	0.069	0.042	0.046	0.049	0.026
	n	1	19	15	13	10	10	2	17	13	12	10	10
1	Mean			0.172	0.386	0.226	0.180		0.809	0.430	0.387	0.453	0.189
	S.E.			-	0.079	0.085	0.052		-	-	0.068	0.063	0.050
	n			1	4	4	6		1	1	5	6	7
2	Mean												
	S.E.												
	n												
3	Mean												0.313
	S.E.												-
	n												1
4	Mean												0.089
	S.E.												-
	n												1

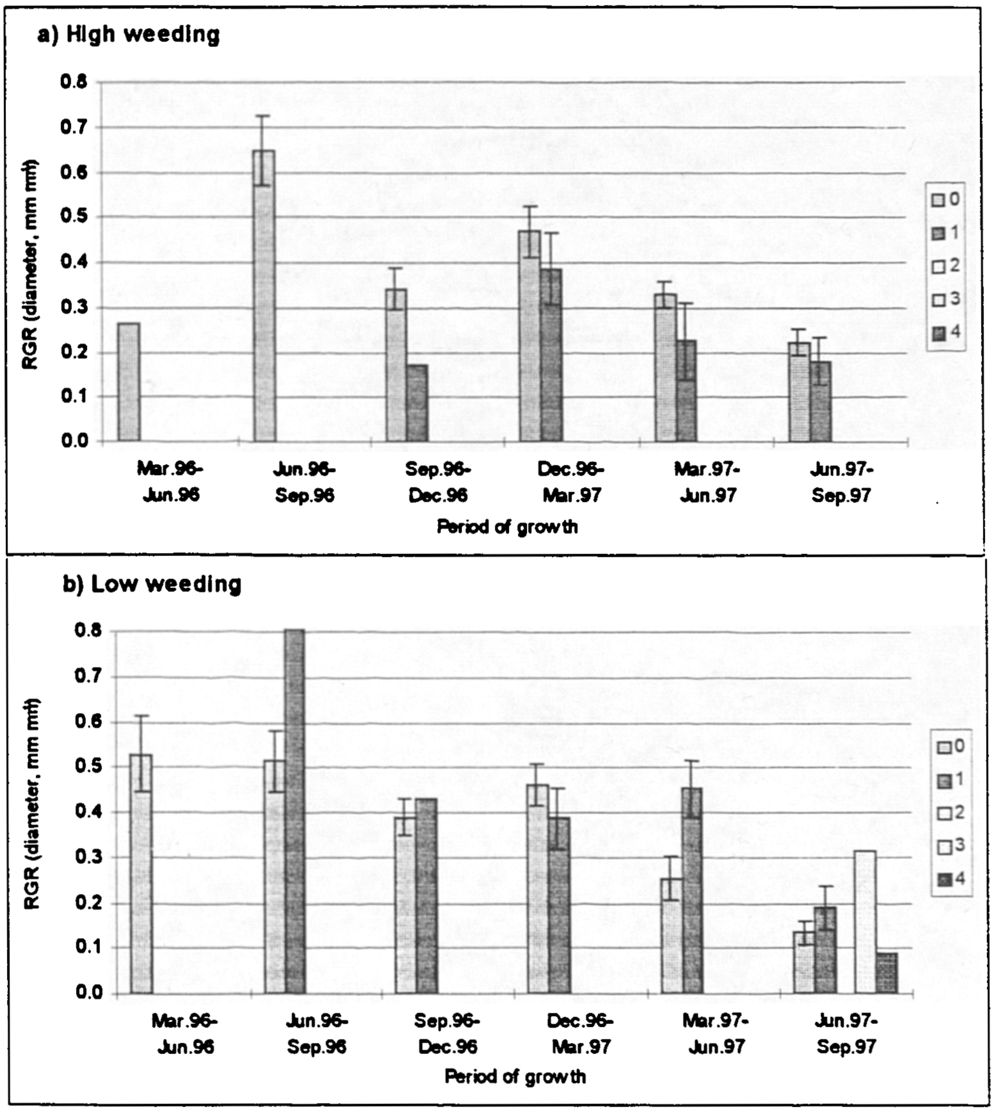


Figure 4.18 Relative growth rates per measurement interval, for seedling rubber trees in different pest-damage classes, for a) trees in the high-weeding treatment and b) trees in low-weeding treatment. Means and standard errors of trees in each damage class are presented; numbers of trees are displayed in Table 4.14.

4.3.7.2 Plot level analysis of tree size (21 months after planting), in relation to pest damage

At the plot level, the effect of pest damage on clonal rubber tree size (21 months after planting) was investigated by linear regression analysis using the index of pest damage (Section 4.2.7.2), for all trees except those which were replanted in June 1996, and those where the stem was missing at that measurement (Table 4.15). There was a significant negative correlation ($p<0.01$), between mean tree diameter per plot and pest damage per plot (Figure 4.19). This relationship accounted for 58% of the variation in tree diameter growth in the experiment.

Table 4.15 Mean diameter of damaged and undamaged clonal rubber trees per plot (21 months after planting), and the index of pest damage per plot[1]

Hill	Block	Plot	Number of trees	Diameter (mm) Mean	S.E.[2]	Pest damage index Mean	S.E.
1	1	2	10	32.6	2.77	0.80	0.39
1	1	11	11	38.3	1.96	0.09	0.09
1	2	4	8	43.6	2.20	0.00	0.00
1	2	6	9	34.9	4.33	1.11	0.42
1	3	8	9	31.8	3.23	0.89	0.56
1	3	10	12	27.9	3.55	0.83	0.34
2	4	14	17	33.9	3.28	1.06	0.46
2	4	23	12	27.8	3.35	2.25	0.64
2	5	15	11	37.6	1.54	0.45	0.37
2	5	18	20	37.9	1.31	0.10	0.07
2	6	20	19	35.5	2.28	0.89	0.25
2	6	21	18	34.3	2.20	1.44	0.44

[1] Index of pest damage: total number of stem-breaks per plot divided by the number of trees in the plot.
[2] Standard error of the mean

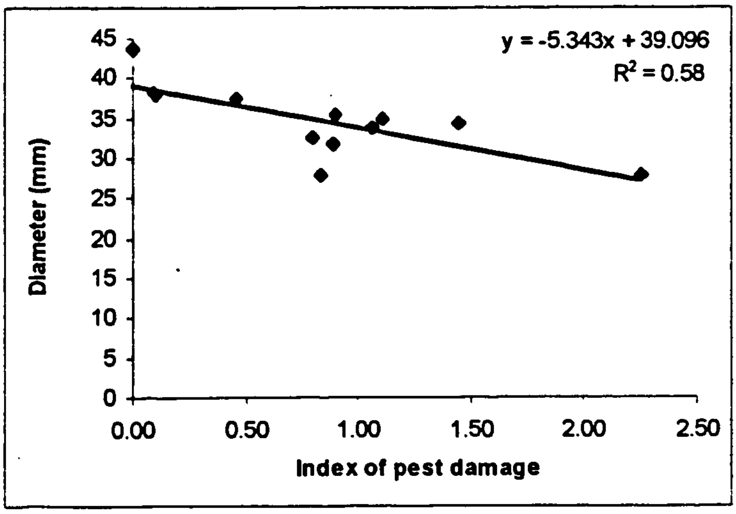


Figure 4.19. Linear relationship between mean clonal rubber tree diameter per plot (in mm), at 21 months after planting, and index of pest damage (total number of stem-breaks per plot divided by the number of trees in the plot).

4.3.8 Foliar nutrient and water contents

There were no significant differences in foliar nutrient contents (N, P, K, Ca, Mg) between trees in high and low weeding treatments, or between rubber planting materials (split-plot ANOVA; Figure 4.20). The interaction between the two treatments was also not significant. There were also no significant differences in foliar water contents among weeding treatments or rubber planting materials (split-plot ANOVA; Figure 4.21), nor was the interaction between treatments significant.

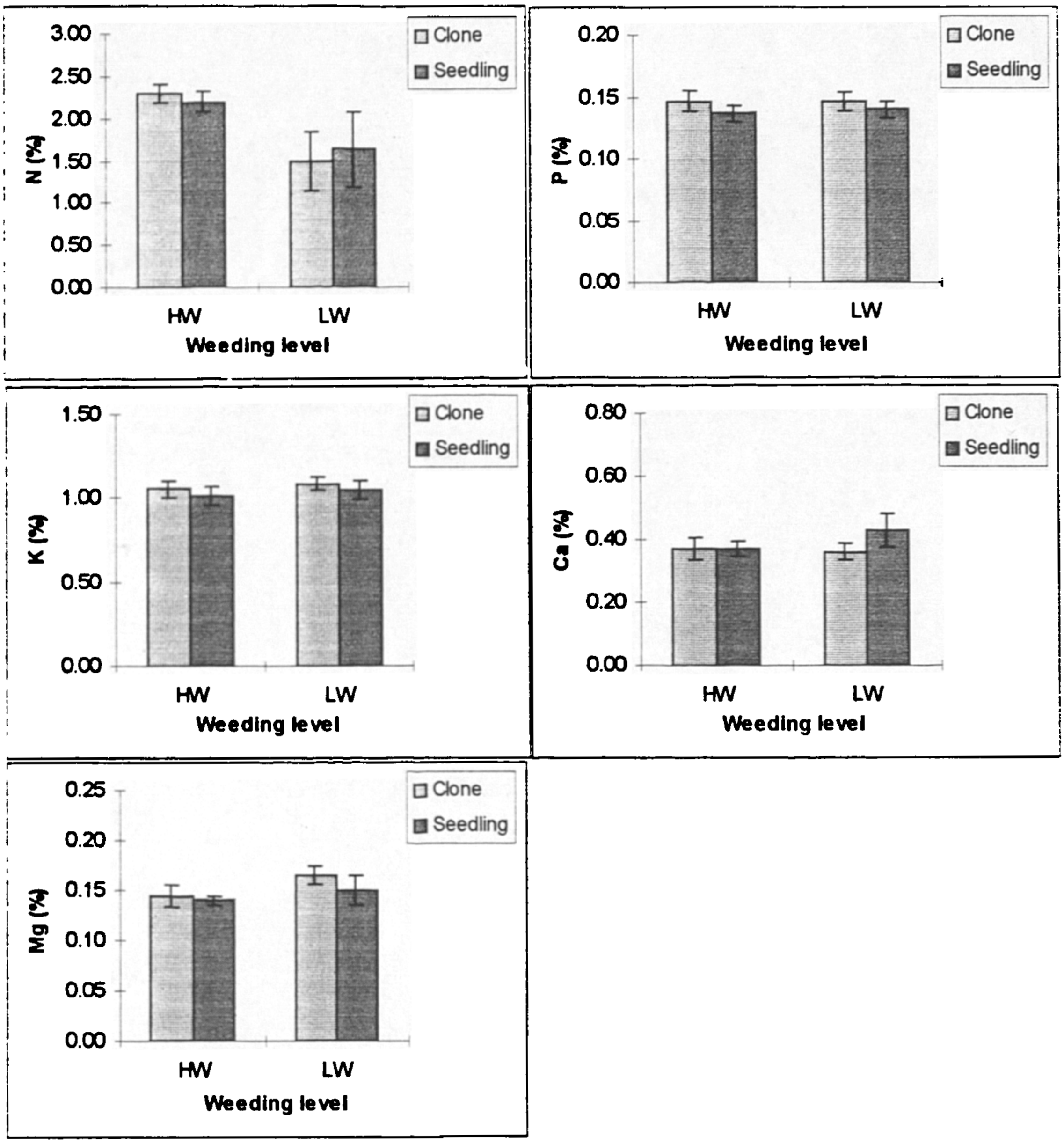


Figure 4.20 Foliar nutrient concentrations in clonal and seedling rubber tree leaves (expressed as percentage dry weights), for high and low weeding treatments (mean of six replicate plots; error bars represent one standard error of the mean).

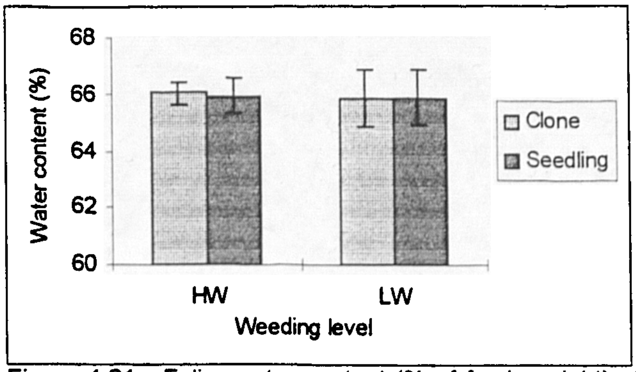


Figure 4.21. Foliar water content (% of fresh weight) of clonal and seedling rubber, in high and low weeding treatments (mean of six replicate plots, error bars represent the standard error of the mean).

4.4 DISCUSSION

The results of the experiment are discussed below, in relation to the questions asked in Section 4.1.5.

1. Can clonal rubber be established and grow successfully on sloping land, in a multistrata agroforestry system, similar to the conditions found in jungle rubber, with only a very low level of weeding in the rubber row?

This question can be answered by considering the survival and growth of clonal rubber trees in the low weeding treatment. Firstly, survival rate was very high (99%), as only one tree died, out of the original 94 that were planted, and this was a result of a minor landslide (Section 4.3.3). Of course, there is a risk of losing high-value improved planting material such as clones to landslides on sloping land, especially in the first few months after planting, before sufficient vegetation has regenerated to protect the soil. No literature could be found on mortality rates of clones in either plantation or smallholder environments, although Penot *et al.* (1994) recommend preparation of an extra 10 % of planting material (surplus to field requirements) to cover possible tree mortality in both the nursery and field.

Although growth of <u>undamaged</u> trees was rapid, with stems attaining an average height of 423 cm and diameter of 40 mm at 21 months after planting (Section 4.3.6.1), this was poor when compared with an average diameter of 65 mm of trees of the same age under plantation conditions (high levels of fertilisation, weeding, and use of a legume cover crop; Figure 5.1). Trees of 40 mm diameter were equivalent in age to 13-month old trees in the plantation (Figure 5.1), i.e. there was approximately an eight-month lag in growth compared to trees grown under optimum conditions.

However, the initial growth of trees in my study was greater than that of intercropped trees under farmers' conditions in South Sumatra (G. Wibawa, pers. comm., unpubl. data). That study, which was comparable with mine (the rubber tree row was often weedy or contained intercrops, and stem diameter was also measured at 10 cm above the graft), showed that nine months after planting, mean diameter and height of trees in 16 intercropped plots (intercropped with a variety of annual and perennial crops) was 11 mm and 89 cm respectively. In one particular plot, which had been intercropped for only three months with rice, banana and cassava and then subsequently abandoned to broad-leaf weeds and grass (i.e. the plot which was weediest, and most similar in terms of inter-row vegetation to my field), mean stem diameter was only 9 mm, and mean tree height was 81 cm (G. Wibawa, pers. comm., unpubl. data). This is in contrast to the much higher mean tree diameter and height in my study at nine months after planting: 17.2 mm and 184 cm respectively (Section 4.3.6.2).

Mean stem diameter and height in my low weeding treatment, twelve months after planting were 24 mm and 260 cm respectively (Section 4.3.6.2). In a researcher-managed intercropping experiment in South Sumatra (Wibawa and Thomas, 1997)[34], where rubber trees were weeded only within a circle (1 m in diameter), at twelve months after planting, mean tree diameter and height was much lower, 11 mm and 84 cm respectively, in the *Imperata cylindrica*[35] treatment. In the upland rice treatment (rice grown for three months, then the plot colonised by weeds), mean tree diameter and height was greater: 15 mm and 111 cm, but still less than the low weeding treatment in my experiment.

Therefore, in comparison with other on-farm studies, even with a low level of inputs and labour, and minimum weeding in the rubber tree row, the growth of clonal rubber in this agroforestry system, is quite satisfactory.

2. Is clonal rubber survival and growth significantly greater when a more intensive level of weeding in the rubber tree row is implemented?

This question can be answered by comparing the survival and growth of undamaged clonal rubber trees in the high weeding treatment with those in the low weeding treatment. The survival rate of trees in this treatment was 98%, as only two trees died, out of the original 90 that were planted, and this was also due to the small landslide (Section 4.3.3). Therefore, increased frequency of weeding did not result in higher rates of survival.

For rubber tree growth, measured at the end of the experiment (21 months after planting), the difference between high and low weeding treatments for <u>undamaged</u> trees was not significant

---

[34] This study was initiated in 1993 in South Sumatra by the Sembawa Rubber Research Institute, as part of the EU-funded STD III Programme: Management of Rubber-Based Intercropping Systems.
[35] A pernicious grass weed (Brook, 1989), known to depress the growth of rubber (Anon., 1938).

for either stem height or diameter (Section 4.3.6.1). Therefore, based on the data obtained for final tree size, the answer to the above question is 'no'. This result was surprising, as the percentage cover and heights of weeds that regenerated between each weeding event was certainly greater in the low weeding treatment than in the high weeding treatment (Section 4.3.2.2).

Over time, however, mean tree height in the high weeding treatment was slightly lower than in the low weeding treatment, from nine months after planting onwards. On inspection of absolute growth rates (AGR, Section 4.3.6.3), some differences between the treatments were observed, which were less noticeable on the plot of treatment means over time (Figure 4.11). In the first dry season (6-9 months after planting) mean AGR of both diameter and height was greater in the high weeding treatment than the low weeding treatment (8.75 mm and 7.56 mm/ three months for diameter, 127 cm and 99 cm/ three months for height). Thus it is possible that competition with weeds for water may be reducing rubber tree growth in the low weeding treatment to a greater extent than in the high weeding treatment, but this has not been proved.

A similar result was reported by Wibawa and Thomas (1997) for the first dry season (6-9 months after planting), where mean AGR (diameter) was greater in the clean-weeded treatment than in either an upland rice or *Imperata* treatment (2.5 mm, 0.5 mm and 0.3 mm/ three months respectively). In that experiment, clear differences in AGR between these treatments were maintained over wet and dry seasons up to three years after planting. These authors showed that seasonal rubber growth was highly correlated with soil moisture and evapotranspiration measurements, and concluded that competition for water was a major process operating in their experiment in dry seasons.

Slight differences were also seen for relative growth rate (RGR) between the two treatments, in the first dry season (Figure 4.15). More noticeable, however, is the steep decline in RGR, after September 1996 (9 months after planting). This is not unusual, as Templeton (1968) found that RGR (in terms of rate of increase of total dry matter, including roots), declined steadily in rubber from nine months after planting.

In the on-farm intercropping study described above (G. Wibawa, pers. comm. unpubl. data), weeding of the entire inter-row area in half of each farmer's field resulted in greater mean tree diameter at 24 months after planting, than in the intercropped half, for 75 % of farms. In the low-input researcher-managed intercropping experiment (Wibawa and Thomas, 1997), mean stem diameters (at 21 months after planting) in the 'clean weeding' treatment (entire inter-row area weeded monthly) were significantly greater than in both the upland rice and *Imperata cylindrica* treatments described above.

These results demonstrate that the presence of inter-row vegetation has a considerable effect on rubber tree growth, by the age of 21 months. In my experiment, it is possible that interference from the secondary forest regrowth in the inter-row was much greater in magnitude than interference from weeds in the row. Because the inter-row vegetation was managed in the same way for both the high and low weeding treatments, then equal amounts of competitive pressure from the secondary forest regrowth in the inter-row would be exerted on all rubber trees throughout the field, regardless of weeding treatment. If competition from inter-row vegetation did have the greatest effect on rubber growth, then this would indeed have overshadowed the effects of weeding within the row. This would explain the non-significant difference between weeding treatments that I observed.

This explanation could be tested in an agronomic manner by including a 'control' treatment where the inter-row area was clean-weeded. Thus, a factorial experiment could be designed whereby the effects of the two weeding levels could be assessed, both with and without the presence of secondary forest regrowth in the inter-row. Such an experiment could quantify the competitive effects of this type of vegetation on the growth of a fast-growing third generation[36] rubber clone. A more ecologically-based experiment could be used to investigate and quantify the relative effects of above- and below-ground interference on the growth of clonal rubber, as both processes are potentially operating in this type of environment. A design similar to the one used by Putz and Canham (1992), could be used, including factorial combinations of root trenching (to exclude below-ground competition from roots of secondary forest species), and tying or slashing back of above-ground growth.

3. How does the performance of clonal rubber compare with the rubber seedlings used in the traditional system? Is there an interaction between weeding and rubber variety?

In terms of survival, clonal rubber trees were far more successful than seedling trees, which had a survival rate of just 65% (Section 4.3.3). There did not appear to be any effect of the weeding treatments on mortality of either seedling or clonal trees. All clonal trees that were replanted in June 1996 survived, whereas only 84% of seedling trees planted at that time survived. All stems present on clonal rubber trees when transplanted survived, in contrast to seedling trees where the original stem often died, and a few months passed before a dominant stem established successfully. Clonal rubber trees appeared to be hardier, although these results may not be entirely due to the genetic composition of the planting material, as the clonal trees were planted from polybags, and so would have had a more-developed root system than the bare-root seedlings.

In terms of size of <u>undamaged</u> trees at 21 months after planting, both stem diameter and height of clonal rubber trees were greater than those of seedling rubber trees (Section 4.3.6.1), despite the low numbers of undamaged seedling trees per plot on which the plot means for the ANOVA were based. There was no significant interaction between rubber planting material type and weeding; there was no evidence that seedlings out-perform clones under low-weeding conditions.

Consistent with the slow establishment of seedling trees compared with clonal trees, absolute growth rates of seedling trees were lower than those of clonal trees, for the first 15 months after planting. Rates of stem elongation per unit height (RGR, Section 4.3.6.4), were also greater for clonal trees up to nine months after planting, although for diameter, the seedling trees had greater RGRs up to 18 months after planting. This latter point was possibly due to the fact that the seedlings had been slower to establish: at each measurement, seedling stem diameter was smaller than clonal stem diameter, therefore RGR in the three months following would be proportionally larger for seedlings, if their AGRs were similar.

In addition, total tree heights of seedling trees were calculated (the height of the shoot plus the height on the original stump that this shoot was initiated), at 21 months after planting. This was because total tree height is a variable that a farmer would use to compare the performance of clones and seedlings, as the stump of the seedling can also be tapped. The values for total tree height of undamaged seedling trees ranged between 289 and 538 cm (mean 440 cm, S.E. 12), but these values were still lower than total tree height of clonal trees (range: 328 - 663 cm; mean 477 cm; S.E. 9).

In addition to the variables measured above, qualitative observations in the field suggested that there was a greater incidence of fungal leaf disease (*Colletotrichum* sp.) in seedling than in clonal trees. Clone PB 260 is known to be resistant to this disease (Penot and Aswar, 1994).

4. What are the other factors besides weeding, that affect growth of clonal rubber under smallholders' conditions, and what are the effects of these?

Damage to rubber trees by vertebrate pests was a major factor affecting clonal rubber growth in this experiment, as 70% of the trees were damaged at least once over the 21 months. Although damage caused by wild pigs was known to occur in the study area (Hadi *et al.*, 1995; Section 4.1.4.2), it was expected that a well-constructed fence would keep them out of the field. Unfortunately, this was not the case (Sections 4.2.7 and 4.3.5).

In addition, based on information given by farmers (Section 4.1.4.2), monkeys (which are not restricted by a fence) were thought to be a minor problem, in comparison with pigs. However, during the first six months after planting, the impact of monkeys on the trees was more severe than expected, because the length of stem broken by these monkeys was large, relative to

[36] see Section 4.1.3.1

the small size of the trees at this time. Furthermore, once the apical stem had been broken off, three to six lateral stems were produced, resulting in a greater number of potentially edible shoots per tree. These were more visible from a distance than a single young shoot, and were also easily accessible from the ground.

The issue of accessibility may partly explain the greater incidence of pest damage on seedling than on clonal trees (Table 4.10), as the seedling trees were generally much slower to establish, which meant that at any particular time, seedling tree stems were shorter and more easily reached by pests than were clonal tree stems. A second explanation for pests preferentially attacking seedlings was that diameters of seedling stems were also smaller than those of clones, and thus the seedlings were more easily broken by pigs, and more easily bent down to ground level by monkeys.

This has implications for the potential replacement of any clonal rubber trees that may die in a field. Because these trees would be smaller than the majority of the trees in the field which were planted originally, it is possible that they would sustain more pest damage than the other trees. This was indeed the case for clonal trees replanted in June 1996 (Section 4.3.4): all the replacement trees were damaged at least once after planting.

The effects of pest damage on relative growth rates of trees which had sustained different numbers of stem breaks per tree was not clear (Section 4.3.7). However, at the plot level (Section 4.3.7.2), mean tree diameter at 21 months after planting was significantly (and negatively) related to the index of pest damage.

Another factor directly related to a smallholder's situation is the low level of fertiliser use compared with plantations. In this experiment, only very low levels of N and P fertiliser were used (Section 2.7), so foliar nutrient levels at 21 months after planting were investigated, to assess the nutrient status of trees in different experimental treatments. This is a common practice in Malaysian plantations (Watson, 1989c).

There were no statistically significant differences in foliar nutrient contents between clonal and seedling trees, or between weeding treatments (Section 4.3.8), however, it is interesting to compare the leaf nutrient contents of trees in this experiment with the optimum levels quoted in the literature, and with other studies. Firstly, the levels of all nutrients measured in this study were 'low, well below optimum, tending to visual deficiency' according to Pushparajah and Tan (1972). Secondly, measured levels of K fell within the 'optimum' range according to Adiwiganda (1992), but the levels of other nutrients were all sub-optimal. Standard plantation practice in this situation would be the application of fertiliser to correct these nutrient deficiencies (Watson, 1989c).

In the rubber intercropping experiment in South Sumatra (Wibawa and Thomas, 1997), there were also no significant differences between treatments for foliar nutrient levels, at 22 and 29 months after planting. These trees were not fertilised at all. Although levels of all nutrients were higher than those observed in my study (except for K), these levels were still below the optimum quoted by Adiwiganda (1992), with the exception of Mg. Foliar nutrient contents in my study were also lower than those quoted by Broughton (1977) for a comparable situation where natural vegetation was allowed to regenerate between rubber tree rows (but there the vegetation was slashed to a height of 1 m, and 'noxious' weeds eradicated).

5. What are the practical issues involved in the establishment and management of a multistrata agroforestry system of this type?

Two problems related to the presence of tall inter-row vegetation on steep slopes were observed in the field. Firstly, trees in the inter-row tended to lean out over the weeded row. As well as increased shading effects on the rubber trees, sometimes the naturally regenerated trees would fall down into the row, and in two instances broke the clonal rubber trees below. The risk of this happening was greatest in the rainy season, when winds were often high. Secondly, it was observed that monkeys (*Presbytis melalophos nobilis*) climbed the large trees in the inter-row in order to gain access to the shoots at the apex of the rubber trees (Mbak Yusnidar, pers. comm.).

In addition, and possibly related to shading effects of the inter-row vegetation, was that it was very difficult to induce branching in the rubber trees (Section 2.2.1.4). Only 45% of trees tall enough had branched by the end of October 1997 (22 months after planting), despite a combination of methods used[37]. Rapid height growth, at the expense of diameter growth, is potentially dangerous in rubber establishment, because if the first branches are produced at heights of over 4 m, on a narrow stem, the trees are more susceptible to wind damage, a common problem in rubber (Watson, 1989a). In addition, without early branch induction, the trees do not gain the benefits of greater leaf area and consequent increased growth rate (Webster, 1989b). A possible reason for this unusual phenomenon (upward growth) could be above-ground competition for light from inter-row vegetation (G. Wibawa, pers. comm.).

With regard to the practicalities of lopping of tall inter-row trees to a height of 1.5 m (Section 4.2.5), feedback from the eight women I employed to do this was not encouraging. They thought it was far more efficient to cut the trees at their base, which of course would save work in the long run. In addition, on steep slopes it was difficult to reach up to lop trees in the inter-row area above a row of rubber, and also it was difficult to perform the operation from the row above, as they could only reach the nearest 2-3 m (of the 6 m-wide strip) without actually pushing their way into the dense vegetation.

[37] bunching leaves over the apical bud, defoliation of half of the uppermost whorl of leaves, and tying

Feedback from farmers on the prototype agroforestry system

Feedback on the multistrata agroforestry system was elicited informally from the women of the village who worked in the field, SRAP farmers, interested farmers who came to visit, and farmers who worked in neighbouring fields. The discussions were deliberately informal, as generally, the people of Muara Buat were 'tired' of ICRAF's questionnaires (Mbak Yusnidar; I. Clement, pers.comm.).

All non-SRAP farmers thought it would be better to plant rubber at a higher density. They suggested filling in the gaps between the trees, as this was wasted space. They would not cut any rubber seedlings that had regenerated naturally in the row[38].

Opinion was divided over weeding within the rubber tree row. Some farmers thought that it should not be weeded so often, as the rubber trees would be obvious to monkeys and pigs. In contrast, however, some thought that the amount of weeds that were allowed to regenerate in the low weeding treatment was too great, and not good for clonal rubber.

Farmers' opinions were also divided over management of the inter-row vegetation. Some thought that its presence was good, in that pests would not see the rubber trees as easily as if the field was clean weeded. However, other farmers thought the field looked 'dirty', and not well managed and this was no good for clonal rubber. They said that the inter-row vegetation would 'disturb' the growth of clones, and could not understand why I would tolerate these weeds, when rubber was so much more important. Surprisingly, only a few farmers recognised the importance of the inter-row vegetation in preventing erosion. They said that they clean weeded their cinnamon gardens every one or two months, and that was not a problem on sloping land[39].

All farmers recognised the advantages of clonal rubber over the seedlings they used, in terms of yield, however they perceived that they could not afford to plant clonal rubber themselves, especially as the risk of pest damage was so high.

---

wire around the stem, slightly below the point where branching was to be induced.

[38] In plantations, these are regarded as weeds, and worthless. Much research has been conducted on the effects of intraspecific competition on tree growth and yield in plantations (Section 1.4.5), and the recommended planting density of 550 stems ha^{-1} was based on this work.

[39] In contrast, I observed soil erosion in a number of immature cinnamon plots around the village.

CHAPTER 5

SMALLHOLDER MANAGEMENT OF CLONAL RUBBER IN A MULTISTRATA AGROFORESTRY SYSTEM: A PARTICIPATORY ON-FARM WEEDING TRIAL

5.1 INTRODUCTION

For an improved agroforestry system to be successfully adopted by farmers, it must be ecologically and agronomically sound, financially profitable and socially acceptable (van Noordwijk *et al.*, 1995). The system being tested in this research programme, where clonal rubber is planted in rows, and secondary forest allowed to regenerate between rows (Section 1.2.3.3) appears to satisfy the first criterion, due to the environmental benefits arising from its forest-like structure. However, the performance of the system has yet to be critically assessed in relation to the other criteria, under real-world (farmer managed) conditions.

5.1.1 The need for participatory on-farm research

A criticism of certain new agroforestry technologies (Ong, 1994), is that they are designed and undergo extensive testing on experimental research stations, with little regard to the practicalities of uptake by farmers. Although this experimental system was designed to be appropriate for smallholders' resources and preferences,[40] the only effective means of confirming this would be testing by the farmers themselves. Their opinions, priorities and experience would be essential (Tripp, 1989) in evaluating the practicalities of the system, and in the continuing research cycle of reappraisal, further adaptation and testing (Seegers *et al.*, 1994).

It is common that the yield advantages of new technologies observed in on-station trials are not borne out under on-farm conditions and under farmer management. For example, Shepherd *et al.* (1997), in an agroforestry, trial reported early growth rates of trees on-farm that were 40 % lower than those on-station. In Malaysia, latex yields (kg/ha) from clonal rubber trees in estates (plantations) were found to be 19% lower than in on-station trials, and these were further reduced under smallholder conditions to only 60% of on-station yields (Benong *et al.*, 1997). The reasons given for this lower yield included low soil fertility and steep slopes in farmers' fields, erratic rainfall, and pests and diseases. Therefore, the performance of the technology needs to be assessed under farmers' conditions, to ensure

[40] based on a comprehensive characterisation of the study area (van Noordwijk *et al.*, 1995), and of Indonesian rubber smallholders in general (Gouyon and Nancy, 1989; Tomich, 1991).

that its advantages over the traditional system are sufficiently large for it to be a viable option for farmers (Huxley, 1999).

The levels of agronomic inputs and field maintenance used by smallholders are generally much lower than by estates, and this too explains the lower yields obtained by smallholders with clonal rubber in Malaysia (Mahmud, 1986). That author goes on to state that "the full impact of technology transfers can therefore be considerably diminished by lax smallholders" (Mahmud, 1986). It appears that smallholders do not adopt the full package of technologies associated with clonal rubber cultivation (see also Anwar *et al.*, 1997). Therefore, it is important to observe farmers' management of clonal rubber in their fields, with respect to the recommendations and standard techniques which they actually do take up, and to discuss their reasons for such management, in order to understand their specific 'socio-technical' constraints (Azwar *et al.*, 1993). Then the effects of these low management inputs (fertiliser and weeding) on the growth of clonal rubber should be assessed.

The importance of weeding is highlighted by the fact that "there are frequent cases of retarded growth of cultivars, delay in maturing, and low yields of latex, that have been directly related to poor weed control in smallholdings", (Mahmud, 1986). Results from a previous experiment (Chapter 3) showed the effects of weeding on rubber growth. However, that experiment was implemented by researchers, not farmers. Only two weeding levels were included, and these were decided by researchers, whereas it was likely that farmer preferences would include a larger range than this. Therefore, in this experiment, it was considered important that the farmers should decide the weeding frequencies in a participatory trial. Data could then be obtained on rubber growth in response to the amount of weeding implemented (and the associated labour costs), and this information could be presented to farmers as a 'basket of choices' (Chambers *et al.*, 1989), from which they could choose the most relevant to their needs and resources (Farrington and Martin, 1988).

5.1.2 Factors influencing adoption of clonal rubber by smallholders

A review of the literature on smallholders in Indonesia, Malaysia, Sri Lanka and India who were not involved in government or development projects (Table 5.1) showed that adoption of clonal rubber was positively correlated with indicators of their wealth, the size of their land holdings, their education level and 'entrepreneurship'. Lack of access to cash or capital was identified as one of the major constraints to the adoption of clonal rubber. A number of studies highlighted the constraints imposed by smallholders' dependence on limited family labour, as only the wealthier farmers could afford to hire labour. Another major factor mentioned in almost half of the studies was the farmers' perception of the risks involved in replanting with clones. Thus it is essential to characterise the socio-economic situation of any farmers participating in an on-farm trial, with respect to the above factors.

Table 5.1. Identification of factors that influence adoption of clonal rubber by smallholders

Factor / Study	Anwar et al., 1997	Benong et al., 1997	Said, 1997	Kumar & Nair, 1997	Azwar et al, 1993	Gouyon et al, 1993	Barlow, 1991	Jayasuria et al., 1991	Cottrell, 1990	Blencowe, 1989	Gouyon & Nancy, 1989	Zain, 1986	Shaban, 1986	Mahmud, 1986	Barlow & Muharminto, 1982
'Wealth'		X							X				X		
Household income				X				X							
Cash / capital availability	X				X	X	X	X		X	X			X	X
Assets / business							X								
Off-farm employment (income)								X					X		X
Family labour					X			X	X	X	X			X	
Hired labour								X							
Allocation of labour (other farm activities /off farm employment)											X				
Total area of land-holdings				X				X			X		X		
Area of rubber land holdings											X				
Farmer's perception of risk		X			X	X	X			X	X				
Education level of farmer				X					X				X		
Technical skill of farmer (training)					X						X		X		
Entrepreneurship of farmer					X						X	X			
Remoteness of village					X								X		
Remoteness of field													X		X
Small field size[1]		X								X	X			X	
Access to information on clonal rubber	X				X		X				X	X			
Appropriateness of technology package for smallholders			X		X		X								
Farmer's perception of the technology					X										

[1] Replanting is considered uneconomic in terms of labour invested in clearing and fencing very small plots, and the large edge effects (e g. shading from surrounding vegetation) on rubber growth

5.1.3 Methodological considerations in designing this participatory on-farm trial

5.1.3.1 Social factors

Agriculture is both a biological and a social process (Richards, 1985). Many social factors could potentially affect the outcome of a participatory on-farm trial, some of which are identified in Section 5.1.2. In a study of this scale, all these variables cannot be adequately replicated and incorporated into the experimental design. However, they still need to be taken into account, and should be observed and recorded in order to further our understanding of the issues which are important to farmers. Therefore, a socio-economic survey was designed to quantify these variables in the cases of the participating farmers. Some potentially important factors, such as farmer motivation, are non-quantifiable and a combination of qualitative methods must be used to collect information (Abbot and Gujit, 1997).

McGee (1997) discusses the advantages of a sustained researcher presence in the area, and notes the many insights gained by ethnographic research when living with farmers in their community. These included learning how to communicate in a culturally sensitive manner, the best times to visit farmers informally without disrupting their routines, and a detailed understanding of the wider context of people's lives, of which farming activities were only a part. Interacting with people on social occasions can also provide a wealth of relevant information (Colfer *et al.*, 1989). As the benefits of living in the community were large, I took up residence with a family in the village of Muara Buat for the duration of the research. Techniques used to elicit information included direct observation, participant observation and semi-structured interviews and, although these were informal, use of a critical evaluation procedure (Carruthers, 1980) improved the objectivity of information obtained. Similarly, the criteria described by Pretty (1994) were used for judging the 'goodness' or 'trustworthiness' of the qualitative information gained when using these interactive participatory research methods.

5.3.1.2 Agronomic and biophysical factors

When research is done on-farm, it is obvious that it cannot be as well controlled as on-station (Beer, 1991). To reduce experimental error, each farmer's field was considered as a block in the experiment, so that variation due to topography, surrounding vegetation and farmer management could be incorporated in the inter-block variation (Gomez and Gomez, 1984). Non-experimental variables on-farm, such as the incidence of pests, diseases, weed species and initial soil fertility, were likely to be different to those variables on-station (Norman, 1994), and thus were quantified as part of the data collection process in the trial.

5.1.4 Experimental objectives

The issues identified as requiring research could be formulated as a series of questions:

1. Is this agroforestry system feasible in practice?:

a) Can clonal rubber be established and grow successfully in a multi-strata agroforestry system similar to the conditions found in jungle rubber?

b) Is the design of the multi-strata agroforestry system acceptable to farmers, and can they successfully adopt the new techniques involved in planting clonal rubber?

2. What level of weeding is necessary to ensure successful establishment of clonal rubber?

3. What are the other factors, besides weeding, that affect growth of clonal rubber under smallholder conditions, and what are the effects of these?

4. What management recommendations can be made for smallholder farmers, taking into account their cash and labour resources?

5. How effective is this type of methodology for participatory on-farm trials which test the introduction of high yielding planting material to multi-strata agroforestry systems?

5.1.5 Weeding management treatments

In order to address these questions, the specific design of the trial was decided at a meeting at ICRAF's office in Bogor in January 1996, which was attended by all senior researchers. One aim of the trial was to compare four weeding management regimes, in order to answer Question 2 above. Rubber trees were to be strip-weeded (1 m on either side of the trees), with a range of weeding frequencies chosen to represent the low management in jungle rubber (Treatment B), intensive management in monoculture plantations (Treatment D), and an intermediate level (Treatment C). Treatment A was a control, comprising the standard management recommendations for a national monoculture rubber project for smallholders (TCSDP)[41], and included a legume cover crop. The actual weeding frequencies were decided in a participatory meeting with farmers and researchers in March 1996.

5.1.6 Trial context

This experiment is one component in the ICRAF/CIRAD/GAPKINDO Smallholder Rubber Agroforestry Project (SRAP), a network of on-farm trials established in three Indonesian provinces, working with 98 farmers. Within SRAP, this particular trial is classified as an 'RAS 1' type (Penot *et al.*, 1994). From January 1996 until October 1997, I was responsible for the implementation of this experimental trial in the field, and for data collection and analysis. Before this, from June 1995, I had participated in farmer visits and the distribution of planting material for this trial. Relevant project activities before January 1996 are included in Section 5.2 below.

5.2 MATERIALS AND METHODS

5.2.1 Farmer and field selection

Farmer and field selection was conducted in April 1995 by the project co-ordinators E. Penot and Dr G. Wibawa. Meetings were held in the villages of Muara Buat and Rantau Pandan (Figure 2.2) to identify farmers who were interested in planting clonal rubber and who showed a strong interest in joining the experiment. Farmers who had already planned to open a field to plant rubber that year (by clearing secondary forest or old jungle rubber plots with slash and burn techniques), and who also agreed to construct a fence were short-listed. Their fields were then inspected, and those which were easily accessible (close to a road), and

[41] TCSDP: The Tree Crop Smallholder Development Project, funded by the World Bank

larger than 0.5 ha in size were chosen (Table 5.2). Three experimental blocks were located in the fields of three farmers (Ismael, Azahri and Bustami), with a further two replicate blocks ('R1' and 'R2') located in the field of Saryono. Each field or block was sub-divided into four plots along the slope (average area 0.125 ha), with each plot extending from the top to the bottom of the slope, and treatments A to D were allocated randomly to these. Field maps are shown in Appendices 5.1 to 5.4.

Table 5.2. Characteristics of experimental fields (blocks)

Farmer	Ismael	Azahri	Saryono 1	Saryono 2	Bustami
Grid reference	1° 39.2' 101° 56.2'	1° 39.0' 101° 56.2'	1° 40.0' 101° 53.3'	1° 40.0' 101° 53.3'	1° 40.6' 101° 53.1'
Village	Rantau Pandan	Rantau Pandan	Muara Buat	Muara Buat	Muara Buat
Altitude (m asl)	230	220	270	270	270
Slope Position	Upper	Whole	Upper	Lower	Whole
Slope (°)	13-18	11-13	22-24	18-22	25-27
Soil erosion	Severe landslide on plots C and D (Sept. 96)	None	Landslides in gullies outside experimental plots		Small localised landslips
Aspect	WSW, 240°	SW, 220°		NNW, 333°	SSE, 150°
Previous land use	5 year old regenerating secondary forest	Cleared from jungle rubber 8 years previously, planted to clove trees which failed, plot subsequently abandoned to secondary forest regrowth	Old jungle rubber (40 years)		2 year old regenerating secondary forest

5.2.2 Field preparation and planting

Dr Wibawa, myself and the SRAP field assistant, I. Komardiwan, visited the farmers in July 1995 to assess the progress of the field clearing operations, to measure the fields, and to teach the farmers how to contour-stake planting holes with an 'A' frame. Farmers were advised to follow TCSDP recommendations for smallholders with respect to contour staking, holing and planting (Delabarre and Benigno, 1994). Each farmer's implementation of these techniques are described later in Section 5.3.3.1.

The rubber planting material (budded stumps) arrived in November 1995, and the farmers were taught how to plant these in polybags, and how to prepare and maintain a nursery. In December, the very low survival rates of these budded stumps necessitated the purchase of an alternative source of planting material: bud-grafted clones in polybags. There were not sufficient numbers of trees of any one clone available to be planted over all farms, and as there was an urgent need to plant in the rainy season, both GT 1 and PB 260 clones were used in the experiment (one clone per farm, allocated to farms at random). Analysis of the experiment did not take inter-clonal variation into account, as the aim was primarily to study growth of *clonal* rubber in the system.

The trees were planted in January 1996 at a density of 550 trees/ha, with a 6 m-spacing between rubber tree rows and 3 m between trees within the rows. A moderate fertilisation regime, that had been designed to be affordable for smallholders, was applied: 113 g TSP/tree at planting (equivalent to 13 kg P ha^{-1}), followed by 50 g urea/tree at three-monthly intervals (equivalent to 55 kg N ha^{-1} $year^{-1}$), for the first two years of growth.

The farmers received free grafted rubber clones, fertiliser, fungicide and technical advice. They were responsible for clearing and burning the field, building a fence, planting and fertilising the trees, selectively pruning the regenerating trees in the inter-row that were overtopping the rubber and implementing the weeding treatments.

5.2.3 Weeding frequencies

The exact frequency of strip-weeding for each treatment was decided together by farmers and researchers in a participatory meeting between in March 1996. They believed weeding in the first year after planting was most important, and that the weeding frequency could be reduced in the second year once the trees were well established (Table 5.3).

Table 5.3. Scheduled weeding frequency treatments for the first and second years after planting (Years 1 and 2), and for the 21 month experimental period reported here, when the trial was under my supervision.

Treatment	Inter-row vegetation	No. of weedings (Year 1: January 1996-December 1996)	No. of weedings (Year 2: January 1997-December 1997)	No. of weedings (Experimental period: January 1996-September 1997)
A	Legume cover crop	9	6	10
B	Secondary forest regrowth	3	1	4
C	Secondary forest regrowth	6	3	7
D	Secondary forest regrowth	9	6	10

5.2.4 Data collection

5.2.4.1 Rubber tree growth

Measurements of rubber tree growth were made every three months, for a subset of trees (Table 5.4), for the first 21 months after planting (the experimental period when I was responsible for the trial). Tree height was measured from the basal graft to the top of the stem (the union of the bud graft and rootstock is approximately 5 cm above ground level). Diameter was measured at 10 cm above the basal graft, with calipers. Vertebrate pest damage (the number of times that each tree's main stem was completely severed) was also recorded.

Table 5.4. Number of measured trees per plot

Farmer/ Plot	Ismael	Azahri	Saryono 1	Saryono 2	Bustami
A	30	30	39	51	30
B	35	30	44	41	33
C	35	30	34	36	30
D	30	32	45	35	31

5.2.4.2 Soil analyses

Initial soil conditions were assessed in September 1996. Using a hand auger, ten samples were taken at random positions in each plot within each farm/block, for each of two depths: 0-5 cm (topsoil) and 5-20 cm (subsoil). These were pooled for each depth, giving two samples per plot for analysis. The soil was air-dried on drying racks and sieved with a 2 mm sieve, then 100g samples were bagged, labelled and sent away for commercial analysis at the Centre for Soils and Agro-Climatic Research, Bogor, Java. Samples were analysed for pH, C_{org}, total N, P_{Bray}, exchangeable K, Ca, Mg, Na and Al, and cation exchange capacity (CEC).

5.2.4.3 Vegetation monitoring

Because of the unpredictable manner in which farmers implemented treatments, it was not possible to monitor weed regeneration quantitatively. Observations were made in each field of the maximum height of the inter-row vegetation, and the dominant morphotypes: trees, shrubs, herbs, grasses, ferns and climbers.

5.2.4.4 Farmer management of experimental fields

Implementation of the new techniques involved in planting clonal rubber by the farmers was monitored by me. The frequency of weeding actually implemented by the farmers, and the time and labour expended on this, was recorded by the farmers using work-books. This was cross-checked by researchers. Socio-economic data were collected by questionnaire survey (Kelfoun *et al.*, in press), and I held regular informal discussions with the farmers in the field regarding experimental management, problems encountered, and their opinions. In October 1997, at the end of the experimental period, I conducted an informal semi-structured interview with each farmer, in order to elicit feedback on the project and upon their experiences with clonal rubber.

5.2.5 Data analysis

5.2.5.1 Soil parameters

Two-way analysis of variance was conducted in Genstat 5.32 to investigate potential variation in soil characteristics between farms, accounting for probable differences due to soil depth. Samples from the four plots per field were used to give four replicates per block. Block structure was defined as block/plot/depth, and treatment structure as block x depth.

5.2.5.2 Rubber tree growth

In order to provide a clear picture of the effects of many biophysical and management variables on rubber tree growth, statistical analyses were conducted only on tree size at 21 months after planting (the end of the 'experimental period'). As management interventions were conducted and quantified at plot level (weeding frequency and weeding effort), plot means were used, not data on individual trees. Pest damage per tree was converted to an 'Index of pest damage' at a plot level (the cumulative number of stem breaks sustained over 21 months for each tree, totalled for all trees in the plot, then divided by the total number of trees).

Statistical analyses of the effects of block (farm), weeding frequency, weeding effort (person-days of labour invested in weeding), pest damage and soil characteristics on rubber diameter and height growth were conducted using ANOVA, simple linear regression and multiple regression in Genstat 5.32.

5.2.5.3 Construction of minimum adequate models of rubber growth

The principle of parsimony requires that models should be as simple as possible. This was ensured when constructing multiple regression models that accounted for all factors affecting rubber growth, by identifying the subset of explanatory variables which were actually necessary for the minimum adequate model (Crawley, 1993). Only those explanatory variables which caused a significant increase in residual deviance when removed from the maximal model were retained. The following two methods were used in this process of model simplification.

Method 1: Analysis of deviance (ANODEV) with all deviances assessed by removal of individual variables from the maximal model

The change in the residual sum of squares resulting from removal of a particular variable from the maximal model (the model which included all possible variables) was divided by the residual mean square from the maximal model to give an F value. This was compared with values in probability tables for the number of degrees of freedom corresponding to:

a) the change in the model, and

b) the residual term in the maximal model.

If the change resulted in a significant increase in residual deviance, then that term was retained in the minimum adequate model. This process was repeated for each explanatory variable individually. The data were then re-analysed using the minimum adequate model to obtain new parameter estimates, and the regression equation constructed with these (Crawley, 1993).

Method 2: ANODEV with deviances assessed by step-wise omission from the maximal model

Here, terms were removed from the maximal model in a sequence, starting with the least significant variables (as judged by their *t*-values). If the deletion caused an insignificant change in residual deviance, then the term was omitted. The parameter estimates of the remaining terms were then inspected, and the least significant term deleted next, until the null model was reached. The minimum adequate model was then constructed from all variables which had caused significant changes in deviance, the data re-analysed, new parameter estimates obtained, and the new regression equation constructed (Crawley, 1993).

NB *F*-tests were calculated on the basis of the residual mean square and d.f. of the model *from which the term was removed.*

5.2.6 Predicting commencement of tapping

A standard growth curve for clone GT1 under plantation conditions (Figure 5.1) was used in predictions of expected tapping time. To enable comparison of tree diameter at 21 months in this trial with diameters of standard trees under plantation conditions, our experimental tree diameters were converted to the equivalent 'ages' (months after planting) of the standard trees, using the regression equation in Figure 5.1. The time it would take trees to reach the minimum diameter when tapping can commence (173 mm, measured at 10 cm above the graft) was then calculated by subtracting the estimated ages of the experimental trees from the standard tree age at which tapping commences (57.36 months, from Figure 5.1). This figure, added to the actual tree age (21 months), would give the predicted tree age when tapping could commence.

N.B. It must be noted that calculation of these predicted tapping times assumes that experimental trees grow at the same rate as trees in plantations. This rate is unlikely to be achieved in reality, as plantation trees are well fertilised and planted with a well-weeded legume cover crop, whereas conditions are very different in the experimental environment, with secondary forest regrowth in the inter-row area (although the trees did receive basic fertilisation for the first two years after planting). However, there is no existing data from which a realistic growth curve could be constructed (this trial itself will provide that information in the future). Therefore, the predicted tapping times modelled here are likely to be under-estimates, and so represent the shortest possible time which could elapse before a tree of a certain size can be tapped, i.e. the tree would be *at least* this age before tapping could commence.

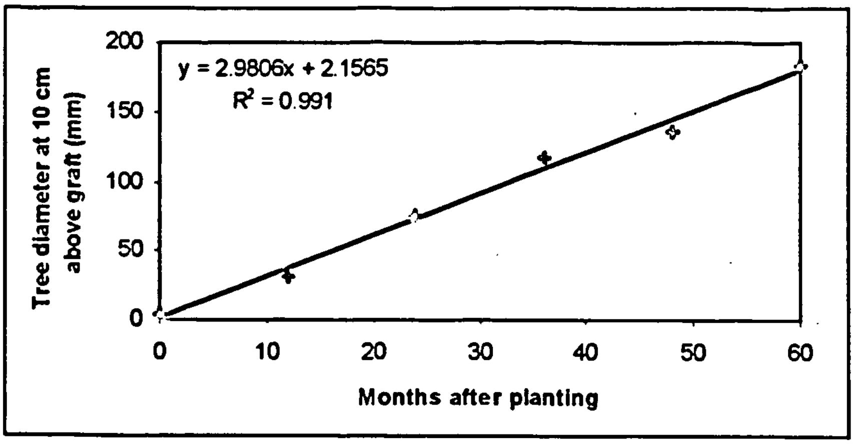


Figure 5.1. Standard growth curve for clone GT1 under plantation conditions, in Sembawa Rubber Research Station, South Sumatra, Indonesia. Data for tree girths measured at 1 m above the graft were provided by Dr G Wibawa, and these were converted to tree diameters at 10 cm above the graft (to enable direct comparison with measurements and predictions made in this trial), by use of a regression equation relating tree diameters at the two heights:
$Y = 0.797943 X + 1.60352$, where Y=girth at 1 m, X=girth at 10 cm, s.e. Y= 1.547, s.e. b= 0.024, and r^2=0.916.

5.3 RESULTS

5.3.1 Initial soil conditions

5.3.1.1 Texture

There were large differences between the fields of the four farmers in soil physical properties (Table 5.5); the differences in the contents of clay and silt were significant at the p<0.001 level, and of sand at the p<0.01 level (Table 5.6). There was also a significant difference between soil depths for sand content. Pooled data for each farmer showed that the clay content of the soil in Azahri's field was significantly lower than in the other fields, and that the silt content in Azahri and Ismael's fields was significantly higher than in the fields of the

Table 5.5 Physical and chemical properties of soil in participating farmers' fields

Farmer	Depth	Mean/ S.E.	Sand %	Silt %	Clay %	pH (H_2O)	pH (KCl)	C org %	N %	C/N ratio	P_2O_5 mg/100g	K_2O mg/100g	Ca me/100g	Mg me/100g	K me/100g	Na me/100g	Total bases me/100g	CEC	% Exch. bases	Al^{3+} mg/100g	H^+ mg/100g
Ismael	0-5 cm	Mean	28.25	36.00	35.75	4.43	3.85	2.68	0.20	13.85	16.00	22.75	3.39	0.89	0.35	0.05	4.67	11.78	41.25	2.37	4.74
		S.E.	7.50	3.67	4.09	0.11	0.09	0.27	0.02	0.80	0.58	3.30	0.59	0.10	0.06	0.01	0.66	1.74	5.75	0.63	0.96
	5-20 cm	Mean	21.50	37.25	41.25	4.03	3.68	1.73	0.14	12.26	13.50	19.00	2.02	0.56	0.16	0.04	2.77	10.62	29.50	4.88	2.98
		S.E.	5.38	1.89	3.71	0.13	0.09	0.15	0.00	0.77	0.29	4.67	0.53	0.07	0.02	0.02	0.60	1.39	10.50	1.33	0.74
Azahri	0-5 cm	Mean	36.75	43.00	20.25	4.05	3.73	2.60	0.20	12.74	17.00	7.00	0.45	0.34	0.10	0.02	0.91	9.05	10.50	3.30	4.84
		S.E.	1.89	0.82	1.11	0.05	0.05	0.35	0.02	0.72	1.58	0.71	0.07	0.03	0.01	0.01	0.07	1.21	0.87	0.32	0.91
	5-20 cm	Mean	20.75	64.25	15.00	3.95	3.65	2.52	0.20	12.30	17.00	7.00	0.39	0.34	0.11	0.00	0.83	8.65	9.75	3.90	3.91
		S.E.	6.87	12.28	5.52	0.06	0.05	0.49	0.03	0.67	1.35	1.29	0.09	0.06	0.02	0.00	0.14	1.21	1.03	0.51	0.63
Saryono 1	0-5 cm	Mean	49.25	12.50	38.25	4.15	3.93	3.05	0.22	13.66	20.75	24.50	1.33	0.51	0.30	0.02	2.16	8.21	26.75	1.70	4.36
		S.E.	1.80	1.66	2.32	0.10	0.05	0.25	0.01	0.47	1.38	7.17	0.28	0.09	0.09	0.01	0.45	0.95	6.43	0.20	0.77
	5-20 cm	Mean	46.25	12.25	41.50	4.18	3.90	2.65	0.19	14.52	18.75	17.00	1.02	0.51	0.27	0.06	1.84	7.19	24.75	1.61	3.74
		S.E.	0.85	0.48	0.87	0.14	0.07	0.23	0.03	1.20	1.80	4.64	0.31	0.08	0.09	0.04	0.43	0.48	4.11	0.29	0.35
Saryono 2	0-5 cm	Mean	42.00	13.50	44.50	4.03	3.73	3.29	0.25	13.47	51.25	9.25	0.74	0.29	0.16	0.03	1.21	9.61	12.25	2.53	5.87
		S.E.	2.35	1.66	1.85	0.09	0.08	0.22	0.01	0.69	1.11	0.63	0.06	0.04	0.01	0.01	0.12	0.43	1.03	0.26	0.25
	5-20 cm	Mean	33.50	12.50	54.00	3.95	3.75	2.41	0.20	11.71	49.75	7.25	0.53	0.21	0.12	0.12	0.89	7.72	11.25	2.50	4.33
		S.E.	5.98	1.50	4.53	0.06	0.09	0.40	0.02	0.99	1.89	0.25	0.06	0.03	0.01	0.09	0.11	0.31	1.18	0.24	0.26
Bustami	0-5 cm	Mean	37.25	19.25	43.50	3.95	3.58	3.43	0.26	13.21	24.25	14.00	0.91	0.32	0.18	0.02	1.43	12.60	11.25	6.25	4.92
		S.E.	2.43	0.75	1.71	0.05	0.05	0.16	0.01	0.20	1.65	1.68	0.17	0.06	0.02	0.01	0.20	1.04	2.10	0.92	0.38
	5-20 cm	Mean	37.25	18.00	44.75	4.00	3.63	2.25	0.20	11.46	20.25	11.00	0.48	0.23	0.11	0.01	0.82	10.63	7.75	6.25	3.56
		S.E.	1.11	0.58	1.55	0.06	0.05	0.09	0.01	0.51	0.48	1.00	0.09	0.04	0.02	0.01	0.08	0.57	1.25	0.68	0.38
ALL FARMS		Mean	35.28	26.85	37.88	4.07	3.74	2.66	0.21	12.92	24.85	13.88	1.12	0.42	0.19	0.04	1.75	9.61	18.50	3.53	4.32
		S.E.	1.89	2.92	1.99	0.03	0.03	0.11	0.01	0.26	2.13	1.37	0.16	0.04	0.02	0.01	0.21	0.39	2.14	0.32	0.21

others. Sand content was also significantly lower for Azahri and Ismael. As a consequence, the soils in the farmers' fields differ in their classification according to the USDA soil texture classification system (Table 5.7).

Table 5.6. Significance of ANOVA results for soil differences between farmers' fields and soil depth

Factor/ Soil parameter	Farmer	Soil depth
Clay	$p<0.001$	ns
Silt	$p<0.001$	ns
Sand	$p<0.01$	$p<0.01$
pH (H_2O)	ns	$p<0.05$
pH (KCl)	$p<0.05$	ns
Corg	ns	$p<0.001$
N	ns	$p<0.001$
P_2O_5	$p<0.001$	$p<0.05$
Ca	$p<0.001$	$p<0.001$
Mg	$p<0.001$	$p<0.001$
K	$p<0.05$	$p<0.001$
Total bases	$p<0.001$	$p<0.001$
Al^{3+}	$p<0.001$	$p<0.01$
H^+	ns	$p<0.01$
Cation exchange capacity	$p<0.05$	$p<0.01$
% Base saturation	$p<0.001$	ns

Table 5.7. Soil texture classification (USDA) of the four farmers' fields

Farmer	Ismael	Azahri	Saryono R1 Upper slope	Saryono R2 Lower slope	Bustami
Soil type	Clay loam	Silt loam	Sandy clay	Clay	Clay

5.3.1.2 Chemical properties

There were also significant differences in soil chemical properties between the farmers' fields and soil depth (Tables 5.5 and 5.6). The differences between farms did not appear to be closely correlated with the soil texture classification, and there was evidence of an interaction between farm and soil depth (Table 5.5).

Results from LSD tests showed that soil pH (KCl) was significantly higher in Saryono's R1 than in any other, and was lowest in Bustami's field (Table 5.5). The level of basic cations for Ismael and Saryono 1 were consistently and significantly higher than in the other replications. Percentage base saturation also followed this trend. Exchangeable bases were significantly higher in the topsoil than in the subsoil (except Na), and there were significant differences between farmers (except for Na). Cation exchange capacity was also significantly higher in the topsoil, and variation across farms was significant at the 5% level; Saryono's R1 being significantly lower than the other replications. Available phosphate was significantly higher in Saryono's R2 (more than twice the level in any other field).

Aluminium levels varied significantly across farms, being highest in Bustami's and lowest in Saryono's R2, and were significantly higher in the subsoil than the topsoil. Exchangeable acidity (H^+) levels were significantly higher in the topsoil. Organic carbon and nitrogen levels were higher in topsoil than in subsoil, but there were no significant differences between farmers.

5.3.2 Socio- economic characterisation of participating farmers

None of the 'farmers' relied totally on farming for their livelihood (this was a result of the criteria used in the farmer selection process, Section 5.2.1). Two were teachers, and had been educated to University level, the other two to Senior High School level, which was above the average for people in the study area (Table 5.8).

Table 5.8. Socio-economic characterisation of participating farmers. Information was collected as part of a survey of SRAP farmers by Kelfoun *et al.*, 1997.

Farmer	Ismael	Azahri	Saryono	Bustami
Local/immigrant	Local	Local	Immigrant	Local
Occupation	Teacher	Head-teacher	Soldier	Village Head
Age	38	47	37	52
Education level	University	University	Senior High School	Senior High School
Number of dependents	4	4	3	6
Available family labour	2	1	1	3
Monthly salary (Rp)	386 000	877 000	400 000	0
Average monthly income from rubber (Rp)	112 000			179 000
Other business[1]	None	Shop	Timber trade	Rattan trade
TOTAL ANNUAL INCOME (excluding other business, in Rp)	5 976 000	10 524 000	4 800 000	2 148 000
House: owned/rented	Owned	Owned	Rented	Owned
House value (000 Rp)	27 000	15 000	5 075	7 600
Livestock value (000 Rp)	1 836	3	0	3
Total land area (ha)	3.5	2.5	1.5	10.5
Productive rubber				
Total area (ha)	1.5	-	-	2.0
Plot age(s) (years)	15	-	-	10 / 25
Unproductive rubber (immature)[2]				
Total area (ha)	-	1.0	-	4.5
Plot age(s) (years)	-	10	-	4 / 5 / 7
Experimental plot (ha)	0.5	0.5	1	0.5
Unproductive rubber (mature)[3]				
Total area (ha)	-	-	-	1.0
Plot age(s) (years)	-	-	-	40 / 50
Cinnamon				
Total area (ha)	1.5	0.25	0.5	2.0
Plot age(s) (years)	4	3	1	4 / 7
Irrigated rice (ha)	0	0	0	0.5

(1 US $=2300 Rp, July 1997)

[1] No financial information available
[2] Rubber trees have not attained sufficient girth for tapping
[3] Plot has reached the end of its productive life

5.3.2.1 Income

Three of the four farmers in this trial had off-farm government jobs with a regular monthly salary, and also received a monthly provision of rice for two adults and two children (Table 5.8). Although Bustami did not receive a government salary, his position as head of the village entailed various 'perks', and he also profited from having two overseas student lodgers. Bustami owned productive rubber gardens, which were partly tapped by him, partly by share tappers (one-third of the cash from the sale of share-tapped rubber goes to the owner). Another farmer with tappable rubber was Ismael, and his garden was tapped by either himself or his wife. Income from other business interests was impossible to quantify, due to lack of written records, and also the sensitivity of this information. The differences between farmers in total annual income (excluding other business) was large, with Azahri earning the most, Bustami the least, and Ismael and Saryono an intermediate amount (Table 5.8).

5.3.2.2 Land holdings

<u>Rubber</u>

Bustami owns the largest area of land, which reflects his age (the oldest in the sample), and the length of time his family have lived in the area (his father was one of the original founders of the village). In addition to two plots of jungle rubber which were inherited from his father and are no longer tappable, he has established at least five plots of jungle rubber. Two of these are productive, and another three have not yet come into production. The latter three were planted really as an investment for his children (and as a land appropriation strategy), and are not managed intensively.

Ismael has just one plot of tappable jungle rubber, which also provides fruits and other NTFPs.[42] Azahri planted 1 ha of jungle rubber ten years previously, and this was not managed intensively, thus the trees are not yet big enough to tap. Saryono owns only 1.5 ha of land (in which he established the experimental plots), as he was only posted to the area in 1993. It is possible that he will be posted to another place in the future, but believed it was a good investment to buy land and plant clonal rubber.

<u>Cinnamon</u>

This was first planted in the study area in around 1990, as a result of spontaneous diffusion of a practice that is widespread in a neighbouring district at higher altitude (Kerinci). Since then, aided by high cinnamon prices, there has been a boom in planting. This explains why all the participating farmers have at least one plot. Bustami and Ismael have already started

[42] Non-timber forest products

harvesting, however a 50% drop in price between 1996 and 1997 has severely reduced the potential income from this labour-intensive crop.

Irrigated rice

Bustami is the only farmer who owns an irrigated rice field. This was purchased five years ago, and is cropped every year with a local rice variety of six months duration. The yield from this plot supplies enough rice to feed the family for approximately seven months, and thus is an important part of the household economy.

5.3.2.3 Ranking of farmers according to socio-economic variables

If the farmers are assigned ranks according to their official income, the value of their assets, and the extent of their land holdings, Saryono is clearly the 'poorest', while the position of the other three farmers is ambiguous. For example, Bustami has the lowest income, but owns the largest area of land. Azahri has the highest income, but in terms of assets and land holdings ranks behind Ismael who has invested more in his house and livestock.

5.3.3 Farmer management of experimental fields

5.3.3.1 Implementation of new clonal rubber planting techniques by the farmers

The establishment and maintenance of clonal rubber required the farmers to implement a number of techniques which they had not previously practised when planting local seedling rubber (Sections 2.2.1; cf. 4.1.4.2). Differences between farmers were apparent in their adoption of the new techniques: Ismael consistently managed his field according to the technical advice given by the project, the next best was Azahri, followed by Saryono and finally Bustami (Table 5.9).

One technique which caused all farmers difficulty was contour staking of the planting holes (Table 5.9). Ismael did not even try this, preferring to have his trees planted in equally spaced rows, regardless of topography. Unfortunately a landslide occurred in September 1996, and around 50 of his trees were lost in plots C and D (Appendix 5.1). It is debatable whether the loss would have been so great if contour planting had been practised. Bustami also planted his trees in straight rows, however as the slope was uniform in his field, this was not of great consequence. Saryono started staking using an A frame, but as this was unwieldy on the steep debris-covered slopes, this method was abandoned after 30% of the field had been staked. Subsequently string was used to mark straight rows, but these often did not meet the first rows correctly. Therefore in this field the layout of the tree rows was quite chaotic (Appendix 5.3). Azahri mastered the A-frame technique correctly, but was confused with the tree spacing. Thus planting holes were dug at a spacing of 6 m along the row, and 3 m down the slope, instead of the opposite way around. Correcting this required considerable time and expense from the farmer, myself and SRAP field staff.

Table 5.9. Farmer implementation of clonal rubber planting techniques (personal observations and observations by project co-ordinators G. Wibawa and E. Penot)

Farmer Management	Ismael	Azahri	Saryono	Bustami
Field preparation				
Date cleared	August 95	September 95	April 95	September 95
Date burned	October 95	October 95	July 95	November 95
Logs cleared from rows	Not cleared	Not cleared	Not cleared	Not cleared
Fencing	Barbed wire (Four rows)	Barbed wire (Four rows)	No fence	Bottom of plot only, plastic sheet
Contour staking with A-frame	No	Yes, but wrong spacing initially	30% of field	No
Planting holes	Correct size	Correct size	Variable	Too small
Weeding before planting	No weeding	No weeding	Two weedings	No weeding
Nursery management				
Polybag preparation	Immediate	Immediate	Delay of one day	Delay of one day
Nursery location	Home garden	Field	Field	Field
Shelter constructed	Yes	Yes	No	No
Watering	Frequent	Infrequent	Infrequent	None: rainfall only
Removal of non-clonal shoots	Frequent	Frequent	Infrequent	Infrequent
Planting				
Date planted	End December 95	February 96	January 96	January 96
Necessary compaction of soil around tree	Satisfactory	Needed more trampling	Satisfactory	Satisfactory
Replacement planting	Not necessary: very low mortality	Not necessary: very low mortality	50 trees, September 96	70 trees, September 96
Maintenance				
Lateral shoot pruning	Frequent	Never	Infrequent	Never
Disease treatment	Regular spraying	Infrequent spraying	Regular spraying	Infrequent spraying
Regular fertilisation	Yes	Yes	Yes	Yes
Branch induction	August 97, but not correctly	Very late	Very late	Not necessary: trees too short

After planting, lateral branch pruning (Section 2.2.1.4) was not implemented by the majority of farmers, and as this was vital for good height growth, the team of technicians and I intervened and corrected this each time the trees were measured (every three months). The scheduled three-monthly urea fertilisation (Section 5.2.2) was carried out faithfully by every farmer, as soon as the fertiliser was received from the project. Branch induction (Section 2.2.1.4) was not performed at the right time by Saryono and Azahri, and Ismael cut the apical shoots of his trees with a machete, as the correct technique was too slow in taking effect. There is a high probability of branch loss from these trees in the future, as a result of wind damage.

5.3.3.2 Farmer implementation of experimental protocol

Weeding frequency in the rubber rows (number of weedings)

Only one farmer (Azahri) implemented the weeding treatments correctly as was agreed in the meeting between farmers and researchers (Table 5.10). Ismael followed the protocol for the first six months, even weeding an extra 0.5 m on either side of the trees (to 1.5 m instead of 1.0 m), but after August 96 did not do any further weeding in the rubber rows. Bustami did the initial weeding in March 96, then at the end of August 96 (the time scheduled to weed Plots A and D only), weeded the whole field. After that, no more row weeding was done, except for circle weeding around replacement trees. Saryono weeded his field three times: initially in March 96, then in September 96 and March 97. Extra weeding was carried out in Plots A and D in R2, the lower replicate block, in November 96 and February 97. This was because these plots were easily accessed, being very close to the field entrance and the hut at the bottom of the hill. No extra weedings were carried out in the less accessible R1 at the top of the hill.

Table 5.10. Scheduled and actual frequency of weeding of rubber tree rows in first 21 months after planting

Farmer/ Plot	Scheduled weeding frequency	Ismael (IS)	Azahri (AZ)	Saryono 1 (S1)	Saryono 2 (S2)	Bustami (BU)
A	10	5	10	3	5	2
B	4	2	4	3	3	2
C	7	2	7	3	3	2
D	10	5	10	3	5	2

Although I visited the farmers one week before each scheduled weeding time to remind them, arranged to accompany the farmers on mutually agreed dates to help supervise weeding of specific plots, conducted regular visits to motivate farmers, and cajoled and reminded them of their obligations, the protocol was not followed. Valuable information pertaining to management of clonal rubber by smallholders, was gained by examining the cases of individual farmers, as follows.

Azahri: The correct weeding frequencies were implemented, however, generally not on time. This was because of his off-farm employment as head-teacher of the local school, where he worked until 2 pm, six days a week. Thus he could only weed for a few hours every afternoon, and so treatments would be implemented over one or two weeks. Initially he had employed labourers to weed, but this proved to be too expensive.

Ismael: The reason for not continuing weeding was that he lost all motivation for working in the field after the landslide occurred. Previously he had thought that the weeding regime was too complicated, and that the high weeding treatments (A and D) required unnecessary work, as weed regrowth was slow. However, despite these comments, Ismael adhered to the protocol, stating that he wished to see a successful conclusion to my research and did not want to 'disappoint' me. The net result though was that the different treatments were only partly implemented.

Saryono: His reasons for not carrying out all the scheduled weeding were that he was away from home on a training course from May to September 1996, that he thought the protocol was too complicated, and that the layout of the plots within the field made it difficult to supervise his hired labourers, and make sure they weeded the right plots. In addition, he believed that the trees were more vulnerable to attack by monkeys if the field was clean. He thought that the most important times to weed were at the beginning and end of the wet season, and this is why he weeded in March and September. The net result was that in block R1 there was no difference between the treatment plots in terms of the number of weedings performed.

Bustami: This farmer and his wife certainly understood the layout of plots, and the principles behind the planned experimental comparisons, however they stated that it was 'a shame' to weed only one plot at a time, as the trees that weren't weeded wouldn't grow so well. So when they did weed, they weeded the whole field. When it became apparent that pest damage was a big problem, they stopped weeding altogether, believing the trees would be more visible to monkeys if the tree rows were clean. The net result that there was no difference between plots in the weeding frequencies implemented.

Management of inter-row vegetation

Legume cover crops (LCCs) in Treatment A

Establishment of these was successful in all farmer's fields, however, maintenance was poor. None of the farmers implemented the second phosphate fertilisation, or weeded the LCCs after they had germinated, as was recommended in the protocol. Thus phosphate deficiency was observed (T. Fairhurst, pers. comm. 1997), and in Ismael and Azahri's fields the cover crop was quickly overtaken by regenerating secondary vegetation. In these fields I intervened and replanted the LCCs at the beginning of the following rainy season (November 96). In Bustami and Saryono's fields the crop appeared to be quite healthy, despite the lack of maintenance. However in Bustami's field, the LCC also colonised the rubber rows, and smothered the trees in treatment A. The El Nino drought in the summer of 1997 killed off the LCCs in all fields.

Other crops planted

Although the inter-row areas in Plots B, C and D were supposed to be secondary forest regrowth, Saryono planted eight durian trees in one plot. He had bought the seedlings, and the obvious place to plant them was in the field that he had spent so much time and money clearing. Ismael planted vegetables (aubergines, tomatoes and chilli peppers) in the upper part of his field. His reason was that this was an efficient use of labour, as the crops could be tended when he visited the field to guard against monkeys, and reciprocally that when his wife went to the field to harvest vegetables, this would deter monkeys.

Management of secondary forest regrowth

The actual management of the inter-row vegetation in Plots B, C and D differed greatly between farmers (Table 5.11); so too did the dominant growth-forms (morphotypes) found in the regenerating vegetation of their different fields.

Table 5.11. Farmer management of inter-row vegetation and frequency and maximum height of morphotypes of regenerating vegetation

Farmer/ Time period		Ismael	Azahri	Saryono 1	Saryono 2	Bustami
Mar 96- Sep-96	Management	Regular slashing of woody species	No management interventions	Slashing of large trees (at base)	Slashing of large trees (at base)	Inter-row completely unmanaged
	Vegetation morphotype/ Frequency/ Height	Trees * 1m Shrubs * 0.5m Herbs * Grasses ** 0.5m Ferns - Climbers **	Trees ** 1m Shrubs *** 0.5m Herbs * Grasses * 0.5m Ferns *** 1m Climbers *	Trees *** 2.5m Shrubs * 1.5m Herbs - Grasses * 0.5m Ferns - Climbers **	Trees * 2m Shrubs ** 1.5m Herbs * Grasses * 0.5m Ferns Climbers **	Trees * 1m Shrubs *** 1m Herbs * Grasses ** 0.5m Ferns - Climbers ***
Oct 96- Sep-97	Management	Regular slashing back, grass cut for cattle fodder	Lower rows slashed 8/97 (advised not to continue by researcher)	Continued removal of large trees	Continued removal of large trees	Inter-row completely unmanaged
	Vegetation morphotype/ Frequency/ Height	Trees * 2m Shrubs * 1.5m Herbs - Grasses *** 0.5m Ferns - Climbers *	Trees *** 4m Shrubs * 2m Herbs - Grasses * 0.5m Ferns *** 2m Climbers -	Trees * 1.5m Shrubs *** 2m Herbs - Grasses ** 1m Ferns - Climbers *	Trees ** 1m Shrubs *** 1.5m Herbs - Grasses ** 1m Ferns * Climbers *	Trees * 2m Shrubs *** 2m Herbs * Grasses ** 1m Ferns - Climbers ***
Oct 97- Sep-98	Management	All inter-row completely slashed back	All inter-row completely slashed back	All inter-row completely slashed back	All inter-row completely slashed back	Inter-row completely unmanaged
	Vegetation morphotype/ Frequency/ Height	Trees * 0.5m Shrubs * 0.5m Herbs - Grasses *** 0.5m Ferns - Climbers *	Trees * 0.5m Shrubs * 0.5m Herbs - Grasses *** 0.5m Ferns *** 0.5m Climbers -	Trees * 0.5m Shrubs * 0.5m Herbs - Grasses *** 0.5m Ferns - Climbers -	Trees * 0.5m Shrubs * 0.5m Herbs - Grasses *** 0.5m Ferns - Climbers -	Trees * 3m Shrubs *** 2m Herbs - Grasses ** 1m Ferns - Climbers ***

***Dominant; ** Abundant; * Present

Right from the start of the experiment, fearing competition with his rubber, Ismael regularly slashed back any regenerating woody species, so herbaceous climbers (*Mikania* spp.) and grasses became dominant. This led to other farmers coming into the field to cut the grass for cattle fodder (this was traditionally allowed in the study area). Therefore, vegetation cover was very sparse, and the lack of deep rooted species may have contributed to the landslide in September 1997. After this, the field was effectively abandoned, with no active management, and secondary forest species began to regenerate. However in October 1997, this was slashed back again, as Ismael believed that secondary forest species provided cover for destructive wild pigs, which could hide in the field without being seen. The highly competitive weed species *Imperata cylindrica* began to colonise the landslip area, and a number of rows in Plot B. By November 1998, *Imperata cylindrica* had invaded many more parts of the field, and there was very little woody vegetation present, as a result of continual cutting back.

In the first year of the experiment, Saryono cut down all large regenerated trees (mainly *Trema* spp.) at ground level, as they were shading his rubber. He thought lopping the tops of the trees and overhanging branches as recommended in the protocol was a waste of time. After this, there was very little tree regeneration, and dominant morphotypes were shrubs (*Chromolaena odorata, Lantana camara, Melastoma malabathricum, Blumea balsamifera)* and grasses. *Mikania* spp. were a big problem in the lower block R2, especially in Plot B. In November 1998, the *Imperata cylindrica* which had only occurred previously in the upper replication (October 1997), had become established in small patches throughout the field.

During the first 20 months after planting, Azahri did not manage the secondary forest regrowth in his field, due to labour and cash constraints. The dominant morphotypes here were trees (*Trema* spp., *Macaranga* spp. and *Mallotus* spp.), and these grew at a similar but slightly faster rate than the rubber to heights of 4 m. Initially the shrub *Melastoma malabathricum* was dominant, along with the fern *Pteridium aquilinum*. The fern persisted through the later stages of regeneration, and even invaded the rubber rows. *Imperata cylindrica* was present in one row at the base of Plot A adjacent to the road where there was most light (*I. cylindrica* is shade intolerant). Due to increasing damage to his rubber trees by pigs in the summer of 1997 (and suggestions from Ismael), Azahri began to clear all the inter-row vegetation, so that there would be no cover for pigs. I asked him to stop, which he did, but when I left in November 1997, he resumed, and cleared the whole field. After that, he slashed back any regenerating woody vegetation on a regular basis. By November 1998, the existing *I. cylindrica* in Plot A had spread to another three rows, and patches had appeared in other parts of the field. This weed is notoriously difficult to eradicate once it establishes in open areas, and quickly becomes dominant (Bagnall-Oakeley *et al.*, 1997). It has been shown to be extremely competitive with young rubber (Menz and Wibawa, 1995).

Bustami did not prune or cut back the inter-row vegetation at all in his field. The dominant morphotypes here were shrubs (*Chromolaena odorata, Lantana camara*), and grasses, with only some trees regenerating. However, there was considerable shading of the rubber trees, as these were very small. The two uppermost rows in Plot A were invaded by *Imperata cylindrica*. There were great problems with *Mikania* spp. which quickly invaded the rubber rows and climbed over the trees: this had a detrimental effect on their growth, and sometimes the weight of *Mikania* caused the grafted clonal shoot to break off from the rootstock completely. This weed was removed every three months by the research team (myself and technicians) when the trees were measured, to allow stem diameters to be measured accurately; the farmer only rarely did this himself. This was a typical example of the very low management effort by this farmer in his field.

5.3.4 Rubber tree performance

5.3.4.1 Mortality

Clear differences can be seen between farms in the percentage of the original trees planted that did not survive (Figure 5.2). In the case of Ismael's farm, mortality in plots C and D was due to a landslide in September 1996, otherwise there would have been 100% survival. Similarly, there was 100% survival in the field of Azahri, until the last measurement when severe pig damage contributed to the death of three trees. In contrast, mortality was extremely high in the field of Bustami (69% of the trees). This reflected the very low management investment by this farmer, in terms of weeding, control of inter-row vegetation and vertebrate pest control. The second highest mortality was found in the upper block R1 in Saryono's field (25%), followed by 13% in the lower block R2. Within the farms of Bustami and Saryono, the highest mortality was observed in plots closest to the field edge, where the adjacent vegetation was mature jungle rubber (plot A for Bustami, and plots D and B for Saryono's R1 and R2 respectively).

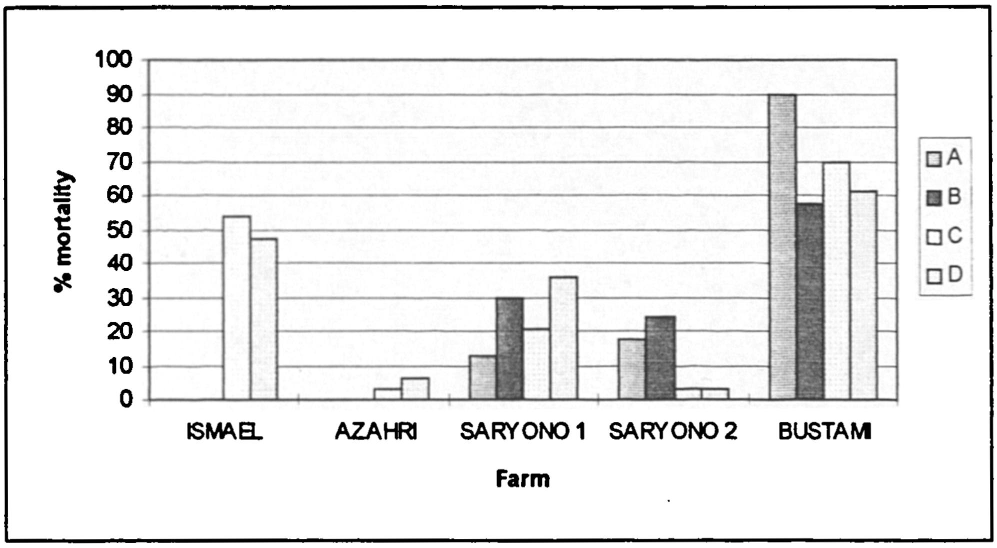


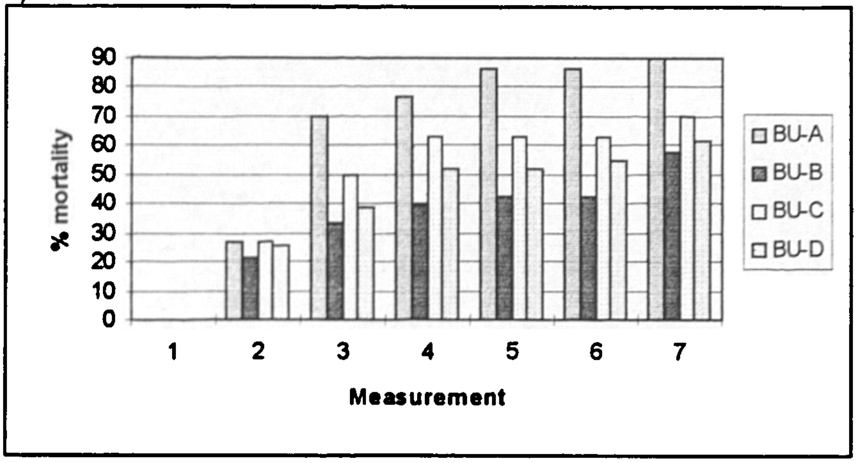
Figure 5.2. Rubber tree mortality between farms and plots (percentage of original trees planted), 21 months after planting. NB. Mortality in Ismael's field was due to a landslide.

In the three experimental blocks where mortality was high (Saryono's R1 and R2, and Bustami's field), mortality increased with time, and a slight seasonal effect was observed. The period between measurements 2 and 3 was the first dry season that the young trees experienced (Table 5.12), and this coincided with the largest increase in mortality (Figure 5.3). From measurement 4 onwards, the rate of mortality declined, until an increase again at measurement 7 (the end of the second dry season, which had been severe due to the El Nino phenomenon).

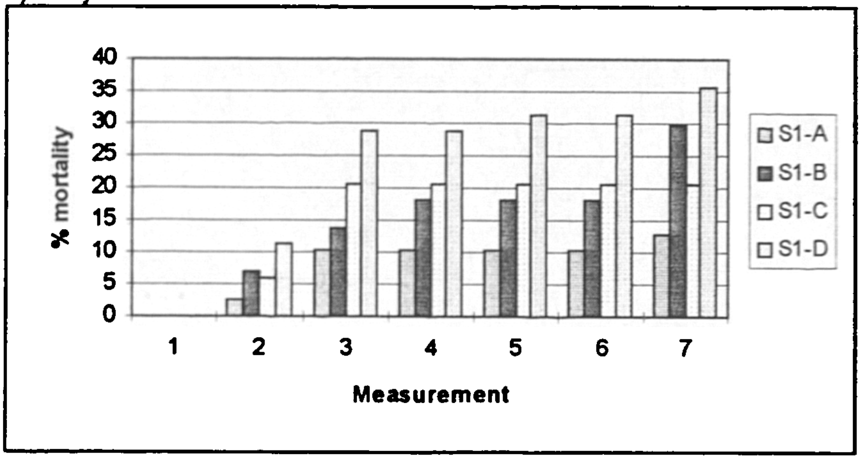
Table 5.12. Measurement times, corresponding season and age of trees

Measurement	1	2	3	4	5	6	7
Month and year	Mar. 1996	Jun. 1996	Sept. 1996	Dec. 1996	Mar. 1997	Jun. 1997	Sept. 1997
Months after planting	3	6	9	12	15	18	21
Season	End of wet season	Middle of dry season	End of dry season	Middle of wet season	End of wet season	Middle of dry season	End of dry season

a) Bustami



b) Saryono R1



c) Saryono R2

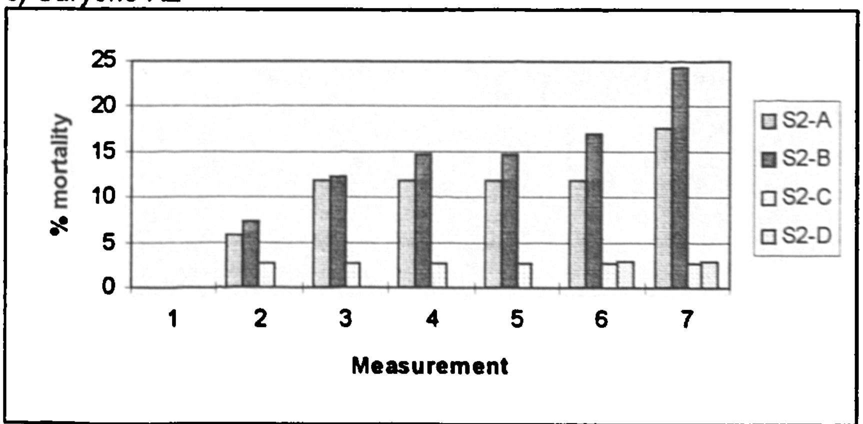


Figure 5.3. Rubber tree mortality over time: percentage of original trees planted that were recorded as dead at each measurement over the experimental period (3-21 months after planting), for a) Bustami, b) Saryono's block R1 and c) Saryono's block R2.

There was a lack of consistent variation in mortality rate between the treatments across the farms. However, high mortality was observed in certain plots within farms, notably treatment plot A in Bustami's field, plots B and D in Saryono's R1, and plot B in Saryono's R2. These plots were all located at the field edges, closest to the mature rubber agroforest which bordered the fields. In these plots, damage by monkeys and pigs was especially high (pers. obs.). It is possible that repeated breakage of tree stems, and removal of the leading shoot each time one was produced could have contributed to the high tree mortality in these plots. High levels of pest damage also coincided with the end of the dry season, as there was little available food for monkeys and pigs in the surrounding forest and agroforest at that time (pers. obs.; Gauthier, 1996a), and so this too may have interacted with the low rainfall in contributing to mortality, although we have no concrete evidence to prove or disprove this.

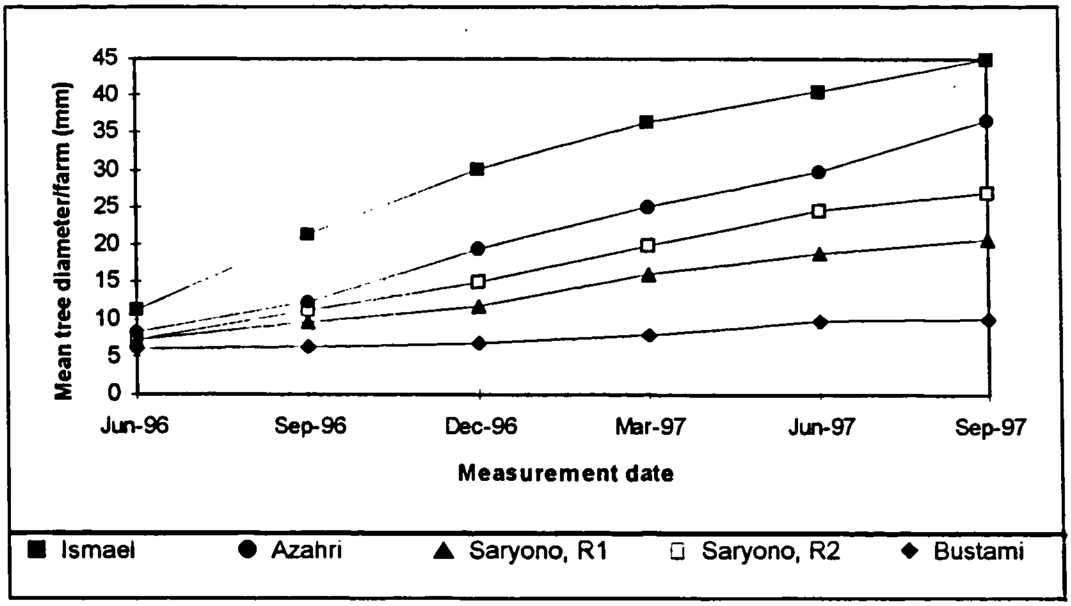
5.3.4.2 Tree growth over time, for each farmer's field (experimental block)

Clear differences were observed in the growth rates of rubber trees among farms by December 1996, 12 months after planting (Figure 5.4). Ismael's trees showed the fastest growth, although the growth rate declined slightly in the second year, probably due to the fact that he did not weed the rubber rows after August 1996 (Section 5.3.3.2). Of the other fields, the growth rate was highest in Azahri's field, and decreased through Saryono's R2 and R1, to Bustami's where diameter increment was only 5 mm in 21 months (Figure 5.4a).

Rubber tree height showed the same trend as diameter for each farmer's field. The largest height increment was seen in Azahri's field in the rainy season between December 1996 and March 1997. In Saryono's block R1, height growth increment was negligible after March 1997, and in Bustami's field mean tree height actually decreased after this date. This was due to damage by vertebrate pests which severed the tree stems, and so the trees decreased in height between measurements, sometimes by up to 1 m. Pest damage is considered further in Section 5.3.4.5 below.

Farmers' fields at 4 and 21 months after planting are illustrated in Plates 5.1 to 5.4, located in Appendices 5.1 to 5.4.

a) Diameter



b) Height

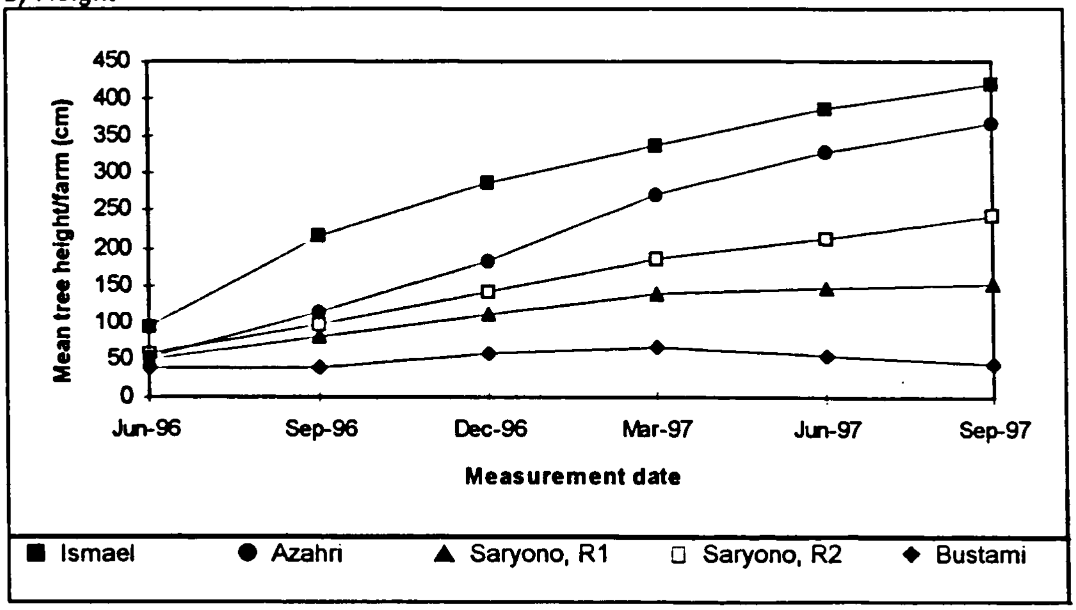


Figure 5.4. Rubber tree growth from June 1996 to September 1997: a) Mean tree diameter (mm) for each farm/experimental block; b) Mean tree height (cm) for each farm/experimental block.

5.3.4.3 Rubber tree size, 21 months after planting

For clarity, from this point forward tree size at 21 months after planting is used as the index of rubber growth. Only those trees that were planted at the beginning of the experiment and survived the full 21 months were included in the following analyses.

Twenty-one months after planting, there were highly significant differences in rubber growth for diameter and height amongst farms ($p < 0.001$), (Figures 5.5 and 5.6). Comparing these figures with Figure 5.2, it can be seen that for farmers with high tree mortality, the size of their trees is correspondingly low.

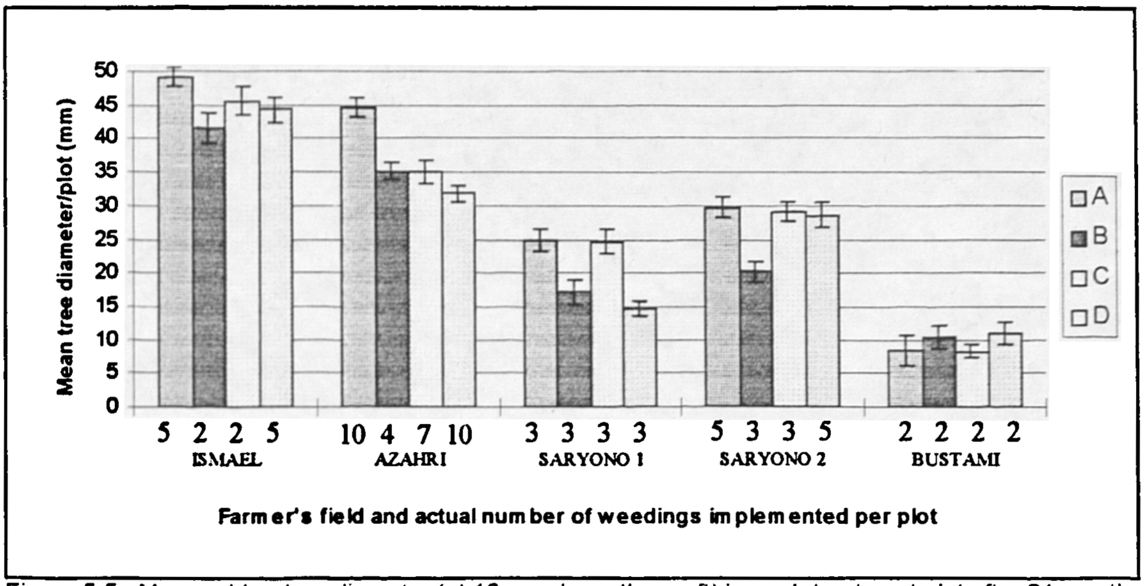


Figure 5.5. Mean rubber tree diameter (at 10 cm above the graft) in each treatment plot after 21 months growth in the field, and the actual number of weedings implemented per plot by the farmers. Error bars denote the standard error of the mean.

Figure 5.6. Mean tree height in each treatment plot after 21 months growth in the field, and the actual number of weedings implemented per plot by the farmers. Error bars denote the standard error of the mean.

5.3.4.4 Effect of weeding on rubber tree size (21 months after planting)

5.3.4.4.1 Weeding frequency

There was no significant difference between the planned weeding frequency treatments A, B, C and D (two-way ANOVA) (Figures 5.5 and 5.6). This was partly because three of the farmers did not implement the treatments as defined in the protocol (Table 5.10).

Variation in tree growth was not explained by the actual frequency of weeding carried out by the farmers; there were major inter-farm differences independent of the number of weedings (Figures 5.5 and 5.6). For example, comparing the plots that were weeded twice, trees in Ismael's field had diameters four times larger than those in Bustami's. In the case of Saryono's R1, weeding frequency was the same over the whole field, but mean diameters in Plots A and C were significantly higher ($p<0.05$, LSD test) than in Plots B and D. Similarly, in his second replicate block (R2), the two plots that were weeded three times also differ significantly ($p<0.05$, LSD test).

The only field which was weeded according to the protocol was that of Azahri. When comparing the treatments within this field, mean diameter in Plot A (LCC control) was significantly higher than in the other plots ($p<0.05$, LSD test). The trend where Plot A was significantly higher than Plot D was also repeated in Saryono's R1, and in Ismael's field, even though the number of weedings was the same for each comparison.

Similar trends were observed for height as for diameter (Figure 5.6), although, when comparing mean heights per plots within fields using LSD tests, there are some significant differences in addition to those found for diameter. Within Ismael's field, mean height in Plot A is significantly higher than all other plots. Within Azahri's field, in addition to trees in Plot A being significantly taller than in all other plots, Plot D has significantly shorter trees than in Plots B and C. In Saryono's R1, trees in Plots A and C are significantly taller than those in Plots B and D, and in addition, mean height in Plot D is significantly lower than in Plot B. These will be discussed later in the section on pest damage (Section 5.3.4.5).

The lack of a significant relationship between weeding frequency and rubber diameter or height growth was confirmed by simple linear regression analyses on these variables over all 20 experimental plots: adjusted r^2 values are 0.204 for diameter, and 0.258 for height. Therefore, the effect on growth of another weeding-related variable, namely the total number of person-days spent weeding a plot (weeding effort) was investigated.

5.3.4.4.2 Weeding effort

Weeding effort was compared with weeding frequency (Table 5.13), however the relationship between the two variables was not significant ($p=0.15$, linear regression on the 20 unweighted plot values). There were significant differences between blocks for weeding effort ($p<0.001$, one-way ANOVA).

Table 5.13. Weeding frequency and corresponding person-days of labour expended per plot (weeding effort) by each farmer, for the first 21 months after planting.

Farmer/ Plot	Weeding variable	Ismael	Azahri	Saryono R1	Saryono R2	Bustami
A	Frequency	5	10	3	5	2
	Person-days	14.22	8.92	7.20	7.89	2.63
B	Frequency	2	4	3	3	2
	Person-days	10.91	3.13	7.20	7.20	2.63
C	Frequency	2	7	3	3	2
	Person-days	9.28	4.92	7.20	7.20	2.63
D	Frequency	5	10	3	5	2
	Person-days	14.22	8.92	7.20	7.89	2.63

Rubber tree diameter and height were significantly ($p<0.001$) and positively correlated with weeding effort, that explained 57.8% and 48.7% of variation in diameter and height growth of rubber respectively (linear regression on the 20 unweighted plot values, Figure 5.7). Weeding effort therefore explains slightly more of the variation in diameter than height.

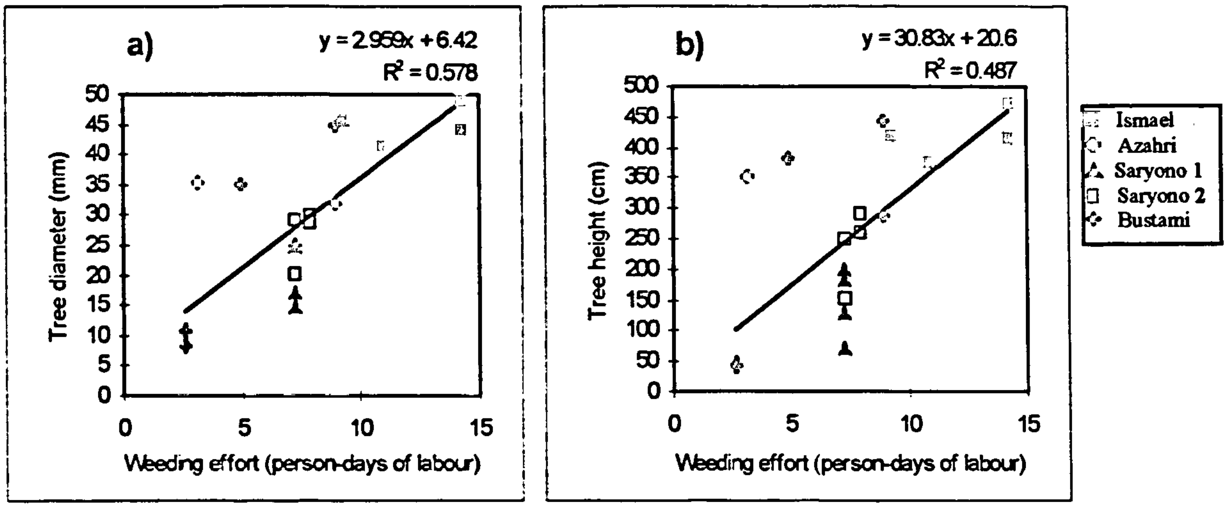


Figure 5.7. Linear regression between a) mean rubber tree diameter per plot after 21 months and weeding effort (person-days/plot), and b) mean rubber tree height per plot after 21 months and weeding effort, for 20 unweighted plot means.

These relationships are largely explained by variation amongst, rather than within farms. The difference in levels of weeding effort amongst farms is largely a result of the different methods of weeding employed by different farmers. These varied in terms of their effectiveness, and their labour requirements. For example, slashing with a machete (Azahri, Saryono and Bustami) was quick, but subsequent weed regrowth was fast, whereas hoeing (Ismael) was much more labour-intensive but also much more effective.

5.3.4.5 Influence of pest damage on rubber tree size (21 months after planting)

Breakage of rubber tree stems by vertebrate pests (monkeys and feral pigs) was a very important factor at the landscape level throughout the study area, the severity of which had not been sufficiently recognised before implementation of the on-farm trial. As for weeding management, there were large differences amongst farmers in the amount of effort invested in guarding and fencing their fields against pests, and this was reflected in the index of pest damage (mean number of stem-breaks per tree) for each plot (Table 5.14, Figure 5.8).

One-way analysis of variance on the index of pest damage showed that the difference amongst experimental blocks was significant ($p<0.001$). Pest damage in Ismael's field was significantly lower than in any other farmer's field ($p<0.05$, LSD test). Azahri's field showed the next lowest pest damage, and this was significantly lower than the fields of Bustami and Saryono. Differences between treatments (A, B, C & D) over all farms were not significant at the 5% level.

Table 5.14. Calculation of the index of pest damage. This is the cumulative number of stem breaks sustained over 21 months for each tree, totalled for all trees in the plot, then divided by the total number of trees. This index was calculated for each plot in each farmer's field. Only trees surviving at 21 months after planting are included in the calculation.

Farmer/ Plot	Pest damage variables	Ismael	Azahri	Saryono 1	Saryono 2	Bustami
A	Total no. of stem breaks	19	38	126	142	10
	No. of trees	30	30	34	42	3
	Index of pest damage	0.63	1.27	3.71	3.38	3.33
B	Total no. of stem breaks	20	42	104	90	44
	No. of trees	35	29	30	30	15
	Index of pest damage	0.57	1.45	3.47	3.00	2.9
C	Total no. of stem breaks	1	38	95	127	32
	No. of trees	16	29	27	35	9
	Index of pest damage	0.06	1.31	3.52	3.63	3.56
D	Total no. of stem breaks	6	45	81	121	49
	No. of trees	16	28	23	34	13
	Index of pest damage	0.38	1.61	3.52	3.56	3.77

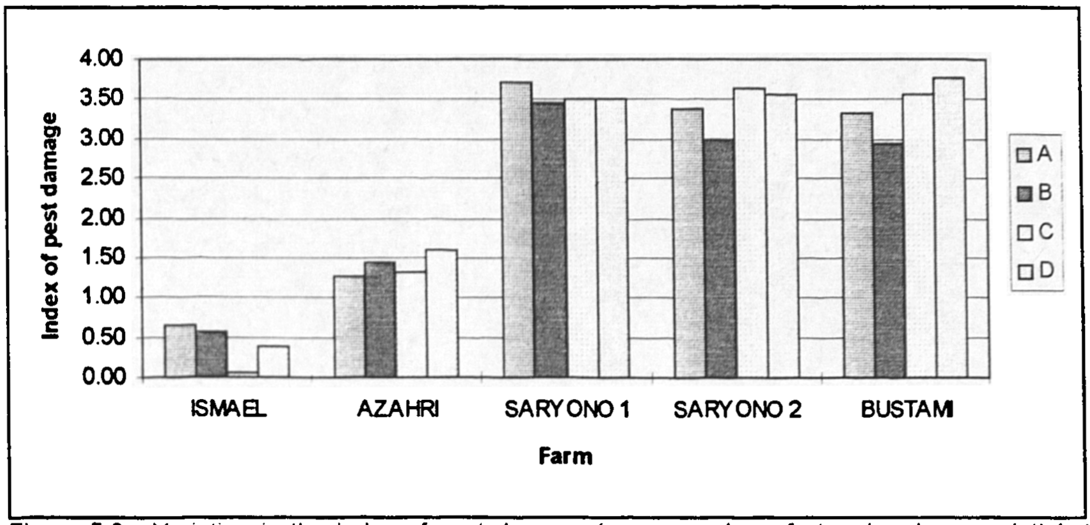


Figure 5.8. Variation in the index of pest damage (mean number of stem-breaks per plot) between farms and plots, at 21 months after planting

5.3.4.5.1 Pest damage incidence and farmer management

The differences in pest damage between farmers can be partly explained by factors such as adjacent vegetation type and various components of management, which were identified in discussions with farmers (Table 5.15). The likelihood of a field experiencing attacks by vertebrate pests was higher if the field was surrounded by vegetation which had a forest-like structure which provided cover. Isolation of the field was another factor influencing damage: the closer the field to roads and houses (especially if dogs were kept), the lower the probability of pest damage.

The severity of damage depended on the control methods used by the farmer (Table 5.15). For example, pig damage was higher when fencing was inadequate, as was the case in Saryono's and Bustami's fields (pers. obs.). Pest type also influenced the farmers' management responses: e.g. when it appeared that monkeys were a problem, Ismael started using poison and guarding the field at critical times. The amount of time which farmers could spend guarding depended on the distance (and travel time) to the field, available transport (Table 5.15), and also on the demands on farmers' time from other activities (Section 5.3.2).

The low incidence of pest damage in Ismael's field can be explained by its proximity to a road, good fencing and regular guarding by the farmer (who had his own transport, and therefore had easy access to the field). In contrast, Bustami's field was difficult to access, very isolated, and family members would not go there to guard as they were afraid of being attacked by pigs themselves. Fences of plastic sheet were constructed around individual trees, and although effective initially, these deteriorated in less than six months. Trees in this field could only rarely grow to heights above 1 m before being broken again. Azahri's field was similar to Ismael's, but less well guarded. It was close to the village so monkeys were less of a problem, however there was an increased risk of goats getting into the field. The higher damage in Saryono's field (blocks R1 and R2) was due to its remoteness, lack of fencing and irregular guarding (Table 5.15).

Table 5.15 Factors affecting the magnitude of pest damage, methods of pest control used by farmers, and factors influencing farmers ability to guard their fields

Farmer	Ismael	Azahri	Saryono 1	Saryono 2	Bustami
Factors influencing pest damage magnitude					
Adjacent vegetation types/land uses	Old durian garden, immature cinnamon garden	Young secondary forest	Old jungle rubber		Old jungle rubber, immature cinnamon garden
Isolation: field close to road/houses?	Road	Road, houses	Road	Neither	Neither
Pest types (in order of importance)	Monkeys Pigs	Pigs Monkeys Goats	Monkeys Pigs	Monkeys Pigs	Monkeys Pigs
Control methods used					
Fence	Barbed wire (4 rows)	Barbed wire (4 rows)	None	None	Partly fenced with plastic sheet
Use of poison	Baited fruit (for monkeys)	None	None	None	None
Guarding	Every morning and afternoon with air rifle	None	Infrequent, with air rifle		None
Factors affecting guarding of field					
Distance from house (km)	0.5	0.75	7.0	7.0	0.7
Method of travel to field	Motorbike	Walking	Car	Car	Walking
Travel time (minutes)	5	15	15	15	30

5.3.4.5.2 Pest damage and tree growth

Simple linear models of pest damage explained 68% and 69% of the variation in rubber stem diameter and height growth in the trial respectively (Figure 5.9). Again, this was strongly associated with variation amongst farms and clear groupings can be seen: fields where pest damage was low showed correspondingly high rubber growth. Field observations of damaged trees confirmed that new leading shoots were usually produced within the first month after stem breakage and, if no further damage was sustained, trees recovered quickly. However, successive damage incidents were observed to have an additive negative effect on tree growth, and also the probability of these incidents occurring was likely to be higher if trees had been damaged previously, as the new shoots produced in response to this were easily accessible from the ground (Plates 4.3c and 4.3d).

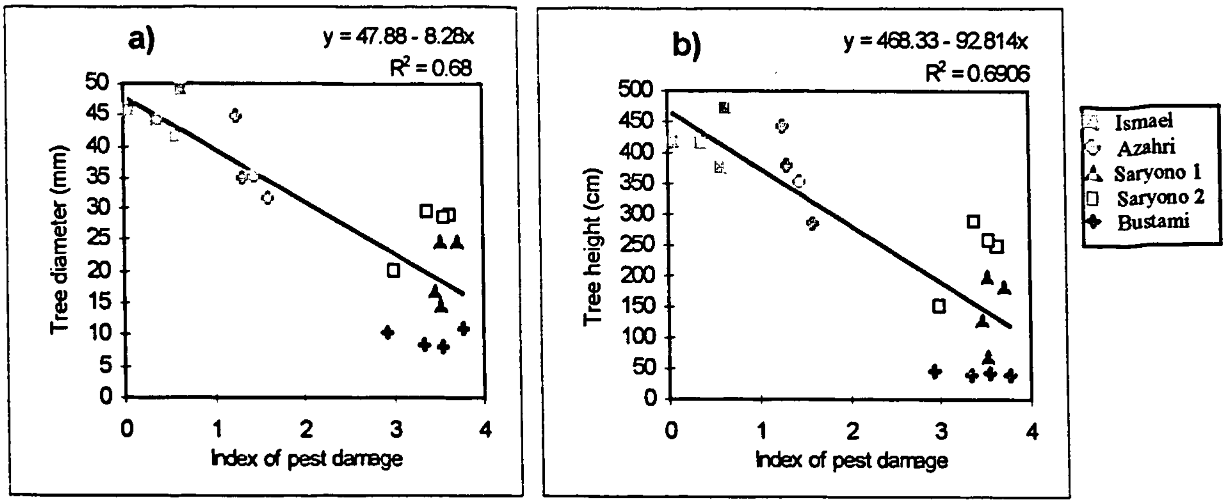


Figure 5.9. Linear regression between a) mean rubber tree diameter per plot after 21 months and pest damage index * and b) mean rubber tree height per plot after 21 months and pest damage index, for 20 unweighted plot means. * The index of pest damage is the cumulative number of stem breaks sustained over 21 months for each tree, totalled for all trees in the plot, then divided by the total number of trees. This index was calculated for each plot in each farmer's field. Only trees surviving at 21 months after planting are included in the calculation.

5.3.4.6 Combined models of rubber tree growth

As was seen in the preceding sections, besides the planned treatment regimes, there was a complex interplay of factors, both positive and negative, which affected tree growth, and which also differed considerably between farmers in occurrence and intensity.

5.3.4.6.1 Stepwise multiple regression with management variables

Stepwise multiple regression was used to estimate the relative importance of weeding frequency (*F*), pest damage (*D*) and weeding effort (*E*) on diameter and height growth of rubber, and to derive regression equations for growth in relation to the most important factors. Model simplification was conducted using the analysis of deviance procedure (Crawley, 1993). Two methods were used (Section 5.2.5.3): firstly the assessment of deviances when each explanatory variable was removed from the maximal model individually, and secondly assessing deviance when non-significant terms were removed from the maximal model in a step-wise manner. Both methods gave the same results. Therefore analysis of deviance tables for diameter and height for only the second method are presented (Table 5.16). Removal of both weeding effort and pest damage from the maximal model caused significant increases in deviance (Table 5.16), therefore the minimum adequate models for both diameter and height growth contain just these two variables, and not weeding frequency.

Table 5.16. Results of multiple regression using the analysis of deviance procedure on mean rubber tree diameter and height per plot, with step-wise elimination of non-significant terms, starting from the maximal model.

		Diameter		Height	
Explanatory variable	Symbol	Deviance	Significance	Deviance	Significance
Weeding frequency	*F*	79.3	F= 2.42, n.s.	20433	F= 4.237, n.s.
Pest damage	*D*	2327	F= 41.44, $p<0.001$	291891	F= 40.10, $p<0.001$
Weeding effort	*E*	408	F= 11.50, $p<0.01$	33431	F= 5.822, $p<0.05$

The estimated regression line between rubber tree size 21 months after planting (*R*), weeding effort in person-days of labour (*E*), and pest damage in mean number of stem-breaks per tree (*D*), over the 20 experimental plots is:

$$R = a + bE - cD \qquad (1)$$

where a, b and c are fitted coefficients.

For *R* = rubber tree diameter (in mm, measured at 10 cm above the graft)
a = 29.81 (s.e. 6.03), b =1.653 (s.e. 0.488), c = 5.75 (s.e. 1.27), adjusted r^2 = 0.798, $p<0.001$.

For *R* = rubber tree height (in cm)
a = 304.7 (s.e. 76.7), b =14.97 (s.e. 6.20), c = 69.80 (s.e. 16.1), adjusted r^2 = 0.742, $p<0.001$.

The above models appear to account for almost 80 and 75% of the variation in diameter and height growth in the trial respectively. Therefore, at least 20-25% of the variation will have been caused by other factors at the farm (or farmer) level. Factors contributing to this could be differences in slope, aspect and soil fertility between farms, amount of shade cast by vegetation surrounding each field, biomass of weeds and secondary forest regrowth in both the rubber row and inter-row, and also unquantifiable differences between the farmers themselves. As comprehensive data was available for initial soil fertility (Section 5.3.1), rubber growth in relation to this was assessed using the same methods of step-wise regression.

5.3.4.6.2 Stepwise multiple regression with both soil and management variables

The above analyses were re-run including the soil parameters which had shown the greatest between-field variation in Section 5.3.1, namely percentages of clay, silt and sand, aluminium and phosphate concentrations, for both topsoil and subsoil positions. Both diameter and height response variables were significantly affected by the same subset of explanatory variables: positively by topsoil and subsoil phosphate levels (P_T and Ps), and negatively by pest damage (*D*) and topsoil Al (*A*) (Table 5.17).

Table 5.17. Results of multiple regression using the analysis of deviance procedure on mean rubber tree diameter and height per plot, with step-wise elimination of non-significant terms, starting from the maximal model which included soil parameters.

		Diameter		Height	
Explanatory variable	Symbol	Deviance	Significance	Deviance	Significance
Pest damage	D	2327.0	$F= 41.44$, $p<0.001$	291891	$F= 40.10$, $p<0.001$
Topsoil phosphate	P_T	142.7	$F= 5.07$, $p<0.05$	9	$F = 0.00$, ns
Subsoil phosphate	Ps	2.2	$F= 0.10$, ns	21608	$F= 5.13$, $p<0.05$
Topsoil aluminium	A	418.0	$F=11.99$, $p<0.01$	42101	$F= 8.05$, $p<0.05$

The estimated regression line between rubber tree size 21 months after planting (R), topsoil phosphate concentration (P_T), subsoil phosphate concentration (Ps), topsoil aluminium concentration (A), and pest damage in mean number of stem-breaks per tree (D), over the 20 experimental plots is:

$$R = a + b\,P_T + c\,Ps - d\,D - e\,A \qquad (2)$$

where a, b, c, d and e are fitted coefficients.

For R = rubber tree diameter (in mm, measured at 10 cm above the graft)
a = 51.2 (s.e. 3.45), b = 0.239 (s.e. 0.11), c = 0, d = 9.08 (s.e. 1.09) and
e = 2.339 (s.e. 0.65), adjusted $r^2 = 0.840$, $p<0.001$.

For R = rubber tree height (in cm)
a = 493.2 (s.e. 42.2), b = 0, c = 2.92 (s.e. 1.29), d = 103.5 (s.e. 13.3) and
e = 21.16 (s.e. 8.12), adjusted $r^2 = 0.811$, $p<0.001$.

Inclusion of soil parameters in these analyses increased the percentage variance accounted for by 4.2 and 6.9% for diameter and height respectively when compared to the simpler model which only included weeding effort and pest damage.

5.3.4.7 Predicted tree sizes, and trade-offs between rubber growth and weeding costs

From the perspective of the farmer, the two soil variables are essentially beyond their control within a given area of land. Therefore, to analyse the trade-offs between weeding costs and rubber growth, the model which included only management variables was used. Equation 1, parameterised for diameter, was used to calculate predicted tree diameter values for a range of person-days of weeding, and different levels of pest damage (Figure 5.10). The range of values for weeding effort (3 to 14 person-days) covered the lowest and highest labour usages per plot in the experiment, and so represented realistic levels of weeding that were obviously within farmers' capabilities. The range of pest damage levels included those that were encountered in the trial. In addition, the analysis did not attempt to extrapolate beyond the values from which the regression equation was constructed (Mead *et al.*, 1993). Tree diameter was modelled because this is a better predictor of the time when tapping can commence than tree height (Paardekooper, 1989).

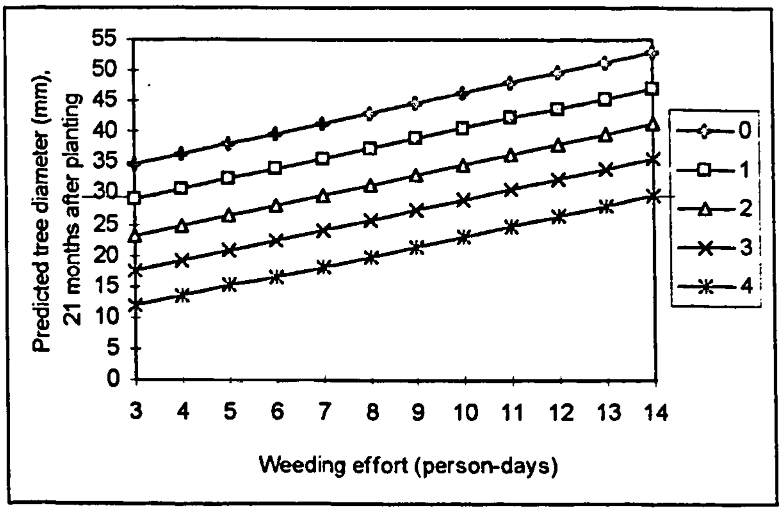


Figure 5.10. Predicted rubber tree diameters (means per plot, in mm) in response to weeding effort, for five levels of pest damage, 21 months after planting. Tree diameters are predicted for the measurement position of 10 cm above the graft.

The difference between each level of pest damage is equivalent to 5.75 mm in stem diameter by the end of the first 21 months of growth (Figure 5.10; Equation 1). Pest damage clearly has a larger influence on tree size than increased weeding intensity. For example, for trees which have been damaged an average of four times the highest predicted diameter achievable requires 14 person-days of weeding. However, this 'maximum' diameter is only equivalent to, and will not exceed, that of trees damaged only once in plots where the lowest level of weeding effort (three person-days per plot of 1/8 ha) has been expended. This indicates that it is very important that farmers protect young clonal rubber trees from pest damage. However, the corollary is that if, for some reason, the farmers cannot stop their trees being damaged, then greater weeding effort can still improve tree growth. As we have no specific data on the amount of time required for guarding the fields to reduce damage to the levels found, we cannot compare the effectiveness of spending time on guarding rather than guarding and weeding in combination.

For each person-day of weeding effort <u>per plot</u> (1/8 ha), during the first 21 months after planting, the benefit is equivalent to an extra 1.65 mm in tree diameter at the end of that 21 months. The cost of this is taken as being the average daily wage in the study area for women (3 500 Rp), as it is usually women who are employed for weeding tasks (if family labour is not used).

As the model above considers labour requirements on a <u>per-plot</u> basis, the number of person-days must be multiplied by four to enable scaling up to a 0.5 ha field (the average block size in this experiment, and the average for Sumatran rubber smallholders). Therefore the cost <u>per field</u> if weeded at an intensity equivalent to three person-days per plot, is 42 000 Rp. Likewise, for the highest weeding intensity encountered (14 person-days per plot), the cost is 196 000 Rp per field. The difference between the two in terms of costs is 154 000 Rp, and, in terms of rubber diameter, is 18 mm (after 21 months growth).

Although this gives valuable information on the efficiency of their investment of cash resources in weeding, for farmers to fully appreciate the benefits of extra weeding effort, they need to know how this translates to the time when tapping of the trees can commence.

In Indonesia, the standard recommendation for commencement of tapping is when trees reach a girth of 45 cm at 1 m above the graft (Paardekooper, 1989). This is equivalent to a diameter of 173 mm, measured at 10 cm above the graft (Section 5.2.6). For the predicted tree diameters which corresponded to each of the weeding effort levels (Figure 5.10), estimates of the number of months before trees reach this minimum diameter were made from standard growth curves for clonal rubber (Figure 5.1, Section 5.2.6). Damage to trees by pests sets back tree diameter growth, and thus a greater number of months elapses before they attain the minimum diameter for tapping (Figure 5.11). The difference between successive levels of pest damage, in terms of the number of months delay before tapping, is 1.93 months. The difference between the two extremes of pest damage (zero damage, and an average of four stem-breaks per tree), is approximately eight months. The difference between successive levels of weeding effort, in terms of the number of months delay before tapping, is 0.55 months. The difference between the two extremes of weeding effort (3 and 14 person-days of weeding), is approximately six months.

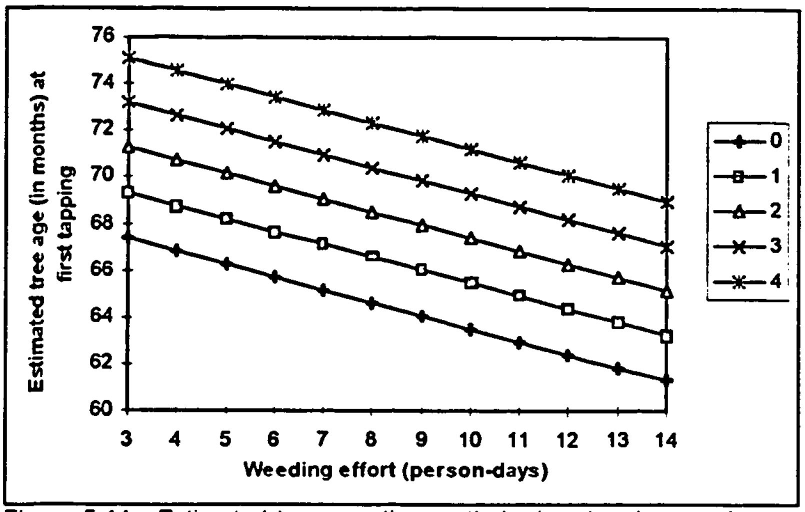


Figure 5.11. Estimated tree age (in months) when tapping can be commenced (tree diameter of 173 mm at 10 cm above the graft), for five different levels of pest damage. The extrapolation was based on the predicted tree size at 21 months after planting, which was calculated using Equation 1.

5.3.4.8 Final farmer interviews

In order to put the farmers' analysis of the experiment into context, the cost of weeding incurred by the farmers, and the benefits they accrued at the end of the first 21 months of growth (in terms of the number of surviving trees, and their size), has been summarised (Table 5.18). In addition, the size of farmers' trees 21 months after planting was compared with trees under intensive plantation management (Figure 5.1). Growth of farmers' trees was slower than the standard trees by between 7 and 17 months, which is substantial, considering the fact that the duration of the experimental period was only 21 months.

Table 5.18. Labour and cash resources invested by each farmer in weeding the experimental fields, compared with number and size of trees 21 months after planting.

	Ismael	Azahri	Saryono (Total)	Bustami
Investment of resources				
Area of field (ha)	0.5	0.5	1.0	0.5
Total labour (person-days)	48.6	25.9	59.0	10.5
Family labour (person-days)	16.0	13.9	1.8	3.5
Hired labour (person-days)	32.6	12.0	57.3	7.0
% Hired labour	67	46	97	67
Expenditure on hired labour (Rp)	114 188	42 000	200 375	24 500
Expenditure on hired labour (Pounds)	34	12	59	7
Benefits accrued				
Number of surviving trees	97	116	255	40
Average tree diameter (mm)	45.09	36.70	23.63	9.58
Average tree height (cm)	420.8	365.6	191.86	42.73
Equivalent age of farmers' trees (in months), compared with trees grown under plantation conditions [1]	14.05	11.08	6.99	3.31
Difference (in months) between growth of farmers trees and trees grown under plantation conditions [2]	6.95	9.92	14.01	17.69

[1] Comparing tree diameter in this table with diameters on a growth curve of trees under standard plantation conditions (Figure 5.1)
[2] Equivalent age subtracted from actual age of trees (21 months)

Farmers views were elicited on the success or failure of the project, problems they encountered, and lessons learned. They were also asked to assess clonal rubber in general, the weeding/management required, and whether they would plant more in the future. The responses of each farmer are given below, beginning with farmers with the best rubber growth. Comments, although paraphrased for ease of translation, are the farmers' own.

Ismael

Ismael thought that the project was a success, and was pleased with the growth of his clonal rubber. It lived up to his expectations of rapid growth, and he expected that he would be able to tap his trees much earlier than local rubber varieties. He also expected high yields per tree. However, he felt he had suffered a great loss with the landslide. After this he had not managed his field according to the protocol because he had 'lost his hopes', and had a 'broken spirit' after seeing all his hard work lost, and could not face putting any more work into the field.

The main problem encountered was pests. He thought the best type of fence to exclude pigs was one with two planks of wood at the base, and two rows of barbed wire at the top. He believed that once the trees were about three years old, they would be safe from pig damage. Another problem he encountered was digging planting holes on steep slopes, as a lot of earth was lost downslope.

As regards weeding, he was not happy with the experiment having four plots. He would have preferred the same regime over the whole field, and a weeding level that was best for him: in his opinion, the experimental protocol involved too much work. His preference would be to let the weeds grow to about 1 m tall, then weed the whole field. To save labour (time and cost), he would use herbicide. Spraying 1 ha required only 1 man-day (5000 Rp), and 10 000 Rp for the chemical. He did not want secondary forest to regenerate between the rubber rows. This was because pigs could hide in it, whereas they would be afraid to enter the field if it was clean. He did recognise the potential value of the vegetation in 'avoiding' soil erosion, and 'catching' the soil, but in practice would still cut it down. He did not perceive that any trees that regenerated naturally were valuable (except rubber, which he would leave), and he preferred to protect his clonal rubber. In any case, he already owned a mixed rubber and fruit garden to provide fruits and NTFPs. He was not afraid of *Imperata cylindrica* invading the field, as this could easily be controlled by spraying with Round-Up. He thought that the legume cover crop was too much work to maintain, and a short grass cover was just as good.

Ismael was pleased that he had learned about, and had experience of, planting clonal rubber. He had already cleared another plot of land that he owned in order to plant more that year. This land was flat, so there would be no danger of landslides. He would use the same tree spacing as in the experiment, and would weed three times a year.

Azahri

Azahri thought the experiment was a great success, and was very grateful to the project for providing him with clonal rubber.

He also found the biggest problem to be pest damage. Goats were the main problem initially, until he reinforced the parts of the fence that bordered the road. Towards the end of the experimental period, pigs had damaged a number of trees. They were still managing to get through the fence, and were repeatedly attacking the damaged trees, so he had made individual fences around these trees, using thorny salak branches (*Salacca edulis*), which appeared to be successful. He apologised for his slow start in the experiment, having had cashflow problems which delayed the construction of the fence, and so planting was late.

He thought that the weeding regime was quite complicated, and labour-intensive, but he had followed the protocol, although not often on schedule as he had no family labour to help him. He could not prune the inter-row vegetation as he had reached the 'limit' of his time and cash resources.

Regarding future planting of clonal rubber, he thought it was a good investment, but required a lot of work. At present he had no spare resources to plant more, and was fully occupied with management of that one field, his full-time job and his shop, especially as the latter two provided 'direct' income. He would certainly consider it in the future, now that he had experience and knew what to do.

Saryono

Saryono thought that the project was a success, as he had gained a field full of clonal rubber. Growth wasn't quite as good as he had expected, but it was good enough. When asked for feedback on ICRAF, and the way the research was conducted, his answer was "I'm very happy, of course. You gave me many trees."

The main problems were monkeys, pigs, and the climber Mikania smothering trees in some parts of the field.

With respect to weeding management, Saryono thought that it was most important to cut the inter-row vegetation as this 'bothered' the rubber trees, as it caused shading, and as there were 'lots of roots that extended a long way'. Within the row, the critical times were the beginning of the dry season, so there was little competition from weeds when rainfall was low, and also at the beginning of the wet season, so that weeds would not spread quickly when there was plenty of water available. Because he always hired labour to weed his field (which was very large), he could not afford to do more weeding.

In theory, he would like to plant more clonal rubber, but could not yet afford to do so, as he had spent a lot of money buying the field and hiring labour. As he was not originally from the area, he had no land to inherit, and he would have to buy another field to plant any more rubber.

Bustami

Bustami considered his field a failure, as he had nothing worth showing for all the effort and money he had expended, and this was due to pests. He was happy with the project, and ICRAF, but embarrassed because we had given him a lot of planting material, but the results weren't good.

The main problems were pigs and monkeys, and also the herbaceous climber Mikania, the weight of which could easily break the clonal trees. He also thought that the amount of labour required for clonal rubber (e.g. regularly pruning lateral shoots) was a problem.

He agreed that weeding was important, as it was good for the trees, and it also made the farmers happy to see a well-managed field, but a clean field meant the trees were obvious, and visible to pests. This is why he had not weeded either the rubber rows or the inter-rows, to try to protect his trees. In this situation (with high risks of pest damage), he thought that local seedlings would be better, as they only require weeding once a year, and then only circle-weeding around each tree. Again, local seedlings are better when there is a lot of Mikania, because they are sturdier than clonal rubber, and the clones need weeding every two months to avoid damage. He did not think *Imperata cylindrica* was a problem, as this could easily be controlled by spraying with Round-Up.

Bustami thought that, in theory, clonal rubber is good as it grows quickly, can be tapped early and gives a good yield. However, to be successful it needs a lot of care, the field must be well fenced and close to the village, and also the planting material should be at least 1 m tall when planted out. In practice, a lot of capital would be needed for buying clones and making a fence, and the vast majority of farmers cannot afford this. He would like to use local rubber seedlings (non-clonal planting material) to fill in the gaps in his experimental field (that were left by clonal trees that had died), as he thought these were hardier. Then at least he would have some rubber to show for the work he had put into the field. He did say that he would be prepared to plant clonal rubber again.

5.4 DISCUSSION

The questions posed in the introductory section of the chapter will be discussed here, with reference to the experimental results, and the wider literature.

5.4.1 Is this agroforestry system feasible in practice?

5.4.1.1 Can clonal rubber be established and grow successfully in a multi-strata agroforestry system similar to the conditions found in jungle rubber?

The answer is 'yes' when considering the case of Azahri. A field of clonal rubber was successfully established, and tree growth was satisfactory, even in the presence of dense secondary forest species which had regenerated in the inter-row area, as in the jungle rubber system. However, as expected, the growth rate of his trees was slower than rates recorded in plantations, where there had been intensive weeding regimes, and relatively high levels of fertilisation (Wibawa, pers. comm., Figure 5.1). Average diameter increment over the first 21 months growth in Azahri's field was 32 mm, as opposed to 60 mm over the same time period under plantation conditions.

The answer to the above question is 'no' in the case of Bustami, where the limits of the system were found. Only 40% of the original number of trees planted actually survived, and the average diameter increment of these was only 5 mm in 21 months. The management interventions performed by this farmer in terms of weeding, control of the inter-row vegetation, removal of climbing weeds and pest control were clearly inadequate. Damage by pests was especially great in this field, and this will be considered further in Section 5.4.3.2.

For the other three farms in the experiment, the question cannot be answered, as the farmers slashed back the inter-row vegetation, and so the conditions were not representative of jungle rubber.

5.4.1.2 Is the design of the multi-strata agroforestry system acceptable to farmers, and can they successfully adopt the new techniques involved in planting clonal rubber?

System design

At the stage of farmer selection, the participating farmers expressed preferences for this system as it required only low management inputs. They were not interested in growing food-crops, or other perennials such as fruit or timber trees, as these required much labour, especially guarding food-crops against pests. Bustami specifically agreed with the presence of secondary forest regrowth in the inter-row, having had much personal experience planting jungle rubber. However, in reality, he was not prepared to manage the inter-row vegetation at all, and this appears to be have been highly competitive with his young rubber trees.

The other farmers' real views on the design of the system either became apparent over time, or changed when they put the experiment into practice. Whichever was the case, it was clear that they did not want secondary forest regenerating in the inter-row, because they cut it down.

Farmer adoption of new clonal rubber planting techniques

The farmers demonstrated that, in general, they could plant and maintain clonal rubber successfully, after only very basic training. There were, however, problems encountered in staking out planting holes along contours: farmers thought was that it was better to use string and thus plant in straight lines, as this was their perception of how things were done in plantations. Difficulties were experienced with the A-frame. In future, the importance of contour planting should be stressed more clearly, and maybe farmers taught to do it by eye instead; this would certainly be quicker. Special care needs to be taken to avoid gullies that may be prone to landslides.

The standard plantation practice of pruning lateral shoots from the lower 2.4 m of the main stem every three months (Webster, 1989b) was recommended by the project, but was only implemented by one farmer. Theoretically, pruning should be a greater priority in the experimental conditions than in plantations, as it ensures that all assimilates are used for height growth, and thus rubber trees can compete for light with the secondary forest regrowth more effectively. Recommendations for smallholders should stress the importance of this, and the suggestion made that trees should be pruned at the same time they are weeded.

5.4.2 What level of weeding is necessary to ensure successful establishment of clonal rubber?

5.4.2.1 Weeding within the rubber row

The planned comparison of the effect of three different strip-weeding frequencies over all farms was not possible, because of the irregular implementation of experimental treatments by the farmers. In the case of the only farmer (Azahri) who implemented the correct weeding frequencies, there were no significant differences in rubber diameter growth between these three treatments within his farm. The same result was found in a similar trial established the following year (Penot, in press); there were no significant differences due to weeding frequency, however, as in this trial, the differences between farms were significant at the 5% level (G. Wibawa, pers.comm. 1998).

In simple linear regressions, weeding effort was found to explain a higher percentage of variation in diameter and height growth across farms than weeding frequency. The importance of this factor was also borne out in the multiple regression analyses: weeding effort was identified as a significant explanatory variable, whereas weeding frequency was not. This accounts for some of the very great differences in tree growth in plots in different farmers' fields that had been subjected to the same weeding frequency. For example, for plots that were weeded twice, weeding effort was equivalent to 10 person-days of labour in Ismael's field, but only 2.6 person-days in Bustami's. Mean tree diameter per plot in the former was 4.5 times that of the latter.

Weeding effort appeared to be related to the different methods employed by different farmers: Ismael invested the greatest number of person-days in hoeing the rubber rows thoroughly (pers. obs.), in contrast to the other farmers who slashed back the weeds with a machete. Hoeing is the method recommended for smallholders by Delabarre and Benigno (1994). However, its suitability for steeply sloping land, as found in the study site is questionable, especially considering the fact that a severe landslide occurred in the only field that was hoed.

The time of weeding also appeared to be important, as the best rubber growth was found in Ismael's field, and all the weeding implemented in his field was during the first eight months after planting. This, in conjunction with diligent guarding, and maybe also the fact that there was little above-ground competition because the inter-row vegetation was slashed back, ensured successful establishment of clonal rubber. In simulations of rubber growth in response to weeding treatments using a modified version of the BEAM rubber agroforestry model (Grist *et al.*, 1995; Thomas *et al.*, 1993), where *Imperata cylindrica* was the dominant weed, Grist and Menz (1995) found that the greatest single-year increase in tree growth rate was obtained by weeding in the initial year after planting rubber. This agrees with Byerlee's (1991) comment that the timing and the methods of implementation of farming practices can be just as important as the amount of labour used.

5.4.2.2 Legume cover crop treatment (treatment A)

This was included as a type of control, representing theoretically optimal plantation conditions. The planned comparison between this and treatment D (same weeding frequency, but secondary forest regrowth in the inter-row) in Azahri's field, showed that tree diameter and height were significantly higher in treatment A. The same result was found in two other fields (Ismael and Saryono 1), where treatments A and D were weeded the same number of times (although not as frequently as in Azahri's field).

On this evidence, it appears that the presence of a legume cover crop in the inter-row was more beneficial to rubber growth than the presence of secondary forest species. There are a number of possible explanations for this. There was little above-ground competition for light, as the cover-crops were low-growing, and even though they died back eventually, the regenerating secondary forest species never attained heights of more than 1.5m (pers. obs.). Many studies (Broughton, 1977; Erwiyono and Soekodarmodjo, 1989; Jayasinghe, 1991; Sinulingga *et al.*, 1989; Watson, 1989b) have shown the beneficial effect of cover crops on the physical, chemical and biological properties of soil, which also favour rubber growth. These include nitrogen fixation, reduction of erosion, shading of soil, increased soil organic matter content, enhancement of soil biological activity, and increased aeration resulting in greater rubber root length densities. Another possible explanation is that because the cover crop was fertilised with phosphate (TSP), in theory, the inter-row vegetation was not competing with the rubber trees for soil phosphorous, and in addition, rubber trees may have taken up the TSP directly from the inter-row, as was reported by Yogaratnam *et al.* (1984).

5.4.2.3 Inter-row management

By the end of November 1997, farmers had completely slashed back all inter-row vegetation in four of the five experimental blocks. The reason for this was that farmers were afraid that pests could hide in this vegetation, and attack the trees without being seen (Section 5.3.4.8). In addition, they perceived that clonal rubber would grow best in plantation conditions, as they had all seen clonal rubber monocultures in other parts of Sumatra, and knew how profitable this system could be. This was a result of the farmer selection process, which was based on farmers' interest in joining the trial: three of the four farmers were highly educated, and had spent considerable time outside the study area. They therefore had a larger world-view than 'traditional' farmers, and had been exposed to cultural systems other than jungle rubber. Moreover, their lack of confidence in agroforestry practices involving clonal rubber may also have stemmed from Government extension services. These generally consider agroforestry a 'backward' technology (Penot, 1997a), and are responsible for promoting a single technological package for clonal rubber, based on monoculture and involving high levels of inputs.

In contrast, many traditional farmers in Muara Buat were not prepared to risk planting clonal rubber, as they were afraid that the system might fail in the local conditions and because they did not have the labour resources for the intensive upkeep that they perceived that clonal rubber required (Pak Effendi, pers. comm., 1996; Appendix 2.1).

5.4.2.4 Researcher and farmer expectations

Researchers assumed that farmers would be in favour of, and more likely to adopt a new cropping system that was similar to their traditional management of jungle rubber (Chapter 1). When farmers were selected to participate in the trial, they were all in favour of a 'low-input' system. However, it is possible that they interpreted this as not growing intercrops, rather than as a requirement to allow secondary forest species to regenerate around their clones. In fact, Ismael told me that he did not really understand the information that was presented about the different systems being offered.

As the farmers had invested considerable time, labour and cash in preparing their fields and planting clonal rubber, the majority were not prepared to sit back and watch the fields be invaded by scrub, which could have competed with their clones, and so delay and/or reduce the return on their investment. This was not anticipated by researchers. They believed that they had allowed for the possibility of farmers wishing to manage their clones intensively, by including a strip-weeding frequency treatment of nine times per year. However, farmers thought weeding this frequently was not justified by the sparse weed regeneration every six weeks. They preferred to slash the whole field less frequently, and in doing so, relinquish their traditional multi-strata system.

It is reasonable to assume that this outcome would be even more likely if farmers had bought the clones themselves,[43] especially if they had taken out a loan or had taken part in a credit scheme, because their investment in the clonal germplasm would then have been greater. The pressure to repay their debts would probably result in farmers trying to maximise their

[43] This would cost approximately 350 000 Rp for a 0.5 ha field (US $145, at an exchange rate of 1US $=2300 Rp, as valid until July 1997), assuming 300 clonal bud-grafted plants in polybags were bought at

returns, as quickly as possible, which would of course entail more intensive management of their clonal rubber. Exactly the same outcome was found in Togo, when CIRAD introduced high yielding hybrid cocoa seedlings to farmers, with the aim of improving the traditional 'jungle-cacao' agroforestry system (Vaast, 1988). The farmers perceived the new planting material to be so valuable that they weeded it very intensively, and changed their traditional system to monoculture.

Researchers' perceptions of the value of the regenerating secondary species in the inter-row were not the same as the farmers'. Most farmers had access to fruits, firewood and NTFPs in other gardens. It is hard to identify any species that farmers perceive to be more valuable than clonal rubber, and which they would tolerate as a potential competitor in their field. Timber trees may be an exception to this, but only in the future; supply is still greater than demand for most species, and prices per stem are very low. Van Noordwijk and Ong (1999) link the negative perceptions of 'competition' to the difference in value between the competing components (per unit resource capture). As rubber is already the most valuable component in the traditional jungle rubber system based on local seedlings, use of clonal rubber clearly increases this difference in value. The notion that higher value representatives of priority components of complex systems can be successfully integrated in a domesticated forest (Michon and de Foresta, 1997) may need revision.

The advantages of the 'conserved biodiversity' inherent in the inter-row vegetation were perceived by researchers, not by the farmers. In fact, conservation of biodiversity would probably be more effective using the 'segregate' approach in the segregate-integrate debate (van Noordwijk *et al.*, 1995b). This could, in theory, be done by setting aside areas of mature jungle rubber within the village boundaries (with adequate compensation payments, of course), and managed as a community forest (H. de Foresta, pers. comm., 1999).

Another perception of researchers was that farmers would value the secondary forest regrowth in preventing *Imperata cylindrica* from invading the field, as this is notoriously difficult to eradicate once established (Bagnall-Oakeley *et al.*, 1997; Brook, 1989). However, surprisingly, the farmers thought that the *I. cylindrica* that had invaded parts of their plots was less of a problem than the regenerating woody species. They were quite prepared to use glyphosate-based herbicide, which they considered more effective, and more efficient than manual weeding to control it. In contrast to the researchers, they had no concerns about the risk of fire (Gouyon, 1999) or the irreversibility of the ecological change caused by *I. cylindrica* encroachment. This may be because there were no large expanses of 'sheet' *I. cylindrica* in the vicinity, in contrast to many other rubber producing areas in Indonesia where there is a more pronounced dry season, and an associated higher risk of fire. Smallholders'

1000 Rp/plant, and transport costs were 50 000 Rp.

preferences for herbicide use were found in a number of other studies (Mahmud, 1986; Supriadi, 1994).

One thing that researchers had expected, and which was borne out in reality, was the farmers' lack of interest in LCCs (legume cover crops). Although farmers had followed the plantation model in slashing the inter-row, LCCs involved too much labour and cash for little obvious gain, and also the seed was not available locally to farmers. Uptake of LCC technology by smallholders in Malaysia and India was similarly low (Blencowe, 1989; Kumar and Nair, 1997; Mahmud, 1986).

5.4.3 What are the other factors, besides weeding, that affect growth of clonal rubber under smallholders' conditions, and what are the effects of these?

A great advantage of this on-farm trial was that it was conducted under conditions representative of those experienced by smallholder farmers, with respect to climate, topography, and pressure from pests and diseases. The influence of soil fertility could also be assessed realistically, in contrast to on-station trials where soil fertility levels are usually higher than in farmers' fields (Huxley, 1999). In addition, it was possible to observe farmers' responses to the above factors, and to relate this to their socio-economic situations.

5.4.3.1 Initial soil conditions

Although there were significant differences between farms for a number of soil parameters (Section 5.3.1.2), the only two which were significantly related to tree growth were aluminium and phosphate concentrations (Section 5.3.4.6.2). It is generally recognised that phosphate fertilisation is necessary for good early rubber growth, as seen by its inclusion in the national fertiliser recommendations of all major rubber-growing countries (Pushparajah, 1983). It has also been suggested that phosphate is the nutrient most limiting to rubber growth in acid soils (Potash and Phosphate Institute (PPI), 1995; T. Fairhurst, pers.comm., 1997).

The deleterious effect of aluminium on the growth of crop plants is commonly observed in tropical acidic soils such as these, due to the high concentration of the Al^{3+} ion in solution (Weischet and Caviedes, 1993; Young, 1976). However, little has been published on its specific effects on rubber growth. In one laboratory experiment (Bueno *et al.*, 1988), rubber plants showed normal growth when grown in solutions of less than 15 ppm aluminium, but above this level symptoms of toxicity were observed in the roots (thickening and browning). For annual crops, liming is a common practice used to alleviate the effects of aluminium, however, this is not the case for rubber, and copper deficiencies in trees have been noted in response to over-liming (Pereira and Pereira, 1987). The same authors noted that liming did not improve the growth of rubber seedlings in a soil with a high exchangeable aluminium content, and this indicates rubber's tolerance to acid soils with high aluminium contents.

5.4.3.2 Damage by vertebrate pests

The index of pest damage (and not weeding management) was found to be the most significant factor which affected rubber growth in the trial in multiple regression analyses (Section 5.3.4.6). The extent of the pest damage problem was not expected, and would not have been detected if the experiments had been carried out on-station (Wibawa *et al.*, in press). Although wild pigs in the study area had previously been identified as a threat to young rubber plants (van Noordwijk *et al.*, 1995a), the researchers and farmers had started the trials on the assumption that the fences around the field would be adequate and a worthwhile investment of the farmers' time.

As a result of the research described above, vertebrate pests were indeed identified as a major constraint to clonal rubber establishment in the study area. This is especially true if farmers' priorities are still for extensive (non-intensive) systems (e.g. Bustami), so they spend little time in their fields, and also if the fields are remote (Wibawa *et al.*, in press). This issue is integral to the intensification of agriculture, as farmers' tolerance of pest damage decreases when their investment in improved planting material and fertiliser increases. As a result, vertebrate pest control has become a higher priority for farmers, for pests are now perceived as having a greater economic impact on their livelihood (Balson *et al.*, 1997).

This research exemplifies Monteith's (1997) argument that agroforestry modelling is too narrowly focused on parameterising the competition between crop components for light, water and nutrients in ideal conditions, whereas in farmers' fields significant reductions in growth caused by pests and diseases are common. As these factors will affect competition, they need to be taken into account if the performance of agroforestry systems is to be realistically predicted.

As was found in the trial, household surveys across the District of Bungo-Tebo confirmed feral bearded pigs (*Sus barbatus*) to be the worst pest encountered, and *simpai* (a reddish-coloured banded leaf monkey, *Presbytis melalophos nobilis*) the second worst (Balson *et al.*, 1997; Gauthier, 1996a). The former author found that levels of depredation by wild pigs were greater with increasing distance of villages from the boundary of natural forest (although damage by monkeys decreased). As our experiment was located relatively close to the forest margins, then damage to clonal rubber by pigs is likely to be even more severe for the majority of smallholders living in the peneplain area.

5.4.3.3 Farmer management

Farmers' management of their experimental plots was influenced by the weeding treatments, their response to other biophysical factors (above), by their socio-economic situation and resource allocation, and also by external events beyond their control.

External events

The occurrence of events beyond farmers' control cannot be predicted, or allowed for in farmer selection processes, but nevertheless can have large impacts on farmers' livelihoods (Richards, 1989). These may also have direct influences on their management (or abandonment) of the experiment, so it is imperative that trials have adequate replication (Statistical Services Centre, 1998). For example, Swinkels and Franzel (1997) reported a 20% drop-out rate of farmers in a hedgerow intercropping experiment.

An example of this was the landslide in Ismael's field, which resulted in him effectively cutting his losses and giving up working in the field. His decision was influenced by the fact that the trees that had survived had reached a sufficient girth and height that they were safe to leave. This was a result which gave us another insight into farmers' management decisions.

For two months in 1996, Azahri was unable to work in his rubber field as a member of his immediate family became ill, and there were unanticipated medical (and funeral) expenses. Saryono was called away unexpectedly to a training course, which again meant no work could be done in the field for a number of months.

Farmer resource allocation strategies

The greatest differences in the growth of clonal rubber in this trial were found between farms. These were primarily caused by differences in the way individual farmers managed their plots (weeding frequency and effort), and their fields (pest control). The management effort invested by the farmers in their clonal rubber field depended on their socio-economic situation and their strategy in allocating labour and/or cash resources to farming or other activities (Table 5.8). This is the major difference between management of clonal rubber in a plantation environment, where critical operations can be timed according to the exact demands of the crop, and management by smallholders, where, for example, labour shortages, and thus delays in weeding, can lead to crops not performing as expected (Botchway, 1993). In the case of farmers, the management of a particular farm activity is compromised in the interest of the performance of the farming system as a whole, because they have to satisfy their household needs through a combination of activities, which compete for limited land, labour and cash (Botchway, 1993).

In an African on-farm agroforestry trial (P. Burgers, pers. comm. 1998), it was found that socio-economic characterisation of farm households (especially with respect to on-farm and off-farm employment) was more important in explaining differential tree growth than the experimental treatments.

In this trial Bustami, whose rubber showed the slowest growth (and who implemented the lowest number of weedings) had no regular salary. His priorities were tapping rubber for cash income, and the production of irrigated rice for subsistence (a short term strategy, typical in a high-risk environment) (McNetting, 1993). Rice production was important for food security, and demanded intensive labour at a number of critical stages in its growth cycle. At these times, work in rubber gardens was halted completely, as was traditional in the low management input jungle rubber system (Dove, 1993). Bustami already owned a large area of immature jungle rubber (planted as an investment for his children), and had found the jungle rubber system perfectly adequate from his past experience, so intensive management of his trial plot was not a priority. This agrees with Dewees' and Saxena's (1995) observation that 'older households may have less of a *need* to cultivate their holdings intensively', especially when they have a low labour-to-land ratio.

The other three farmers had regular incomes from government salaries, which provided for their subsistence needs, and so they were able to invest more cash and labour in their plots than Bustami. However their resources were still limited, and Ismael and Saryono restricted the amount of strip-weeding to what they perceived as economically justified, and this was usually less than the protocol stipulated. This was especially true in the case of Saryono, who viewed the planting of clonal rubber as a business investment. He was prepared to invest enough resources to ensure successful tree establishment, but drew the line at more intensive management which he considered uneconomic. He incurred considerable costs for hired labour (97% of his total weeding costs, Table 5.18), as the field was large, and he himself was unable to work there due to off-farm employment. In addition, he had had to weed the whole field twice after burning, as planting was delayed because of the failure of the first batch of planting material (the traditional practice is to plant rubber one month after burning (Ketterings *et al.*, 1999).

The three farmers with off-farm employment considered that the most efficient use of their resources was cutting back the inter-row vegetation, rather than weeding within the rubber row. Their perception was that clonal rubber performs best in monoculture, and they were unwilling to allow secondary forest regrowth to compete with such a valuable asset. Furthermore, the risk of pest damage could explain these farmers' preference for the monoculture model, as this is currently the most common practice for planting clonal rubber, and the farmers perceived that this type of system would guarantee success.

5.4.4 What management recommendations can be made for smallholder farmers, taking into account their cash and labour resources?

Due to the limited number of farmers in the trial, it is obviously not possible to generalise from these results about all rubber smallholders in Indonesia. The information gained in this trial will be incorporated into the results from other on-farm trials in the SRAP network. As this project has worked with over one hundred farmers, from four different ethnic groups in three rubber-producing provinces across Indonesia, only on this scale may generalisations be made. Nevertheless, the lessons learned from this particular experiment have been very instructive, and the very close contact with this limited subset of farmers led to a detailed understanding of their socio-economic situation and their priorities. It is in this context then, that the above question is considered.

5.4.4.1 Pest management

As pest damage explained the greatest amount of variation in rubber growth in the trial, minimising this should be a top priority for farmers.

Potential control measures

In order of importance, the three most common control methods for pigs in the study area were guarding, constructing wooden fences, and using poisoned baits (Balson *et al.*, 1997). For monkeys, the top three methods were guarding, hunting with air rifles, and using poisoned baits. Guarding is inexpensive and effective, especially against simpai. However, as seen from the cases of farmers participating in the trial, actual time spent in the field can be limited by off-farm income generating activities, other agricultural activities, and also remoteness of the field. Fences can be effective against pigs, but need to be high enough to prevent animals jumping over, and flush with the ground to prevent them from tunnelling under. However, fences can be very expensive, both to construct and to maintain, are likely to disintegrate beyond repair after 2-3 years, and can never be entirely pig-proof. Poison is also expensive, and there is a risk that baits could be ingested by domestic animals or children.

A combination of control methods is necessary to deter different pest species. Construction of plastic fences around individual trees is also an option. These were successful in Bustami's field, until they disintegrated in April, 1997 (see the decrease in mean tree height per plot in Figure 5.4). Similar designs made with bamboo have proven very effective, and also very durable, however these do require a relatively large investment of farmers' time. Organisation of community hunting groups has been shown to reduce damage to crops (Gauthier, 1995a). Another possible way to avoid pest damage is to plant 'high stump' clones. Although these are more expensive, they have greater girth and height than the standard one-whorl buddings, and would thus have a greater chance of reaching the minimum tree size where pest damage no longer has a serious impact. Farmers who built a temporary house and lived in the field for the critical first two years of rubber growth considerably reduced the risk to their investment from pests (pers. obs.). The farmers participating in this experiment, did not live in (or even close to) their fields, and their response to the risk of pests was to cut the inter-row vegetation, and manage the field as a monoculture.

Costs and benefits of pest control

The cost of pest control is high and falls mainly in the initial years. This is the time when farmers' resources are most limited, after they have purchased the planting material, and incurred considerable expense in clearing and preparing the field. This is the reason why Bustami and Saryono could not afford to build fences around their fields at the start of the trial. In the study area, the initial cost of fencing a 0.5 ha field against ground-dwelling pests ranged from 200 000 up to 800 000 Rp (pers. obs.). The lower cost fences are generally less effective and need more maintenance over time, which of course brings up the total cost considerably. Guarding against monkeys is most effective with air rifles, but the cost of these was 100 000 Rp in 1996. Regular guarding also requires time, which depends on available labour, and is less easy to quantify. Research in another Sumatran province (Gauthier, 1996b) highlighted the relatively large investment of cash and labour resources by farming households in vertebrate pest control.

The benefits of pest management can be seen by modelling the theoretical losses in revenue resulting from delayed tapping of trees that had suffered pest damage. For plots with different levels of pest damage, the estimated number of months delay in trees reaching tappable size (relative to undamaged trees) was averaged over all levels of weeding management (Figure 5.11), then the approximate yields of latex for those months calculated, and converted to revenues (with no discounting) (Table 5.19).

Table 5.19. Theoretical 'loss' of revenue from the delay in tapping trees, due to various levels of pest damage.

Pest damage index [1]	Delay in trees reaching tappable size, compared with undamaged trees (in months) [2]	Equivalent latex yield (kg of rubber 'slab') [3]	Revenue (Rp) [4]
1	1.93	119.29	89 464
2	3.86	238.57	178 928
3	5.79	357.89	268 418
4	7.72	477.18	357 882

[1] Mean number of stem breaks per tree
[2] Difference between levels in Figure 5.11
[3] Number of months delay, multiplied by 61.83. This figure was derived from the latex yield of clone GT1 in the first year of tapping: 742 kg/ha, where the dry rubber content (d.r.c.) is 100% (data obtained from large-scale trials in Malaysia, cited in Penot and Aswar, 1994). One twelfth of this (61.83 kg) is equivalent to the monthly yield from a 0.5 ha field of 50% d.r.c. 'slab' rubber that is sold by farmers.
[4] Kg of slab rubber, multiplied by 750 (Rp): the average farm-gate price for slab rubber in the study area between 1995 and 1997 (pers obs.).

The calculated revenues in the table above are considerable, when compared to the average daily wage in the study area, which was only 3 500 Rp (July 1997), although small in relation to the cost of fencing, for example. However, if insufficient labour and cash are invested in pest management, there is a risk of farmers losing their investment completely. In this trial, Bustami considered his field a failure, as trees were attacked so frequently that they never reached heights of more than 1.5 m.

As pests can be so destructive, it is important that any field where farmers wish to plant clonal rubber should be easily accessible, to enable regular guarding and relatively intensive management, compared with traditional jungle rubber practices. The best option would be for the field to be very close to (or even adjacent to) the house. If this is not possible, and farmers are serious about protecting their investment, then it may even be worth building a temporary house in the field, and the farmer living there for the first critical two years. This certainly cuts down the risk of damage by pests in the early morning and late evening (monkeys), and at night (pigs).

5.4.4.2 Weeding

As a general rule of thumb, it is recommended that in the first year after planting, the minimum level of weeding management per field should be strip-weeding of the rubber rows three times, involving no less than 8 person-days of labour per weeding event.[44] The inter-row vegetation should be controlled every six months to prevent this overtopping the rubber. In the second year after planting, strip-weeding only twice should be sufficient, and, as the rubber trees would in theory have gained a competitive advantage over the secondary vegetation in terms of height growth, inter-row management should not be necessary. This

[44] This is based on the average amount of labour (two person-days) used to weed each plot (a quarter of the field) in the experiment, and so represents an 'average' weeding intensity over the range of farmers.

minimum management should guarantee successful establishment of clonal rubber in this type of environment (if precautions are taken to protect trees from pests).

Over the first critical two years of growth, the strip-weeding would cost approximately 140 000 Rp (40 days of labour, at a cost of 3 500 Rp per day). This is affordable by the majority of the farmers in the study area, as the average annual income is 1.3 million Rp (Gintings, 1995). The inter-row management may require a total of 16 person-days for a 0.5 ha field (experience from the experiment in Chapter 4), and so cost 56 000 Rp. The total costs of 196 000 Rp should still be affordable.

Of course, more intensive weeding management will result in faster tree growth (Section 5.3.4.7). However, in practice, this depends on farmers' socio-economic situations, i.e. how much cash/labour they have available, or wish to allocate to intensive management.

Considering the case of 'minimum management' above, 40 person-days of weeding labour per field translates to 10 person-days per plot in the trade-off analyses in Section 5.3.4.7. From these models, this investment of labour (costing 140 000 Rp), would give a mean tree diameter of 46.34 mm at 21 months after planting, and an estimated age at tapping of 63.53 months. The highest management level encountered in the experiment was 14 days/plot (equivalent to 56 days/field), incurring a cost of 196 000 Rp, and giving trees with mean diameter of 52.95 mm, which could be tapped at 61.32 months. For a difference in cost of 56 000 Rp, the earlier opening for tapping from the most intensive management level would result in 2.2 months extra revenue from latex. This approximates to 102 000 Rp, the income from the extra 136 kg of rubber slab (Section 5.3.4.7).

From a purely economic point of view, this appears to be worthwhile. However, it is only the farmers themselves who could decide if this is so, or if that 56 000 Rp over the first two years could be better spent elsewhere (especially if they have already invested 140 000 Rp on the 'minimum management' regime), or if the extra 16 days of their time could be used in other activities that gave a higher return to labour, or immediate cash income.

5.4.4.3 Cash vs. labour availability

If the availability of cash was lower than that of labour then, in theory, farmers would be most likely to invest their time in weeding their fields intensively themselves. If the opposite were true, for example if farmers had off-farm employment, then it is expected that they would prefer to hire labour, or invest in inputs such as fertiliser and/or herbicide for weeding. The farmers in this experiment agreed that the fertiliser/herbicide option was far more efficient.

This was also found to be the case in the province of W. Kalimantan (Courbet *et al.*, in press; Schueller *et al.*, in press).

5.5.5 How effective is this type of methodology for participatory on-farm trials which test the introduction of high yielding planting material to multi-strata agroforestry systems?

5.5.5.1 The range of alternative approaches

To assess the effectiveness of the method used in this study, it must be considered in relation to a number of hypothesised alternatives. The options available to researchers span a continuum from fully researcher-controlled experiments through to extension-oriented pilot dissemination trials, and are summarised in Figure 5.12. The different approaches are suitable for different circumstances, depending on the objectives of the research. This experiment was pitched at option C in this classification, for reasons explained in Section 5.1.

Greatest researcher input, controlled experimental conditions	A) Give clones to farmers, but researcher pays for, organises and supervises all treatment implementation. Monitor rubber growth comprehensively.	Researcher-managed technology testing trials
	B) Give clones to farmers on condition they follow experimental protocol; give them incentive payments to do so (conditional on them following the protocol so far). Monitor rubber growth.	
	C) Give clones to farmers on condition they follow experimental protocol. Discuss, observe and record their decisions and actions, collect socio-economic information. Monitor rubber growth.	
	D) Give clones to farmers, establish one experimental treatment per farmer (their choice). Discuss, observe and record their decisions and actions, collect socio-economic information. Monitor rubber growth less frequently (bi-annually?).	
Greatest farmer participation, real-world conditions	E) Sell clones to farmers (reduced price? but guaranteed quality). No experimental treatment. Discuss and record their decisions and actions, collect socio-economic information. Monitor rubber growth less frequently (annually?).	Pilot dissemination projects

Figure 5.12. Possible approaches in testing the introduction of high yielding clones to rubber agroforestry systems using on-farm trials

5.5.5.2 Advantages of the experimental methodology

The use of approach C identified two unanticipated factors that would not have been identified by the use of standard researcher-managed trials (approach A). These were the slashing of the inter-row vegetation by three farmers, which highlighted their perceptions of the necessity for intensive management of clones, and the variation in pest damage between fields which was related to farmer management. Results obtained from this kind of trial provide hard evidence of farmers' management preferences, because these were unequivocally demonstrated by the farmers' actions. This approach obtained more realistic information than could be obtained from farmer surveys or interviews on management preferences.

In addition, in this case, where project resources were limited, it was necessary to use approach C for technology-testing with farmers, in order to maximise the quantity of information obtained (on both the biophysical interactions and farmers' responses). It was also a good starting point for a pilot study of this type, where clonal rubber growth had never before been assessed on farm, in jungle rubber-like conditions. However, there are a number of inherent issues and problems with this approach, and these are considered below.

5.5.5.3 Problems with the experimental methodology (approach C), and related issues

Although information on both biophysical and farmer management/socio-economic issues is obtained using this approach, it is questionable whether the data obtained is sufficiently detailed or rigorous for definite conclusions to be drawn on either issue. This can often be the case in on-farm trials, where precise research objectives have not been identified (Coe, 1997).

Range and levels of experimental treatments

Because the experiments were on-farm, the range of management treatments that could be tested was limited. The upper management limit could not exceed realistic estimates of the farmers' capabilities (in terms of labour and cash resources), whereas the lowest management limit had to be high enough to ensure there was no tree mortality, or unacceptably detrimental effects on tree growth. However, it is possible that differences in tree growth between treatments in this narrow range are not great enough to be perceived by the farmers (Huxley, 1999), so why should they be expected to follow a complicated experimental protocol involving the management of four different plots in their field? Even though the growth differences may be significant statistically, are the magnitude of the differences actually important to farmers in the real-world, if they are not obvious from observations of trees in the field? Should researchers be using Borel and Romero's (1991) suggested criteria of 'practical' as opposed to 'statistical' significance?

Treatment implementation

With approach C, treatment implementation by farmers is not guaranteed. Researchers have to accept that management may not be carried out according to the experimental protocol, and so balanced data for a rigorous statistical analysis (e.g. ANOVA) may not be obtained. Therefore, the biophysical results will not be as clear-cut as if approach A was used, and it is less likely that comprehensive management recommendations can be derived from them. It is also possible that some replications may be lost from the experimental programme completely. It has even been argued (Shepherd *et al.*, 1994) that "research resources are often wasted in attempting to get this information (e.g. information on the biological performance of treatments) from farmer-managed trials".

The four management regimes tested were designed to be suitable for farmers with different socio-economic circumstances. Therefore, as only one treatment was likely to be relevant to the situation of each participating farmer, there was no incentive for them to implement every one of the four treatments in their field. This was illustrated by two farmers in the study who, once they had received the clonal planting material, proceeded to manage the whole field uniformly, according to their particular preferences. In fact, approach C relies upon the goodwill and co-operation of farmers for implementation of treatments that are not specifically relevant to their circumstances, and which do not benefit them directly. An ethical issue also arises. Is the provision of improved planting material and inputs from the project enough to compensate these resource-poor farmers for their efforts in supplying experimental results which are applicable to other farmers in Indonesia?

Participatory approach

Selection of farmers was based on their interest in joining the project, and on the suitability of their fields for the experiment. It was not conducted with the aim of representing certain target groups of farmers, or any particular socio-economic groups. Thus, the conclusions from the socio-economic side of the study are directly applicable only to that subset of farmers. Certainly, the fact that three of the four farmers had secure off-farm employment does not allow generalisations to be made about 'typical' rubber smallholders. However, relating the management of farmers' fields to their socio-economic situations has given us insights into the issues involved in the management of clonal rubber by smallholders.

Although the experiment was designed to be relevant to smallholders' conditions, especially with respect to low management inputs, the farmers who participated in the trial were not involved in the design or planning of the experiment in a truly collaborative manner (*sensu* Biggs, 1989). They were involved in deciding the weeding levels, however, the discussion was structured around the frequency of strip-weeding, rather than being an open-ended discussion, where the farmers preferences for removal of the inter-row vegetation or alternative weeding methods may have come to light. Therefore, the lack of participation in setting the experimental objectives may have resulted in farmers feeling little ownership of the experiment, and may also have contributed to them not following the protocol.

The attitude of researchers was more trial-centred than farmer-centred. Time limitations meant that the project co-ordinators did not spend much time in the field on their two-monthly visits, and these tended to be focussed on the fields, as it was often hard to arrange times when the farmers themselves could also be present. Under pressure to produce experimental results for donors (Bingen, 1994; Merrill-Sands *et al.*, 1991), sometimes researchers found themselves admonishing the farmers for not adhering to the protocol. This was not compatible with a truly participatory approach, but a result of using approach C in a case where it seemed important to get standard weeding treatments replicated across farms.

5.5.5.4 Suggested improvements to approach C

<u>Researcher pays for treatment implementation in one 'baseline' field</u>

One possible way to ensure that the experimental protocol is implemented in at least one of the trial fields, would be to select one field and pay for the correct weeding treatments to be conducted (Wibawa, pers. comm., 1997). Statistical comparisons (e.g. using t-tests) of tree growth between treatments in this field could then be used to test the biophysical hypotheses of the experiment. However, there would be no replication of treatments or farmers, and conclusions based on one field are unlikely to be representative of the range of variability that was found in our results, for example with respect to farmers' weeding methods and pest damage and/or pest control methods. This approach would not be satisfactory from the participation perspective. The other farmers involved in the trial would be envious of the farmer whose weeding was being paid for (my experiences when replanting legume cover crops, and implementing the experiment in Chapter 4 highlighted this issue). These farmers may possibly demand payment from the project for their own weeding costs, or neglect their fields, expecting the project field staff to step in and manage the trial (this was seen in a similar trial in Costa Rica (Beer, 1991).

<u>Increase the number of participating farmers</u>

The effectiveness of approach C could be improved by substantially increasing the number of farmers/blocks, so that the analysis of variance technique could be used (S. Abeyasekera, pers. comm., 1999). In addition to looking at the effects of planned treatments (on tree growth, for example), a number of variables could be added to the ANOVA which could theoretically account for a large 'farmer' effect (e.g. wealth, soil type in their field, etc) i.e. partitioning farmer variation into a number of explanatory 'treatment factors'. Consideration of these factors individually would give insights into which variables were important, and, moreover, the interaction of these factors with experimental treatments would provide an understanding of the practicalities of implementing the treatments over a wide range of farmers' conditions. When deciding how many farmers are necessary for the trial, the number of variables to be investigated, and the number of interactions between these, must be considered. Once a theoretical ANOVA table has been drawn up with the relevant degrees of freedom (d.f.) involved, a general rule of thumb is that the residual d.f. should be around 10-12, or even more, up to around 20 (S. Abeyasekera, pers. comm., 1999)

The case of the second-generation trial

Building on the experience gained from the study described in this chapter, including the problems with pest damage, and the high level of off-farm employment of participating farmers, a second trial was planted in 1997 (Penot, in press). Here, farmers did actually implement the weeding frequencies as defined in the protocol. The reasons for this were the trial location, characteristics of the selected farmers, and the project generally running more smoothly in its second year. The trial was located in another sub-district, where pest pressure was much lower, farmers lived adjacent to their fields (which again reduced pest damage) and there was very little land available for expansion, so farmers were keen to manage their experimental plots more intensively.

The farmers themselves had no off-farm employment, the average level of education was much lower than the original group of farmers, and they were poorer, in terms of cash income and assets (Kelfoun *et al.*, in press). They could be considered 'typical' rather than 'progressive' farmers. They had also seen good clonal rubber growth in the plots of their neighbours who had participated in the project the previous year. In 1997, the project was able to ensure good quality planting material, so this could be planted earlier, at the beginning of the rainy season, and contact with project field assistants was more frequent from the start, as extra staff had been employed.

Farmer selection

It is clear that farmers' socio-economic circumstances are relevant to the issue of treatment implementation, and so are their personalities (e.g. how headstrong or malleable they are when under pressure from researchers to adhere to the protocol). Working with farmers in a participatory context, however, should not have to involve pressurising them in this way. To minimise the likelihood of this, I suggest two brief surveys that should be conducted before farmers are even selected for participation in a trial.

The first survey should cover the farmer's socio-economic situation, in order to assess whether they actually have enough time, labour, and cash resources to carry out the experimental treatments, and also to get an idea of their strategies/priorities in allocating these resources. The second should address their perception of the technology: whether or not they agree with the basic principles involved in the trial (e.g. allowing secondary forest species to regenerate in the inter-row area).

Although all these precautions can be taken, there is still no guarantee that farmers would actually implement the planned weeding frequencies, as defined in the protocol. If the objectives of the experiment are to get 'hard', well replicated biophysical data on the effects of weeding on clonal rubber growth in farmers' conditions, which can be used confidently to produce management recommendations, then approach C is obviously not satisfactory.

5.5.5.5 Recommendations for different approaches to future on-farm trials

<u>Approach B</u>

To have greater control over the experiment, and thus increase the likelihood of getting good experimental results, approach B could be used, and all farmers paid to implement treatments. Although this greatly increases the chances that the protocol will be followed, there are still no firm guarantees. Approach B involves more cost to, and time from, the researchers, but less than if the trial was fully managed by them. Paying for weeding would be an efficient use of resources, as the extra cost is small compared to the investment in planting material in setting up the trial, especially if some replicate blocks (farms) have to be disregarded completely due to farmer management being incompatible with the experimental objectives. However, it was impossible for me to use approach B to ensure treatment implementation, as this would have created conflict with other project farmers who were participating in different SRAP trials.[45] The great disadvantage of this method is that little can be concluded regarding socio-economic issues, or potential adoption of the technology by farmers.

The previous discussion has centred on a single phase of research, which tries to achieve multiple goals. A more effective procedure may be to split the whole process into two discrete sequential phases, with each phase designed to address very specific objectives. **Therefore, I suggest that the best approach is the use of both options A and D, in combination**[46] (if sufficient funds are available). Definitive results could then be obtained for both issues: the biological performance of trees in response to different weeding management regimes, and also the adoption of the new clonal rubber technology by farmers in this agroforestry system.

---

[45] Beer (1991) summarises this issue succinctly: "Biophysical academic research (e.g. for a higher degree) within existing on-farm technology trials can create management conflicts between student, farmer and project, and therefore should be attempted with caution."

[46] Although researchers should take steps to avoid social discord which could result from having both

Approach A: advantages and practicalities

Approach A, involving researcher-managed on-farm biophysical experiments, will provide reliable results, replicated over a number of sites, which will be representative of a range of physical on-farm conditions. The number of treatments can be increased if necessary, as the trials are entirely controlled by research staff. Treatments can also encompass greater extremes (for example to enable regression analysis), without influencing the livelihoods of farmers.[47]

The actual weeding methods in the trial should be based on farmers' existing practices and preferences (Dupraz, 1999). These should be elicited through meetings with farmer groups (Cornwall *et al.*, 1994), using PRA techniques, and cross-checked with field observations. Many farmers in the study area decide to weed when secondary vegetation reaches a certain height (Ismael, Yusnidar, pers. comm.), so it may be suggested that treatments are based on this principle. This would not pose too much of a logistical problem, because treatment implementation would be controlled by researchers. In our case, using approach C, this would have been more difficult to monitor (or control). This was because farmers weeded when it was convenient for them, and so it was unlikely that researchers would have had the opportunity to record the height and composition of weeds before they were cut. This was why weeding frequency was chosen by researchers as being the easiest method to implement logistically.

Valuable feedback from farmers could be gained about the technology by using the field sites as demonstration-plots, and by organising regular visits by groups of farmers. Informal discussions in the field would reveal farmers' general perceptions of the technology, their preferences for different management regimes (treatments) and their reasons for these. In addition, the trials would be instrumental in demonstrating the feasibility of the technology, especially to farmers who had previously been exposed only to the dominant model for clonal rubber cultivation: monoculture.

Once relationships amongst components (such as high yielding clones), management interventions (such as weeding method and frequency) and outcomes (productivity, sustainability and/or environmental impacts) have been identified, suitable combinations can be tested by a sample of farmers in a fully collaborative manner.

Approach E could be used for these participatory trials, as it represents pilot dissemination projects (Shepherd *et al.*, 1994), and would guarantee results representative of real-world

researcher- and farmer- managed trials in the same community (Shepherd et al, 1994).

[47] However this does depend on the arrangements made with farmers on whose land the trial is conducted (Shepherd *et al.*, 1994). If, for instance, a particular treatment retards rubber growth unacceptably, then compensation should cover the costs of replanting the trees.

conditions. However, only a small percentage of farmers in the study area would actually have enough capital to be able to buy clones without credit provision (Kelfoun *et al.*, in press). Unless the project was able to provide this, the most practicable option in terms of numbers of participating farmers, and ensuring a wider range of farmers' socio-economic situations, is Approach D.

<u>Approach D: advantages and practicalities</u>

The approach-A trials would have quantified rubber tree growth in relation to the amount of work invested, for a number of different weeding levels. Therefore, a range of management options can be presented to farmers, from which they would be able to select one: trading-off maximum rates of rubber growth against their available resources.

Selection of participating farmers would depend on the objectives of the trial. In all cases, however, the brief socio-economic survey, and technology-perception questionnaire (Section 5.5.5.4) should be conducted. If the experiment aimed to identify extrapolation domains, then all 'types' of farmers should be included, and so approximately equal numbers of farmers from each social or wealth stratum in the community should be selected. If the trial aimed to evaluate a large range of weeding management levels, then approximately equal numbers of farmers who had chosen each specific level should be included.

Researchers should follow farmers' decision-making processes closely, to identify the farmers' own criteria, and should also collect more detailed information on farmers' socio-economic situations. In addition, researchers need to observe the farmers' actual management of their fields, when and why they weed, and whether in reality they adhere to their chosen management level, and, if not, on which criteria they based their decision.

Thus, farmer adaptation of the technology can be observed, and this can be related to their socio-economic situation, so that the constraints and opportunities for adoption of particular technological interventions can be identified from the farmers' perspective.

5.5.6 Summary

The on-farm trial identified two hitherto unrecognised constraints to the adoption of high cost genetically improved planting material in multi-strata systems: damage by vertebrate pests, and farmers' perceptions of the necessity for intensive management of these valuable clones. Furthermore, the risk of pest damage could explain the farmers' preference for the monoculture model, as this is currently the most common practice for planting clonal rubber, and the farmers perceived that this type of system would guarantee success. Although researchers assumed that farmers would prefer to retain their traditional management practices, the reality in this trial was that if farmers were taking a step towards intensification, then they were prepared to move the whole way to monoculture, and to abandon their traditional multi-strata system.

The differences in the growth of clonal rubber in this trial were primarily caused by differences in the way in which individual farmers managed their plots (frequency and effectiveness of weeding), and managed their fields (pest control). Farmers' management decisions were in turn related to their socio-economic situation. The four management interventions tested were designed to be suitable for farmers with different socio-economic circumstances. Therefore, as only one treatment was likely to be relevant to the situation of each participating farmer, there was no incentive for them to implement every one of the four treatments in their field (unless financial inducements were provided by the project). Treatment replication at the farm level (i.e. one treatment per farm) may have been more appropriate. In that case, for each of the management levels to be tested, replicate farmers with representative socio-economic profiles could be identified using a brief questionnaire covering socio-economic variables and also people's attitudes to the technological intervention proposed.

For on-farm trials that aim to explore biophysical interactions in multi-strata systems or develop new technological interventions, the trials should be on farmers' land to ensure relevant conditions, but the treatment implementation and plot management should be controlled by the researcher. Once relationships amongst components (such as high yielding clones), management interventions (such as weeding method and frequency) and outcomes (productivity, sustainability and/or environmental impacts) have been identified, suitable combinations can be tested by a sample of farmers, selected as described above, in a fully participatory manner. Researchers can then observe how farmers' adapt the combinations, relate this to their socio-economic situation, and thus identify the constraints upon, and opportunities for, the adoption of particular technological interventions from the farmers' perspective and define their extrapolation domains.

CHAPTER 6

GENERAL DISCUSSION & CONCLUSIONS

6.1 INTRODUCTION

The results of the experimental programme conducted in this study will be discussed with reference to the aims stated at the beginning of Chapter 1. In addition, the implications arising from the results, for the future of improved rubber agroforestry systems in Indonesia will be considered, and the methodology used in the programme will be discussed.

The general aim of this thesis was fulfilled; recently-developed, fast-growing and high-yielding rubber clones were tested in a prototype agroforestry system that was modelled on the traditional jungle rubber system, under the conditions experienced by smallholders in the piedmont zone of Sumatra. This had never been done before. Moreover, specific effects of the interference from secondary forest regrowth on both the above- and below-ground growth of clonal rubber were investigated, using a combination of researcher- and farmer-managed experiments.

Clonal rubber growth was used to assess the integrated effects of competitive interactions in various management and weeding regimes. These regimes had been designed to mitigate the effects of interference from secondary forest regrowth, and thus to answer practical questions regarding the suitability of such an agroforestry system for resource-poor farmers wishing to adopt clonal rubber.

6.2 DISCUSSION OF INDIVIDUAL OBJECTIVES

Objective 1: To quantify the effects of interference from secondary forest regrowth on the above-ground growth of clonal rubber trees, and to determine how the outcome of that interference is controlled by variation in the total amount of below-ground soil resources.

This objective was addressed by the design and implementation of the trenching experiment in Chapter 3. The effect of weeding on clonal-rubber tree diameter and trunk volume[48] was significant ($p<0.05$) at 18 and 21 months after planting. At 21 months after planting, the mean diameter of trees in the low weeding treatment was 17% lower than that of trees in the high weeding treatment (Table 6.1, Section 3.3.1.2), and mean trunk volume was 37% lower (Section 3.3.1.2).

[48] Index calculated as tree height multiplied by the square of tree diameter

Table 6.1 Size of undamaged clonal rubber trees (21 months after planting), in relation to weeding management and field characteristics, for each experiment.

		CHAPTER 3 Trenching experiment		CHAPTER 4 Researcher-managed trial		CHAPTER 5 Farmer-managed trial				
						Ismael			Azahri	
Weeding treatment [1]		HW	LW	HW	LW	'HW' (Plot D)	'LW' (Plot C)	'HW + LCC' (Plot A)	'LW' (Plot C)	'HW + LCC' (Plot A)
No. of undamaged trees		18	18	13	44	12	15	17	4	3
Diameter (mm)	Mean	71.1	58.7	39.3	39.5	46.3	44.7	50.2	44.5	49.1
	(s.e.)	(2.02)	(1.89)	(1.67)	(1.73)	(1.72)	(2.08)	(1.33)	(3.80)	(3.70)
Height (cm)	Mean	665	594	491	473	422	413	501	506	483
	(s.e.)	(16.5)	(21.8)	(11.9)	(15.4)	(22.1)	(24.4)	(20.0)	(87.5)	(55.3)
Weeding: no. of times strip-weeded (and 'weeding effort' [2])		15 N/A	2 N/A	15 N/A	5 N/A	5 (11 days)	2 (9 days)	5 (14 days)	7 (5 days)	10 (9 days)
Inter-row vegetation [3] (and maximum height)		Clean-weeded	SFR Woody growth-forms infrequent grasses & herbs dominant (1 m)	SFR	SFR Woody growth-forms dominant (3.5 m)	SFR Woody growth-forms cut down regularly, grasses dominant (1.5m)	SFR	LCC Small shrubs and herbs also present (0.8 m)	SFR Woody growth-forms dominant (4 m)	LCC Small shrubs and herbs also present (0.8 m)
Weeds in rubber-tree row	Cover index (%) [4]	26.0 (7.50)	73.7 (16.43)	8.5 (1.85)	43.8 (2.15)	NM	NM	NM	NM	NM
	Height index (cm) [5]	8.7 (3.05)	18.0 (3.25)	8.6 (1.45)	22.6 (1.96)					
Topography of field		Flat		Sloping (4°-25°)		Sloping (13°-18°)			Sloping (11°-13°)	
Soil properties [6]	Texture	Sandy loam		Sandy clay loam		Clay loam			Silt loam	
	Depth (cm)	0-15		0-15		0-5 5-15	0-5 5-15	0-5 5-15	0-5 5-15	0-5 5-15
	pH (H_2O)	5.11 (0.168)		4.42 (0.64)		4.50 4.40	4.50 4.00	4.10 3.80	4.10 4.10	3.90 3.80
	N_{tot} (%)	0.08 (0.004)		0.14 (0.06)		0.15 0.15	0.18 0.14	0.26 0.14	0.15 0.11	0.24 0.20
	C_{org} (%)	2.16 (0.173)		1.85 (0.27)		2.18 2.18	2.25 1.82	3.27 1.66	1.84 1.14	3.33 2.51
	P_{Bray} (mg kg^{-1})	9.63 (1.209)		4.70 (0.70)		15.00 14.00	15.00 14.00	17.00 13.00	15.00 13.00	21.00 18.00
	CEC ($cmol_c$ kg^{-1})	3.47 (0.237)		5.05 (0.73)		9.56 7.04	8.08 10.17	15.04 13.66	8.25 5.20	11.97 9.16
	Al ($cmol_c$ kg^{-1})	0.44 (0.078)		0.52 (0.08)		1.11 1.90	1.65 3.38	2.76 6.97	2.65 2.44	4.14 4.55

1 HW: High weeding; LW: Low weeding; LCC: Legume cover crop.
2 Number of days spent weeding the plot over the first 21 months after planting (Section 5.3.4.4). N/A: not applicable as plot sizes were not equivalent.
3 SFR: secondary forest regrowth. Inter-row vegetation composition and size, 21 months after planting.
4 Mean of four measurements of total percentage cover between 7 and 19 months after planting (Sections 3.3.1.3, 4.3.2.2), and s.e. of this mean. NM: not measured, due to irregular implementation of weeding treatments by farmers (Section 5.2.4.3).
5 Mean of four measurements of average height for all growth-forms, over the period 7 to 19 months after planting (Sections 3.3.1.3, 4.3.2.2), and s.e. of this mean.
6 Texture: USDA classification (USDA, 1975); Chapters 3 and 4: mean values per field (and s.e.), data from Tables 3.5 and 4.6; Chapter 5: data for individual plots presented.

This significant retardation of rubber tree growth occurred despite the fact that the 'secondary forest regrowth' in the inter-row was dominated by grasses and herbaceous climbers (*Mikania* spp.), and there was only limited regeneration of woody growth-forms (Table 6.1, Section 3.3.1.3). As this low-growing vegetation was not tall enough to shade the rubber trees, it can be concluded that the effects of the weeds were mediated entirely by below-ground interference.

Varying the total amount of below-ground soil resources, by trenching off three different volumes of soil around trees which were planted at standard plantation spacing, did not have a significant effect on clonal rubber tree growth. The interaction between soil volume and weeding was also not significant. On the basis of these results, it appears that the total amounts of below-ground resources were not sufficiently limiting to affect rubber tree growth in this experiment. Therefore, the depressed growth of trees in the low weeding treatment relative to the high weeding treatment, may have been due to interactions at the level of individual roots, i.e. interference with resource-capture, with weed roots directly affecting the size of depletion zones (for nutrients and water) around each rubber tree root (Section 3.4.1).

Objective 2: To investigate effects of interference from secondary forest regrowth and variation in the total amount of below-ground soil resources on the response of allocation within clonal rubber trees (roots versus shoots, and vertically- versus horizontally-oriented roots).

This objective was addressed by studying cross-sectional areas (CSAs) of the stems and 'proximal' roots (which arise from the base of the stem) of clonal rubber trees within the trenching experiment (Chapter 3). Above- versus below-ground allocation within the clonal rubber trees was assessed by calculating a 'shoot:root ratio' based on the CSA of the stem and all the proximal roots, for each tree. However, the results showed that this ratio was not affected by either weeding or soil volume treatments.

Allocation within the root system of each tree was studied by calculating the number and CSA of horizontally-oriented roots as a percentage of the total number and CSA of all proximal roots (both horizontally- and vertically-oriented). The percentage of horizontal roots (based on root number) was significantly greater in the small soil volume treatment than in the large soil volume treatment ($p<0.05$). With low weeding, the percentage of horizontal roots (based on root CSA) was greater in the small soil volume treatment, whereas with high weeding it was greater in the large soil volume treatment. Therefore, there were no consistent trends in allocation, either between roots and shoots or within the root system, in relation to weeding or below-ground soil resources. Thus there is no evidence from this study to indicate that interference from weeds results in greater allocation to roots relative to shoots in rubber, nor is there evidence that there is greater allocation to vertically-oriented roots relative to horizontally-oriented ones. These findings are in contrast to a previous study by the author in a rubber intercropping experiment (Williams *et al.*, in press).

Objective 3: To identify the most limiting nutrient to clonal rubber growth in the clonal rubber-secondary forest regrowth environment.

Nutrient limitation was investigated within the trenching experiment (Chapter 3), by studying root in-growth into cores of soil which had been enriched with various nutrients or cores which were unfertilised (control). The nutrients were those specifically recommended in smallholder rubber fertilisation programmes (Delabarre and Benigno, 1994; Junaidi *et al.*, 1996), i.e. N, P, K and a Ca/Mg combination. However, the results showed that the effect of soil-core nutrient enrichment on rubber root ingrowth was not significant, either in terms of root biomass or root length density. In fact, there was no significant difference between any of the cores with added nutrients and the unfertilised control. Thus no evidence could be obtained from this study to indicate that a specific nutrient was limiting to clonal rubber growth. It is possible that this apparent lack of response to nutrient enrichment, by both rubber trees and weeds, was due to impaired nutrient uptake from the dry soil caused by the El Nino drought (total rainfall was only 215 mm during the 20-week incubation period of the ingrowth core experiment, and there were only 15 days when rain fell).

Potential N-limitation in the system was also studied at plot level within the trenching experiment, by investigating rubber tree growth in response to N-fertiliser addition, in small volume, low-weeded plots (Section 3.3.1.2). The result was that, at 21 months after planting, mean rubber tree height and stem volume in these N-fertilised plots was significantly greater than in comparable non-N-fertilised plots, and was not significantly different from the high weeding small volume plots. Thus evidence was found that under low-weeding regimes, the growth of clonal rubber trees was limited by soil N-availability, and addition of N appeared to partly compensate for the higher weed competition in the low-weeding plots. This weed competition did appear to be related to N, as levels of soil nitrate-nitrogen (21 months after planting) were significantly lower in the low weeding treatment than in the high weeding treatment (Section 3.3.1.4.1), and this could be attributed to uptake by the weeds.

Objective 4: To compare the effect of two levels of weeding on the survival and above-ground growth of clonal rubber in the prototype agroforestry system, on sloping land, and to compare this with the growth of the unimproved rubber variety that is traditionally used by farmers.

This objective was addressed in a researcher-managed trial on a whole-field scale, comparing the performance of clonal and seedling rubber (Chapter 4). In this experiment, the regenerated inter-row vegetation was typical of the secondary forest regrowth in the study area, in contrast to the grass-dominated inter-row vegetation in the trenching experiment (Table 6.1). Furthermore, and again in contrast to the trenching experiment, damage by vertebrate pests (banded leaf monkeys and feral bearded pigs) had a major impact on rubber tree growth in this experiment. Seedling rubber trees sustained more damage than clones, with a mean of 1.3 and 2.3 stem-breaks, respectively, per planting position (Section 4.3.5). This was probably due to the fact that seedling rubber trees were slower to establish than clones, after transplanting in the field (Sections 4.3.3, 4.3.6.2), and so were relatively smaller at any given time, and were therefore more easily damaged by both types of pest (pest damage will be further considered under Objective 6). The mortality of seedling rubber trees was much greater than that of clonal trees (2 and 35 % respectively, for trees planted in December 1995), and was not affected by weeding treatment.

For undamaged trees, at 21 months after planting, the mean height and diameter of clonal rubber tree shoots was significantly greater than those of seedling rubber trees ($p<0.001$). However, the effect of weeding frequency within the rubber tree row was not significant for either shoot height or diameter (Table 6.1). Neither was there any significant difference between weeding treatments, nor between clones and seedlings, in terms of foliar nutrient and water concentrations. It may be that competition exerted by the inter-row vegetation was of a greater magnitude than the competition exerted by weeds within the rubber tree rows, and, as the inter-row vegetation was not managed as part of the experimental weeding treatments, this would explain the lack of effect of the strip-weeding treatments on rubber tree growth. There was, however, some indication that absolute and relative growth rates of clonal rubber were lower in the low weeding treatment than in the high weeding treatment during the first dry season experienced by the trees (6-9 months after planting); this could have been due to competition for water with the weeds within the rubber tree rows.

The mean heights and diameters of the clonal rubber trees, 21 months after planting, were considerably lower than those in the trenching experiment (Table 6.1). The main factor contributing to this could be the very high density of tall tree and shrub growth-forms that regenerated in this experiment; these may have exerted greater below-ground competition than the smaller growth-forms in the trenching experiment, and also would have shaded the rubber trees to a certain extent, especially as the experiment was conducted on steep slopes. In contrast, above-ground competition in the trenching experiment was assumed to be negligible, as the height of the inter-row vegetation was much lower (Table 6.1), and the experiment was located on flat land. Therefore, the height of the secondary forest regrowth in the inter-row possibly has important implications for the growth of clonal rubber in this prototype agroforestry system on sloping land.

Objective 5: To assess the effect of alternative management regimes on the above-ground growth of clonal rubber in the prototype agroforestry system, when implemented by farmers, on sloping land.

This objective was addressed in a farmer-managed experiment; this aimed to compare the growth of clonal rubber in four management regimes in each farmer's field (Chapter 5). Three of the planned treatments involved regeneration of secondary forest regrowth in the inter-row area, and strip-weeding of 'high', 'low' and 'intermediate' frequencies within the rubber-tree row. The fourth treatment was a 'plantation control', representing theoretically optimum conditions for clonal rubber growth; a legume cover crop (LCC) was planted in the inter-row, and there was a 'high' frequency of strip-weeding in the rubber-tree row.

Only one farmer implemented the planned frequencies of strip-weeding. In all other replicate farms, the number of weedings was lower than agreed in the protocol, and was not consistent with the planned experimental design. Furthermore, in the majority of replicate farms, the regenerating secondary forest species in the inter-row were slashed back severely by farmers. In addition, the incidence of vertebrate pest damage was high, and varied considerably between plots and farms, so much so that in three farms, none of the trees escaped damage. In these three farms mortality was also high, ranging from 13 to 69% of the original trees planted.

The variation in weeding frequency and pest damage necessitated the use of linear regression analyses, at the plot level, to investigate the effects of weeding on the height and diameter of clonal rubber trees at 21 months after planting. There was no significant relationship between weeding frequency and rubber tree size, however, 'weeding effort' (the number of person-days spent weeding a plot) was significantly ($p<0.001$) and positively correlated with rubber tree size. Pest damage was significantly ($p<0.001$), but negatively correlated with rubber tree size. In a multiple linear regression analysis, weeding effort and pest damage in combination explained 80% of the variation in tree diameter and 75% of the variation in tree height in the experiment.

Direct comparison of the size of undamaged trees in this trial (at 21 months after planting), with that of undamaged trees in the previous two experiments (Table 6.1), was only possible for five plots within two farms (Azahri's and Ismael's), because in all other plots, there were no undamaged trees. However, in the two plots in Azahri's farm, one contained only three undamaged trees, and the other only four (Table 6.1). In general, in this trial, the mean size of undamaged trees was intermediate between the trenching experiment and the clone-seedling comparison trial (Chapter 4). Within Ismael's farm, the mean tree height and diameter was very slightly lower in the plot with 'lowest' weeding frequency than in the 'highest' weeding frequency plot. In both farms, tree size was greatest in the LCC + 'high' weeded plot. Possible reasons for this are the greater weeding frequency and person-days expended in weeding these plots, and the small amount of above-ground competition from the low-growing inter-row vegetation (Table 6.1).

Objective 6: To identify other factors (in addition to interference from weeds) that influence the growth of clonal rubber under smallholders' conditions.

This research identified vertebrate pests as a major constraint to clonal rubber establishment in the study area. The extent of the pest damage problem would not have been detected if the experiments had been carried out on-station. Breakage of rubber tree stems by vertebrate pests (banded leaf monkeys, *Presbytis melalophos nobilis* and bearded pigs, *Sus* *barbatus*) was a very important factor affecting rubber tree growth in the experiments described in Chapters 4 and 5[49]. Before implementation of the on-farm trials, it was assumed that the construction of a fence around each field would be adequate to exclude pigs, and would therefore constitute a worthwhile investment of the farmers' time. Although considerable effort was expended in building fences around most of the plots (e.g. Sections 4.2.4, 4.2.7), these fences were not fully effective against pigs and hardly a hindrance to monkeys. As was the case for weeding management, there were large differences amongst farmers in the amount of effort invested in pest control (Table 5.15).

The problem of pest damage would appear to be greater if farmers' priorities are for extensive (low input non-intensive) systems akin to the traditional jungle rubber system (e.g. for Bustami in Chapter 5), where they need to spend only a small amount of time in their fields, or if the fields are remote. In the extensive jungle rubber system, planting material has virtually no cost, as it is collected from existing agroforests (Section 4.1.4.1); this means that farmers can plant trees at high densities to accommodate losses from pest damage.

Dupraz (1999) proposed a classification of farmers' strategies based on the ratio of the density of trees planted and the intended final density ('6-8 = conservative, 4 = prudent, 2 = risky and 1 = daring'). Conventional management of monocultural rubber plantations follows a 'daring' or 'risky' strategy, suitable only with near complete control over pests, diseases and weeds and with the use of high-cost planting material. Typical management of rubber agroforest regeneration, based on locally-obtained seedlings, falls into the 'prudent' category, appropriate for conditions where complete control is unfeasible, and where low-cost planting material is used. This issue is integral to the intensification of agriculture, as farmers' tolerance of pest damage decreases when their investment in improved planting material and fertiliser increases. Therefore, vertebrate pest control has tended to become a higher priority for farmers planting clonal rubber, because pests are then perceived as having a greater economic impact on their livelihood (Balson *et al.*, 1997).

This research exemplifies Monteith's (1997) argument that agroforestry modelling is too narrowly focused on parameterising the competition between crop components for light, water and nutrients in ideal conditions. In farmers' fields significant reductions in growth caused by pests and diseases are common and, since this will affect competition, need to be taken into account if the performance of agroforestry systems is to be realistically predicted (Monteith, 1997).

[49] The trees in the trenching experiment (Chapter 3) were not damaged. This was attributable to the sturdy stockade-type fence (1.8 m in height), built by the farmer who owned the field, the fact that he lived in a temporary house in the field for the first two years after planting the clonal rubber (to protect his investment), and that he also owned a guard dog.

Objective 7: To investigate the ability of farmers to adopt the new techniques involved in planting clonal rubber, and the acceptability of the prototype system to farmers

In general, and with only basic training, farmers demonstrated that they could plant and maintain clonal rubber successfully (Chapter 5). However, farmers encountered problems in marking out contours in the field, they dug the planting holes to a smaller size than was recommended (Section 2.7.1), and also they did not prune lateral shoots regularly. Moreover, two farmers did not construct fences around their entire field, as they said they did not have enough resources; in their fields, the incidence of pig damage was high.

Although the participating farmers expressed preferences for this prototype system at the start of the research programme (because it required only low management inputs), in reality, three of the four farmers removed the regenerating secondary vegetation in the inter-row, and so demonstrated that the prototype system was not acceptable to them. The reasons that they gave were that the inter-row vegetation could provide cover for destructive pests such as wild pigs, and that they thought clonal rubber performs best in monoculture; they were unwilling to allow secondary forest regrowth to compete with such a valuable asset. Cutting the inter-row was a higher priority than weeding within the rubber row for these farmers, because they perceived that weed regrowth was slow in the rubber row and did not justify the weeding frequencies in the protocol, whereas the woody species in the inter-row (up to 4 m in height) were a more significant problem.

Objective 8: To produce, based on the above, recommendations compatible with the resources of smallholders, on weeding management of clonal rubber in the prototype agroforestry system

In the trial reported in Chapter 5, farmers' irregular implementation of experimental weeding treatments meant that not even one strip-weeding frequency was replicated over all farms. Therefore, no weeding recommendations could be produced that were based on a rigorous statistical analysis which compared standard weeding treatments over a number of replicate sites and farmers. However, some inferences regarding the management of the prototype agroforestry system can be drawn from the results of the trials presented in this thesis, although it must be stressed that these are mainly conjectural.

Firstly, it is reasonable to assume that within one field, if there were no significant differences in rubber growth amongst plots where different frequencies of strip-weeding had been imposed on the trees, then the lowest of these weeding frequencies would be sufficient to enable successful establishment of clonal rubber (if adequately protected from pests). Two examples from this thesis where multistrata secondary forest regrowth was present in the inter-row area (for the first 20 months after planting), and where the effect of strip-weeding frequency was not significant, are the field of Azahri (Chapter 5), and the experiment presented in Chapter 4. The lowest weeding frequency in the latter was five weedings (in the first 21 months after planting), and in the former, four weedings (involving three person-days per 1/8 ha plot). Thus, in this environment, it appears that four strip-weedings of the rubber-tree row (1 m either side of the trees) in the first 21 months after planting, would be sufficient for clonal rubber to establish successfully in a competitive multi-species environment like that of the jungle rubber system. This is approximately half the labour requirement previously estimated for the establishment of a monoculture clonal rubber plantation by smallholders (Penot, 1997a; Gouyon, 1999).

The lack of an effect of strip-weeding frequency on rubber tree growth within fields was also seen in two other trials in the SRAP project. These trials, in contrast to this study, were located on flat land in the peneplain zone of Sumatra[50] (Akiefnawati and van Noordwijk, in press; Wibawa *et al.*, in press). In the latter, a farmer-managed trial, the difference in rubber tree size (21 months after planting) between farms was significant at the 5% level (G. Wibawa, pers. comm., 1998), as was also the case in the trial in Chapter 5. Because the between-farm variation appeared to be important, the range of weeding management effort and pest damage levels encountered over all farms in the Chapter 5 trial was used to model predicted tree diameter using an equation derived from linear regression analysis (Section 5.3.4.7). The model showed that pest damage had a larger influence on tree size than increased weeding effort/intensity (Figure 5.10), and indicated that it is very important for farmers to protect young clonal rubber trees from pest damage. Furthermore, if, for some reason, the farmers cannot stop their trees being damaged by pests, then greater weeding effort can still improve tree growth. However, as no specific data was collected regarding the amount of time required for guarding the fields to reduce damage to the levels found, it was not possible to compare the effectiveness of the time farmers spent time guarding, with the effectiveness of the time spent guarding + weeding.

In summary, clonal rubber can technically be established in a multistrata environment, with a minimum level of weeding management (3 person days per 1/8 ha plot). However, trees cannot be expected to attain the size of those grown under intensive weeding regimes (Table 6.1: 'high weeding' treatment in the trenching experiment) or of those grown under well-fertilised plantation conditions with legume covers (65 mm diameter at 21 months after planting, G. Wibawa, pers. comm., 1999; Figure 5.1). Nonetheless, the first priority for farmers after planting should be the protection of their trees against pest damage.

[50] Around Sepunggur (Figure 2.2), approximately 50 km from the study area described in this thesis

6.3 THE PROTOTYPE AGROFORESTRY SYSTEM VERSUS JUNGLE RUBBER AND CLONAL RUBBER MONOCULTURE

6.3.1 Inherent compromises

The prototype rubber agroforestry system tested in this study integrated elements of both the jungle rubber and clonal rubber monoculture systems: high yielding clonal rubber trees from monoculture systems, and management practices from the jungle rubber system. Modifications were, however, made to the jungle rubber management practices. These included fertilisation of the rubber trees, although at lower levels than in monoculture; regular strip-weeding of the rubber tree rows, and management of the secondary forest regrowth between the rubber rows (cutting overhanging branches, and lopping the tops of tall trees). The compromises made in designing the prototype systems were shown by results from the trials: although clonal rubber could be established successfully in a multistrata multi-species environment, tree growth was slower than under monoculture plantation conditions. It is also possible that weeding management may have compromised the future environmental benefits of the diverse secondary forest regrowth seen in mature jungle rubber (Gouyon *et al.,* 1993; de Foresta, in press), as it is not known how different species respond to lopping or disturbance (Werner, 1999).

6.3.2 Farmers' perceptions regarding management of clonal rubber

From the results of Chapter 5, and from feedback elicited informally from farmers in the study area, it is evident that farmers perceived that there were two possible systems which could be used when planting clonal rubber:

1. Jungle rubber-type, with low weeding inputs, and low levels of pest control
2. Monoculture-type, with high weeding inputs, and high levels of pest control

Farmers in favour of the first system stated that it was advantageous because trees were not visible to pests, and it did not require much weeding. They suggested that seedling rubber trees should be planted in the spaces between the clonal trees, to make better use of available space.

These farmers could be classified as 'traditionalists', and one may speculate that their views were based on their previous experience of planting seedling rubber in the jungle rubber system, employing a risk-reduction strategy (quantity rather than quality). It is certainly true that there is a large risk of damage to trees by pests (Chapters 4 and 5) and also a high rate of mortality amongst seedling rubber trees (Chapter 4); both these factors explain the traditional strategy of planting trees at a very high density (Objective 6, above). Of course, this strategy is economically feasible with seedling rubber trees, as they are effectively a free resource. It is not certain, however, that if these farmers had bought clones themselves, they would have adopted such a system. In fact, the only farmer who held these views and had actually planted clonal rubber himself was Bustami (a farmer participating in the Chapter 5 trial), and he admitted his field was a failure (Section 5.3.4.8). His very low management input in terms of weeding, pest control, and lack of pruning of the inter-row vegetation was clearly inadequate for clonal rubber growth in this environment (40% mortality and growth increment of only 5 mm in 21 months).

The farmers' suggestions for planting seedling rubber trees between clonal trees goes against all recommended practice; they in fact constitute an anathema to conventional clonal rubber planting wisdom. Much research has been conducted on intra-specific competition in rubber, and recommended planting densities have been based on widespread experimental trials which gave detailed results about how tree density affects the growth of trees, and the yields per tree and per field (Section 1.4.6). However, in the study area where the risk of pest damage is high, there is some intuitive logic in the farmers' suggestions. It was observed in the researcher-managed trial (Chapter 4) that seedling rubber trees grew more slowly than clonal trees, and also suffered greater amounts of pest damage (Objective 4, above), probably due to selective predation by pests of smaller rubber trees (Section 4.4, Q4). There could thus be a case for considering these inter-planted seedling rubber trees as a 'trap' crop, especially as they cost virtually nothing.

The second group of farmers, who perceived that monoculture was the best management system for clonal rubber, included three farmers who participated in the trial in Chapter 5, and who did actually convert their experimental fields to this type of system. Although researchers assumed that farmers would prefer to retain their traditional management practices, the reality in this trial was that if farmers obtained valuable germplasm[51], then they were prepared to make the entire transition to monoculture, in order to protect this asset, and in so doing were willing to abandon their traditional multistrata system.

It is uncertain how representative the management of these particular farmers is of smallholders in Indonesia more generally. However, these farmers could be considered to be 'progressive'. With their 'safety-net' of a regular income from off-farm employment, they might be expected to be the most likely group to adopt high yielding rubber clones in the absence of development projects or government incentives. Given that the farmers participating in the above trial received the clonal rubber trees from the project free of charge, it could be argued that farmers who had purchased this type of improved planting material themselves would be even more likely to switch to the monoculture model in order to reduce risks.

[51] One grafted clonal plant in a polybag cost 1000 Rp in July 1997 (the exchange rate at that time was 1 US $ = 2300 Rp).

6.3.3 Increased pruning of inter-row vegetation as a potential management option

As the farmers in Chapter 5 were not in favour of tall inter-row vegetation in their fields (Objective 7), the prototype system could be further refined by pruning the inter-row vegetation more frequently and to a lower height (e.g. 1 m). The potential advantages of this would be to decrease shading of the clonal rubber trees on sloping land, to prevent possible damage to the rubber caused by tall tree species falling into the rubber tree row (Section 4.4), and to prevent monkeys climbing the tall trees in order to gain access to the rubber (Section 4.4).

The potential disadvantages of increased pruning, however, would be the increased labour requirements, and also the effect on natural regeneration processes, and hence on future biodiversity in the system. It is possible that this method of management would preclude the establishment of useful, late-successional species such as timber trees. Evidence for this possibility comes from studies of secondary forest regeneration by Werner (1999), also conducted in the piedmont agro-ecological zone of Sumatra. She showed that such late-successional species increased in dominance in fallows aged eight to nineteen years old, and that after a twenty year fallow period almost all early colonisers, such as those found in the trial in Chapter 4, had disappeared. However, in rubber gardens of the same age (20 years) which had been regularly weeded (i.e. the vegetation was slashed back to ground level, once a year), succession had been 'frozen' at an early stage (Werner, 1999). In these gardens there was still a high percentage cover of herbs and grasses which had not been shaded out, and the dominant trees were still pioneer and early-successional species (Werner, 1999).

Furthermore, trees which are lopped regularly would be unlikely to reach reproductive maturity, and so the inter-row vegetation would not play a role in conserving viable populations of tree species (as suggested by Penot, 1999). The exception to this would be tree species that farmers perceive to be useful, as farmers would not cut these if they had regenerated naturally within the plot (Werner, in press). In addition, if trees were not allowed to reach reproductive maturity, then any species that relied on flowers or fruit as a food source (insects, birds or bats) could also not be supported.

Thus, increased pruning of inter-row vegetation as a potential management option must be carefully considered. It is not yet known whether this type of intervention would decrease the interference from regenerating secondary forest species while maintaining their soil protection and environmental benefits, or whether the impact on interference would be small, while the biodiversity value would be greatly reduced.

6.4 EXPERIMENTAL METHODOLOGY

The possible approaches which could be used in an on-farm research programme, in order to test a prototype agroforestry system with improved planting material, were discussed fully in Section 5.5. It was concluded that an ideal programme should be split into discrete phases (Section 5.5.6). The first should investigate biophysical interactions between components, and test a suite of farmer-relevant management interventions in researcher-managed on-farm trials. The second phase should involve farmers testing suitable combinations in a fully participatory manner, which would allow the potential adoption of the system to be studied.

Thus, the experiments described in Chapters 3 to 5 in this thesis should, ideally, have been conducted sequentially, as their objectives relate to different phases in the research strategy outlined above. The results from each experiment could then have been used to design the objectives of trials in the following phase, thus ensuring that the line of research progressed in a relevant direction, and the results could be widely extrapolated. In reality, the results from the experiments in this thesis are location-specific, confined only to a limited subset of farmers, and thus extrapolation is very limited. However, added to the results of the Smallholder Rubber Agroforestry Project which spans three Indonesian Provinces, this research has provided valuable insights on the feasibility of a low-input improved rubber agroforestry system in one sector of the diverse Indonesian rubber smallholder economy.

REFERENCES

Abbot, J. and Gujit, I. (1997). Creativity and compromise. PLA Notes 28 (February 1997) 16-23.

Ahmad-Faiz, M.A. (1992). Comparison of three weeding methods in rubber cultivation. Planters' Bulletin, Rubber Research Institute of Malaysia 212: 99-101.

Akiefnawati, R. and van Noordwijk, M. (in press). Effects of P and N nutrition and weeding frequency on early growth of selected germplasm for rubber agroforestry in Jambi, Sumatra. In: Penot, E., Wibawa, G. and Williams, S.E. (eds.), Proceedings of the Smallholder Rubber Agroforestry Project (SRAP) Workshop, Bogor, Indonesia, 29-30 September 1997. ICRAF/CIRAD-TERA/TH.

Anderson, J.M. and Ingram, J.S.I. (1993). Tropical Soil Biology and Fertility: A Handbook of Methods. Second Edition. CAB International, Wallingford, UK. 221 pp.

Anderson, L.S. and Sinclair, F.L. (1993). Ecological interactions in agroforestry systems. Agroforestry Abstracts 6(2): 58-91.

Anon. (1938). The effect of *Lalang* on the growth of young rubber trees. Journal of the Rubber Research Institute of Malaysia 8 : 2270-31.

Anwar, C. and Bacon, P. (1986). Comparison of Imperata control by manual, chemical, and mechanical methods for smallholder rubber farming systems. BIOTROP Special Publication 24 : 307-316.

Anwar, C., Suryaningtyas, S., Hendratno, S. and Nancy, C. (1997). Factors related to the transfer of technology to the smallholders. Paper presented at the ANRPC Seminar on Modernising the Rubber Smallholding Sector, 8-10 July, 1997, Padang, Indonesia.

Azwar, R., Sumarmadji, Haris, U. and Basuki. (1993). Intercrops in smallholder rubber-based farming systems. IARD Journal 15 (3): 45-51.

Bagnall-Oakeley, H., Conroy, C., Faiz, A., Gunawan, A., Gouyon, A., Penot, E., Liangsutthissagon, S., Nguyen, H.D. and Anwar, C. (1997). *Imperata* management strategies used in smallholder rubber-based farming systems. Agroforestry Systems 36 : 83-104.

Balson, J., Davie, J. and Gillison, A. (1997). Impact of vertebrate pests on the management of natural and agro-forests in Jambi province, Central Sumatra. Internal report, CIFOR, Bogor, Indonesia. 20 pp.

Bandy, D.E., Garrity, D.P. and Sanchez, P.A. (1993). The worldwide problem of slash-and-burn agriculture. Agroforestry Today 5(3): 2-6.

Barber, S.A. (1984). Soil Nutrient Bioavailability. Wiley, New York. 353 pp.

Barlow, C. and Lim, S.C. (1967). Effect of density of planting on growth, yield and economic exploitation of Hevea II. The effect on profit. Journal of the Rubber Research Institute of Malaya 20: 44-51.

Barlow, C. and Muharminto. (1982). The rubber smallholder economy. Bulletin of Indonesian Economic Studies 18 (2): 87-119.

Barlow, C. and Jayasuria, S.K. (1986). Stages of Development in Smallholder Tree Crop Agriculture. Working Papers in Trade and Development No. 86/8. Department of Economics and Development Studies, Australian National University, Canberra. 42 pp.

Barlow, C. (1991). Developments in plantation agriculture and smallholder cash-crop production. In: Hardjono, J. (ed.) Indonesia: Resources, Ecology and Environment, pp. 85-103.

Baulkwill, W.J. (1989). The history of natural rubber production. In: Webster, C.C. and Baulkwill, W.J. (eds.), Rubber. Longman Scientific and Technical, Harlow, UK. pp. 1-56.

Baxter, J. (1995). *Chromolaena odorata*. Weed for the killing or shrub for the tilling? Agroforestry Today, April-June 1995, pp. 6-7.

Beaufils, E.R. (1955). Recherches sur la variation des constituents mineraux dans les feuilles et le latex del' *Hevea brasiliensis*. [The variation of mineral constituents in the leaves and latex of *Hevea brasiliensis*]. Revue Generale du Caoutchouc 32 (4): 323-331.

Beer, J. (1991). Implementing on-farm agroforestry research: lessons learned in Talamanca, Costa Rica. Agroforestry Systems 15 (2-3): 229-243.

Benong, M., Othman, R. and Huat, O.S. (1997). Rubber breeding: is there a need for a new approach to selection of clones for smallholders? Paper presented at the ANRPC Seminar on Modernising the Rubber Smallholding Sector, 8-10 July, 1997, Padang, Indonesia.

Beukema, H., van Noordwijk, M., Stolle, F. & de Foresta, H. (in press). Biodiversity in rubber agroforests. In: Penot, E., Wibawa, G. and Williams S.E. (eds.) Proceedings of the Smallholder Rubber Agroforestry Project Workshop, Bogor, 29-30 September 1997.

Biggs, S.D. (1989). Resource-Poor Farmer Participation in Research: a Synthesis of Experiences in Nine Agricultural Research Systems. OFCOR Comparative Study Paper No. 3. International Service for National Agricultural Research (ISNAR), The Hague.

Bingen, R.J. (1994). Policymakers, planners and donors in FSR priority setting. In: Douwe Meindertsma, J. (ed.) Setting Research Priorities: Towards Effective Farmer-Oriented Research, pp. 94-108. Royal Tropical Institute, Amsterdam.

Blencowe, J.W. (1989). Organisation and improvement in smallholder production. In: Webster, C.C. and Baulkwill, W.J. (eds.) Rubber, pp. 499-538. Longman Scientific and Technical, Harlow, UK.

Bogidarmanti, R. (1988). The impact of *Mikania* spp. on forestry and agricultural land. Buletin Penelitian Hutan 511: 29-40.

Bolle-Jones, E.W. and Mallikarjuneswara, V.R. (1957). A beneficial effect of cobalt on the growth of the rubber plant (*Hevea brasiliensis).* Nature 179 : 738-739.

Bolton, J. (1960). The response of Hevea to fertilizers on a sandy latosol. Journal of the Rubber Research Institute of Malaya 16: 178-190.

Borel, R. and Romero, F. (1991). On-farm research in a silvopastoral project: a case study. Agroforestry Systems 15 (2-3): 245-257.

Botchway, J. (1993). Implications of farming and household strategies for the organisation of a development project. In: De Boef, W., Amanor, K., Wellard, K., and Bebbington, A. (eds.) Cultivating Knowledge: Genetic Diversity, Farmer Experimentation and Crop Research, pp. 27-34. Intermediate Technology Publications, London.

Bovi, M.L.A., Godoy, G., Nagai, V. and Cardoso, M. (1990). Planting density for palmito intercropped among rubber trees. Pesquisa Agropecuaria Brasileira 25 (7): 1023-1029.

BPS (1993). Jambi Dalam Angka. Kerjasama Bappeda dan Kantor Statistik Tingkat I Jambi.

Brook, R.M. (1989). Review of the literature on *Imperata cylindrica* (L.) Raeuschel with particular reference to South East Asia. Tropical Pest Management 35 (1): 12-25.

Broughton, W.J. (1977). Effect of various covers on soil fertility under *Hevea brasiliensis* Muell. Arg. and on the growth of the tree. Agro-Ecosystems 3 : 147-170.

Budiman, A.F.S., Penot, E., de Foresta, H., and Tomich, T. (1994). Integrated rubber agroforestry for the future of smallholder rubber in Indonesia. Paper presented to the National Rubber Conference, IRRI, Medan, Indonesia.

Bueno, N., Haag, H.P., Pereira, J.P. and Viegas, I.J.M. (1988). Mineral nutrition of rubber. IX. Substrate aluminium affecting the development, toxic symptoms and concentration in rubber (*Hevea* sp.). Anais da Escola Superior de Agricultura Luis de Quieroz, University of Sao Paolo 45 (1): 319-339.

Buranatham, W., Chugamnerd, S. and Kongsripun, S. (1997). Agroforestry under rubber plantations in Thailand. Paper presented at the Joint Thailand/Malaysia Technical Seminar on Rubber, 7-9 April, 1997, Phuket, Thailand. 15 pp.

Buttery, B. R. and Westgarth, D.R. (1965). The effect of density of planting on the growth, yield and economic exploitation of *Hevea brasiliensis* . I. The effect on growth and yield. Journal of the Rubber Research Institute of Malaya 19: 62-71.

Buttery, B.R. and Boatman, S.G. (1967). Effects of tapping, wounding and growth regulators on turgour pressure in *Hevea brasiliensis*. Journal of Experimental Botany 18: 644-659.

Byerlee, D., Triomphe, B. and Sebillotte, M. (1991). Integrating agronomic and economic perspectives into the diagnostic stage of on-farm research. Experimental Agriculture 27 (2): 95-114.

Cairns, M. (1994). Stabilisation of upland agroecosystems as a strategy for protection of national park buffer zones: a case study of the coevolution of Minangkabau farming systems and the Kerinci-Seblat National Park. MSc thesis, York University, Ontario, Canada.

Caldwell, M.M. (1987). Competition between plant roots in natural communities. In: Gregory, P.J., Lake, J.V., and Rose, D.A. (eds.) Root Development and Function, pp. 167-185. Cambridge University Press, Cambridge.

Caldwell, M.M. (1994). Exploiting nutrients in fertile microsites. In: Caldwell, M.M. and Pearcy, R.W. (eds.) Exploitation of Environmental Heterogeneity by Plants: Eco-physiological Processes Above- and Belowground, pp. 325-347. Academic Press, London.

Campbell, C.D., Mackie-Dawson, L.A., Reid, E.J., Pratt, S.M., Duff, E.I. and Buckland, S.T. (1994). Manual recording of mini-rhizotron data and its application to study the effect of herbicide and nitrogen fertiliser on tree and pasture root growth in a silvo-pastoral system. Agroforestry Systems 26: 75-87.

Carruthers, I. (1980). A mental construct for unstructured on-farm interviews for use in Rapid Rural Appraisal. Agricultural Administration 8 : 271-278.

Ceulemens, R., Impens, I. and Ng, A.P. (1983). Photosynthesis, stomatal conductance and leaf water potential during water stress situations in young rubber trees *(Hevea brasiliensis)* under tropical conditions. In: Marcelle, R., Clijsters, H. and Poucke, M.V. (eds.) Proceedings of the Conference on Effects of Stress on Photosynthesis. The Hague, Netherlands, pp. 111-119.

Ceulemans, R., Gabriele, R., Impens, I., Yoon, P.K., Leong, W. and Ng, A.P. (1984). Comparative study of photosynthesis in several *Hevea brasiliensis* clones and *Hevea* species under tropical field conditions. Tropical Agriculture 61 (4): 273-275.

Chambers, R., Pacey, A. and Thrupp, L.A. (1989). Farmer First. Intermediate Technology Publications, London. 219 pp.

Chandrasekara, L.B. (1984). Intercropping *Hevea* replantings during the immature period. In: Proceedings of the International Rubber Conference: 75 Years of Rubber Research in Sri Lanka, September 1984, Colombo, pp. 389-393.

Chee, Y.K. (1990). Recent weed management developments in rubber. BIOTROP Special Publication 38 : 189-197.

Chee, Y.K., Lee, S.A., Ahmad, A.I., Teo, L., Chung, G.F. and Khairuddin, H. (1990). Weed management in Malaysian plantations. In: Lee, S.A. and Kon, K.F. (eds.) Proceedings of the Third Tropical Weed Science Conference, Malaysian Plant Protection Society, Kuala Lumpur, Malaysia. pp. 1-21.

Chee, Y.K. (1993a). Editorial. Planters' Bulletin 216: 74.

Chee, Y.K. (1993b). Weed management in rubber. Planters' Bulletin 216:75-79.

Chee, Y.K. (1994). Competitive effects of weeds on young rubber. Proceedings of the Fourth International Conference on Plant Protection in the Tropics, 28-31 March 1994, Kuala Lumpur, Malaysia. pp. 195-197.

Coe, R. (1997). Agroforestry research - from alchemy to science. Agroforestry Today 9 (July-September): 6-9.

Colfer, C.J.P., Gill, D.W. and Agus, F. (1988). An indigenous agricultural model from West Sumatra: a source of scientific insight. Agricultural Systems 26: 191-209.

Colfer, C.J.P., Agus, F., Gill, D.W., Sudjadi, M., Uehara, G. and Wade, M.K. (1989). Two complementary approaches to farmer involvement: an experience from Indonesia. In: Chambers, R., Pacey, A., and Thrupp, L.A. (eds.) Farmer First, pp. 151-155. Intermediate Technology Publications, London.

Cornwall, A., Gujit, I. and Welbourn, A. (1994). Acknowledging process: methodological challenges for agricultural research and extension. In: Scoones, I. and Thompson, J. (eds.) Beyond Farmer First: Rural People's Knowledge, Agricultural Research and Extension Practice, pp. 98-117. Intermediate Technology Publications, London.

Cottrell, A. (1990). Smallholder rubber planters in South Sumatra. PhD, University of Queensland.

Courbet, P., Penot, E. and Ilahang. (in press). Farming systems characterization and innovations adoption process in West Kalimantan. In: Penot, E., Wibawa, G. and Williams, S.E. (eds.), Proceedings of the Smallholder Rubber Agroforestry Project (SRAP) Workshop, 29-30 September 1997, Bogor, Indonesia. ICRAF / CIRAD-TERA/TH.

Crawley, M.J. (1993). GLIM for Ecologists. Blackwell Scientific Publications, Oxford. 329 pp.

Cuevas, E. and Medina, E. (1988). Nutrient dynamics within Amazonian forests II. Fine root growth, nutrient availability and litter decomposition. Oecologia 76: 222-235.

Cuevas, E., Brown, S. and Lugo A.E. (1991). Above- and below-ground organic matter storage and production in a tropical pine plantation and a paired broadleaf secondary forest. Plant and Soil 135: 257-268.

Cui, M.Y. and Caldwell, M.M. (1997). A large ephemeral release of nitrogen upon wetting of dry soil and corresponding root responses in the field. Plant and Soil 191 (2): 291-299.

da Conceicao, H.E.O., Oliva, M.A., Lopes, N.F. and da Rocha-Neto, O.G. (1985). Drought resistance in rubber trees. I. Water balance and primary production in six clones subjected to a water deficit. Pesquisa Agropecuaria Brasileira 20 (9): 1041-1050.

da Conceicao, H.E.O., Oliva, M.A. and Lopes, N.F. (1986). Drought resistance in the rubber tree. II. Growth and assimilate partitioning of six clones subjected to a water deficit. Pesquisa Agropecuaria Brasileira 21 (2): 141-153.

da Cunha, R.L.M., Pinheiro, F.S.V., and Viegas, R.M.F. (1989). Rubber and black pepper intercropping. Boletim da Faculdade de Ciencias Agrarias de Para 18(8): 27-51.

de Castro, F. A. (1979). Silvicultural management of natural rubber stands in the Aito Purus region, State of Acre, Brazil. Acta Amazonica 9:(4): 629-632.

de Filho, A V., Alvim, R., de Araujo, A.C. (1988). Cocoa planting in mature rubber groves in southern Bahia. Proceedings of the Tenth International Cocoa Research Conference, Santo Domingo, Dominican Republic, 17-23 May, 1987, pp. 33-38.

de Foresta, H. and Michon, G. (1992). Complex agroforestry systems and conservation of biological diversity (II). In: Kheong, Y.S. and Win, L.S. (eds.), Harmony with Nature: an International Conference on the Conservation of Biological Diversity, Kuala Lumpur, Malaysia The Malayan Nature Journal (Golden Jubilee issue), pp. 488-500.

de Foresta, H. and Michon, G. (1996). Tree improvement research for agroforestry: a note of caution. Agroforestry Forum 7(3): 8-10.

de Foresta, H. (in press). Smallholder rubber plantations as viewed through the eyes of a forest ecologist. In: Penot, E., Wibawa, G. and Williams, S.E. (eds.), Proceedings of the Smallholder Rubber Agroforestry Project (SRAP) Workshop, 29-30 September, 1997, Bogor, Indonesia. ICRAF/CIRAD-TERA/TH.

de Montard, F.X., Rapey, H., Delpy, R., and Massey, P. (1999). Competition for light, water and nitrogen in an association of hazel *(Corylus avellana L.)* and cocksfoot *(Dactylis glomerata L.)*. Agroforestry Systems 43: 135-150.

Delabarre, M.A. and Benigno, D.A. (1994). Rubber: A Pictorial Technical Guide for Smallholders. CIRAD, Département des Cultures Pérennes, Montpellier, France. 171 pp.

Denslow, J.S., Newell, E. and Ellison, A.M. (1991). The effect of understory palms and cyclanths on the growth and survival of *Inga* seedlings. Biotropica 23 (3): 225-234.

Dewees, P.A. and Saxena, N.C. (1995). Tree planting and household land and labour allocation: case studies from Kenya and India. In: Arnold, J.E.M. and Dewees, P.A. (eds.) Tree Management in Farmer Strategies: Responses to Agricultural Intensification, pp. 242-262. Oxford University Press, Oxford.

Dijkman, M.J. (1951). Hevea. Thirty years of research in the Far East. University of Miami Press, Coral Gables, Florida. 329 pp.

Dissanayake, S.N. and Waidyanatha, U.P. (1987). The performance of some tropical forage grasses interplanted with young *Hevea* trees and their effect on the growth of the rubber. Tropical Agriculture 64 (2): 119-121.

Dove, M.R. (1993). Smallholder rubber and swidden agriculture in Borneo: a sustainable adaption to the ecology and economy of the tropical forest. Economic Botany 47 (2): 136-147.

Dove, M.R. (1994). Transition from native forest rubbers to *Hevea brasiliensis* (Euphorbiaceae) among tribal smallholders in Borneo. Economic Botany 48 (4): 328-396.

Drew, M.C. and Saker, L.R. (1975). Nutrient supply and the growth of the seminal root system in barley. II. Localised compensatory increases in lateral root growth and rates of nitrate uptake when nitrate supply is restricted to only part of the root system. Journal of Experimental Botany 26 : 79-90.

Drew, M.C. and Saker, L.R. (1978). Nutrient supply and the growth of the seminal root system in barley. III. Compensatory increases in growth of lateral roots, and in rates of phosphate uptake when nitrate supply in response to a localised supply of phosphate. Journal of Experimental Botany 29 : 435-451.

Drew, M.C. (1987). Function of root tissues in nutrient and water transport. In: Gregory, P.J., Lake, J.V., and Rose, D.A. (eds.) Root Development and Function, pp. 71-101. Cambridge University Press, Cambridge.

Duckett, J.E. (1985). Notes on *Asystasia*. Planter 61: 226-229.

Dupraz, C. (1999). Adequate design of control treatments in long-term agroforestry experiments. Agroforestry Systems 43 : 35-48.

Edwards, D.G., Sharifuddin, H.A.H., Mohd, Y.M.N., Grundon, N.J., Shamshuddin, J., Norhayati, M. and Yusoff, N.M.N. (1991). The management of soil acidity for sustainable crop production. In: Wright, R.J., Baligar, V.C. and Murrman, R.P.(eds.), Proceedings of the Second International Symposium on Plant-Soil Interactions at Low pH, 24-29 June, 1990, Beckley, West Virginia, USA. Developments in Plant and Soil Sciences, Vol. 45, pp. 383-396. Kluwer Academic Publishers, Dordrecht.

Enjalric, F., Ngeuma, J. and Hugot, N. (1997). Rubber trees (*Hevea brasiliensis*) intercropped with food plants: evaluation of interactions between plants in the cropping system. Part 1: Food crops and water parameters. Paper presented at STD III Meeting in Sembawa Rubber Research Institute, 8-9 July 1997, Palembang, Indonesia. 13 pp.

Erwiyono, R. and Soekodarmodjo, S. (1989). Sifat fisik latosol di bawah *Calopogonium caeruleum* yang mempengaruhi perkembangan akar karet [Physical properties of latosols under *Calopogonium caeruleum* which affect the development of rubber roots]. Menara Perkebunan 57 (3): 79-82.

Fabiao, A., Persson, H.A. and Steen, E. (1985). Growth dynamics of superficial roots in Portuguese plantations of *Eucalyptus globulus* Labill. studied with a mesh bag technique. Plant and Soil 83: 233-242.

Fadiga, S. and Akpagni, K. (1983). The problem of *Eupatorium odoratum* in village rubber plantations in Ivory Coast. In: Deat, M. and Mamotte, P. (eds.), Proceedings of the The Second Biannual Conference, West African Weed Science Society, Abidjan, Ivory Coast.

Farrington, J. and Martin, A. (1988). Farmer participation in agricultural research: a review of concepts and practices. Overseas Development Institute, London, UK. 79 pp.

Fitter, A.H. (1994). Architecture and biomass allocation as components of the plastic response of root systems to soil heterogeneity. In: Caldwell, M.M. and Pearcy, R.W. (eds.) Exploitation of Environmental Heterogeneity by Plants: Eco-physiological Processes Above- and Belowground, pp. 305-323. Academic Press, London.

GAPKINDO (1997). Natural Rubber from Indonesia. Promotional brochure. 20 pp.

Garrity, D.P. (1996). Tree-soil-crop interactions on slopes. In: Ong, C.K. and Huxley, P. (eds.) Tree-Crop Interactions: A Physiological Approach. CAB International, Wallingford, UK. pp. 299-318.

Gauthier, R. (1996a). Jambi field trip report on pest damage in RAS and jungle rubber systems.

Gauthier, R. (1996b). Wildlife and farming communities in North Lampung: the interactions between vertebrate pests, farming systems and household livelihood, with implications for governmental programs. Internal ICRAF report. ICRAF-S.E.Asia, Bogor, Indonesia.

Gerhardt, K. and Fredriksson, D. (1995). Biomass allocation by broad-leaf mahogany seedlings, *Switenia macrophylla* (King), in abandoned pasture and secondary dry forest in Guanacaste, Costa Rica. Biotropica 27 (2): 174-182.

Gintings, A.N. *et al.* (1995). Agroforestry characterization in Pelepat sub district Bungo Tebo, Jambi Province. Paper presented at a Regional Workshop on Alternatives to Slash and Burn, 6-9 June 1995, Bogor, Indonesia.

Gockowski, J.J. and Drury, S. (1999). The economics of cocoa-fruit agroforests in Cameroon. In: Jimenez, J. and Beer, J. (eds), Proceedings of the International Symposium on Multistrata Agroforestry Systems with Perennial Crops, held at CATIE, Turrialba, Costa Rica, February 22-27, 1999. pp. 239-241.

Goldberg, D.E. and Werner, P.A. (1983). Equivalence of competitors in plant communities: a null hypothesis and a field experiment approach. American Journal of Botany 70: 1098-1104.

Gomez, J.B. and Chen, K.T. (1967). Alignment of anatomical elements in the stem of *Hevea brasiliensis.* Journal of the Rubber Research Institute of Malaya 20: 91-99.

Gomez, J.B., Narayanan, R. and Chen, K.T (1972). Some structural factors affecting the productivity of *Hevea brasiliensis.* I. Quantitative determination of the lactiferous tissue. Journal of the Rubber Research Institute of Malaya 23: 193-203.

Gomez, J.B. (1977). Demonstration of latex coagulants in bark extracts of Hevea, and their possible role in latex flow. Journal of the Rubber Research Institute of Malaysia 25: 109-119.

Gomez, J.B. (1983). Physiology of latex (rubber) production. Malaysian Rubber Research and Development Board Monograph No.8.

Gomez, K.A. and Gomez, A.A. (1984). Statistical Procedures for Agricultural Research. John Wiley and Sons, New York. 680 pp.

Gouyon, A. and Nancy, C. (1989). Increasing the productivity of rubber smallholders in Indonesia: a study of agro-economic constraints and proposals. In: Proceedings of the RRIM Rubber Grower's Conference, 21-23 August, 1989, Malacca, Malaysia, pp. 587-613. Rubber Research Institute of Malaysia.

Gouyon, A., De Foresta, H. and Levang, P. (1993). Does 'jungle rubber' deserve its name? An analysis of rubber agroforestry systems in southeast Sumatra. Agroforestry Systems 22 : 181-206.

Gouyon, A. (1995). Paysannerie et heveaculture: dans les plaines orientales de Sumatra: quel avenir pour les systemes agroforestiers? PhD thesis, INA-PG, Paris.

Gouyon, A. (1999). The Sustainable Development of Tree Crops and the Prevention of Vegetation Fires in South Sumatra, Indonesia: Jungle Rubber. Forest Fire Prevention and Control Project Report, EU/Ministry of Forestry and Estate Crops, Palembang, Indonesia. 61 pp.

Gregory, P.J. (1987). Development and growth of root systems in plant communities. In: Gregory, P.J., Lake, J.V., and Rose, D.A. (eds.) Root Development and Function, pp. 147-166. Cambridge University Press, Cambridge.

Grime, J.P. (1979). Plant Strategies and Vegetation Processes. John Wiley and Sons Ltd, Chichester, UK. 222 pp.

Grime, J.P. (1994). The role of plasticity in exploiting environmental heterogeneity. In: Caldwell, M.M. and Pearcy, R.W. (eds.) Exploitation of Environmental Heterogeneity by Plants: Eco-physiological Processes Above- and Belowground, pp. 1-19. Academic Press, London.

Grist, P. and Menz, K. (1995). Modelling the economics of *Imperata* control in smallholder rubber plantations. Imperata Project Paper 1995/5. Centre for Resource and Environmental Studies, The Australian National University, Canberra.

Grist, P., Menz, K. and Thomas, T.H. (1995). A modified version of the BEAM rubber agroforestry model: smallholders in Indonesia. Imperata Project Paper 1995/3. Centre for Resource and Environmental Studies, The Australian National University, Canberra.

Hadi, P.U., Manurung, V.T. and Purnama, B.M. (1995). Socio-economic characteristics of slash and burn agriculture at the community level in three ecological zones of Sumatra, Indonesia. Paper presented at a Regional Workshop on Alternatives to Slash and Burn, 6-9 June 1995, Bogor, Indonesia.

Haines, W.B. (1934). The uses and control of natural undergrowth on rubber estates. Planting Manual No.6, Rubber Research Institute of Malaya, Kuala Lumpur. 39 pp.

Hairiah, K., van Noordwijk, M. and Setijono, S. (1991). Tolerance to acid soil conditions of the velvet beans *Mucuna pruriens* var. utilis and *M. deeringiana*. I. Root development. Plant and Soil 134: 95-105.

Halle, F. and Martin, R. (1968). Study of the growth rhythm in *Hevea brasiliensis* (Euphorbiaceae Crotonoideae). Adansonia 8 (4): 475-403.

Harper, J.L. (1977). Population Biology of Plants. Academic Press, London, UK. 892 pp.

Hitanyake, H.M.G.S.B. (1996). Farmers' Knowledge and the Development of Complex Agroforestry Practices in Sri Lanka. PhD thesis, University of Wales, Bangor. 275 pp.

Hunt, R. (1990). Basic Growth Analysis: Plant Growth Analysis for Beginners. Unwin Hyman Ltd., London. 112 pp.

Huxley, P. (1999). Tropical Agroforestry. Blackwell Science, Oxford. 371 pp.

Jackson, R.B. and Caldwell, M.M. (1996). Integrating resource heterogeneity and plant plasticity: modelling nitrate and phosphate uptake in a patchy soil environment. Journal of Ecology 84 : 891-903.

Jayasinghe, C.K. (1991). The role of leguminous cover crops in soil improvement with special reference to the nitrogen economy of tropical rubber soils. Bulletin of the Rubber Research Institute of Sri Lanka 28 : 23-26.

Jayasuriya, S., Barlow, C. and Shand, R.T. (1991). Farmers' long-term investment decisions: a study of Sri Lankan rubber smallholders. Journal of Development Studies 18 : 47-67.

Joseph, T., Punnoose, K.I., Haridasan, V., Mathew, M. and Mani, J. (1988). A survey of the agro-economic conditions of the small rubber growers in Anakkara village of Idukki District. Rubber Board Bulletin 24 (1): 12-15.

Junaidi, U., Amypalupy, K., Tambunan, D., Hendratno, S. and Suwardin, D. (1996). Sapta Bina Usahatani Karet Rakyat. [Smallholder Rubber Planting Manual.] Indonesian Rubber Research Institute, Sembawa Research Station. 147 pp.

Kelfoun, A., Penot, E. and Komardiwan, I. (in press). Farming systems characterization and innovations adoption process in Jambi. In: Penot, E., Wibawa, G. and Williams, S.E. (eds.), Proceedings of the Smallholder Rubber Agroforestry Project (SRAP) Workshop, 29-30 September 1997, Bogor, Indonesia. ICRAF / CIRAD-TERA/TH.

Keli, J.Z., Omont, H. and Hainnaux, G. (1990). L'association temporaire heveas vivriers dans le sud de la Cote d'Ivoire. [The temporary association of rubber and food crops in south Cote d'Ivoire.] Revue Generale des Caoutchoucs et Plastiques 701(22): 181-187.

Ketterings, Q.M., Wibowo, T.T., Penot, E. and van Noordwijk, M. (1999). Farmers' perspectives on slash-and-burn as a land clearing method for small-scale rubber producers in Sepunggur, Jambi Province, Sumatra, Indonesia. Forest Ecology and Management 120 (1-3): 157-169.

Kheowvongsri, P. (1990). Les jardins a Heveas des contreforts orientaux de Bukit Barisan, Sumatra, Indonesie. Diploma in Applied Tropical Biology, University of Montpellier, France.

Komardiwan, I. and Penot, E. (in press). IGPM (Improved Genetic Planting Material) availability and use in Jambi Province. In: Penot, E., Wibawa, G. and Williams, S.E. (eds.), Proceedings of the Smallholder Rubber Agroforestry Project (SRAP) Workshop, 27-29 September, 1997, Bogor, Indonesia. ICRAF/CIRAD-TERA/TH.

Kumar, A.K.K. and Nair, P.M.M.K. (1997). Transfer of technology - Indian experience. Paper presented at the ANRPC Seminar on Modemising the Rubber Smallholding Sector, 8-10 July, 1997, Padang, Indonesia.

Lake, J.V. (1987). Interactions in the physical environment of plant roots. In: Gregory, P.J., Lake, J.V., and Rose, D.A. (eds.) Root Development and Function, pp. ix-xiii. Cambridge University Press, Cambridge.

Landon, J.R. (1991). Booker Tropical Soil Manual: a Handbook for Soil Survey and Agricultural Land Evaluation in the Tropics and Sub-Tropics. Longman Scientific and Technical, Harlow, Essex. 474 pp.

Laosuwan, P., Sripana, P., Sirisongkram, P., and Tongsomri, A. (1987). Potential of food legumes as intercrops with young rubber. In: Wallis, E.S., and Blythe, D.E.J. (eds.), Food Legume Improvement for Asian Farming Systems. Australian Centre for Agricultural Research, Canberra. p. 240.

Laosuwan, P., Sripana, P. and Thongsomsri, A. (1988a). Research on mungbean as an intercrop with young rubber and as a sequential crop with rice. In: Shanmugasundaram, S., and McLean, B.T. (eds.), Proceedings of the Second International Symposium on Mungbean, Bangkok, Thailand, 16-20 November, 1987. AVRDC Publication No. 88-304, pp. 392-397.

Laosuwan, P., Yeedum, I., Sripana, P. and Sirisonkram, P. (1988b). A study of intercropping of young rubber I. Yield potential of different intercrops. Thai Journal of Agricultural Science 21(3): 179-188.

Laumonier, Y. and Djailany-Syafi, U.R. (1989). An evaluation of SPOT satellite data for forestry in Sumatra. Biotropia 3: 1-24.

Levang, P. and de Foresta, H. (1991). Economic Plants of Indonesia: A Latin, Indonesian, French and English Dictionary of 728 Species. ORSTOM / SEAMEO-BIOTROP. 180 pp.

Levang, P. (1996). From rags to riches in Sumatra: how peasants shifted from food self-sufficiency to market-oriented tree crops in six years. Bulletin of Concerned Asian Scholars 29 (2): 18-30.

M'Boob, S.S. (1991). Preliminary results of a survey and assessment of *Chromolaena odorata (Siam weed)* in Africa. BIOTROP Special Publication 44 : 51-55.

Mackie-Dawson, L.A. and Atkinson, D. (1991). Methodology for the study of roots in field experiments, and the interpretation of results. In: Atkinson, D. (ed.), Plant Root Growth: an Ecological Perspective, Blackwell Scientific Publications, Oxford, UK. pp. 25-47.

Mahmud, Z.B.H. (1986). The manner and mode of technology transfer in the rubber smallholding sector of Malaysia. Geographica (Malaysia) 15 : 43-53.

Mainstone, B.J. (1963). Residual effects of ground cover and of continuity of nitrogen fertilizer treatments, applied prior to tapping on the yield and growth of *Hevea brasiliensis.* Empire Journal of Experimental Agriculture 31: 213-225.

Mainstone, B.J. (1969). Residual effects of ground cover and nitrogen fertilization of *Hevea* prior to tapping. Journal of the Rubber Research Institute of Malaya 21: 113-125.

Mainstone, B.J. (1970). Planting density – early effects on growth pattern of *Hevea brasiliensis*. Journal of the Rubber Research Institute of Malaya 23: 56-67.

Mangoensoekarjo, S., Tjitrosemito, S., Nurdin and Siswanto. (1987). Reclamation of an *Imperata* field into a plantation based agroproduction system. In: Proceedings of the 11th Asian Pacific Weed Science Society Conference, Medan, Indonesia, pp. 485-496. Asian Pacific Weed Science Society.

Manurung, G.E.S. (in press). Rubber fertilisation trial (RAS 1.3), in an 'RAS-1' environment. In: Penot, E., Wibawa, G. and Williams, S.E. (eds.), Proceedings of the Smallholder Rubber Agroforestry Project (SRAP) Workshop, 27-29 September, 1997, Bogor, Indonesia. ICRAF/CIRAD-TERA/TH.

Marattukalam, J.G. and Saraswathyamma, C.K. (1992). Propagation and planting. In: Sethuraj, M.R. and Mathew, N.M. (eds.), Natural Rubber: Biology, Cultivation and Technology. Elsevier, New York. pp. 164-199.

Marschner, H. (1995). Mineral Nutrition of Higher Plants. Academic Press Ltd, London. 889 pp.

McGee, R. (1997). Ethnography and rapid appraisal in doctoral research on poverty. PLA Notes 28 (February 1997): 55-58.

McNetting, R.C. (1993). Smallholders, Householders: Farm Families and the Ecology of Intensive, Sustainable Agriculture. Stanford University Press, Stanford, USA. 388 pp.

Mead, R., Curnow, R.N. and Hasted, A.M. (1993). Statistical Methods in Agriculture and Experimental Biology. Chapman and Hall, London. 415 pp.

Menz, K. and Wibawa, G. (1995). Economic aspects of *Imperata* control in rubber smallholdings in Indonesia. Imperata Project Paper 1995/2, Centre for Resource and Environmental Studies, The Australian National University, Canberra. 13 pp.

Merrill-Sands, D.M., Biggs, S.D., Bingen, R.J., Ewell, P.T., McAllister, J.L. and Poats, S.V. (1991). Institutional considerations in strengthening on-farm client-oriented research in national agricultural research systems: lessons from a nine country study. Experimental Agriculture 27 (4): 343-373.

Michon, G., Mary, F., and Bompard, J. (1986). Multistoried agroforestry garden system in W. Sumatra, Indonesia. Agroforestry Systems 4: 315-338.

Michon, G. and de Foresta, H. (1996). Agroforests: an original agroforestry model from smallholder farmers for environmental conservation and sustainable development. In: Ishizuka, K., Hisajima, S. and Macer, D.R.J. (eds.), Traditional Technology for Environmental Conservation and Sustainable Development, University of Tsukuba, Japan, pp. 52-58.

Michon, G. and de Foresta, H. (1997). Agroforests: pre-domestication of forest trees or true domestication of forest ecosystems? Netherlands Journal of Agricultural Science 45 (4): 451-462.

Monteith, J.L. (1997). Agroforestry modelling: a view from the touchline. Agroforestry Forum 8 (2): 52-54.

Nair, P.K.R. (ed). (1989). Agroforestry Systems in the Tropics. Kluwer, London. 664 pp.

Norman, D. (1994). The research-research interface. In: Douwe Meindertsma, J. (ed.) Setting Research Priorities: Towards Effective Farmer-Oriented Research, pp. 32-46. Royal Tropical Institute, Amsterdam.

Ong, C.K., Corlett, J.E., Singh, R.P. and Black, C.R. (1991). Above and below-ground interactions in agroforestry systems. Forest Ecology and Management 45: 45-57.

Ong, C.K. (1994). Alley cropping: ecological pie in the sky? Agroforestry Today 6 (3): 8-10.

Ong, C.K. (1996). A framework for quantifying the various effects of tree-crop interactions. In: Ong, C.K. and Huxley, P. (eds), Tree-Crop Interactions: a Physiological Approach, CAB International, Wallingford, UK. pp. 1-24.

Ong, C.K., Deans, J.D., Wilson, J., Mutua, J., Khan, A.A.H. and Lawson, E.M. (1999). Exploring below ground complementarity in agroforestry using sap flow and root fractal techniques. Agroforestry Systems 44 : 87-103.

Onuwaje, O.V. (1983). Yield reponse of rubber *(Hevea brasiliensis)* to fertilizers on an Ultisol in Nigeria. Fertilizer Research 4 (4): 357-360.

Paardekooper, E.C. and Newall, W. (1977). Considerations of density in Hevea plantations. Planter 53: 143-156.

Paardekooper, E.C. (1989). Exploitation of the rubber tree. In: Webster, C.C. and Baulkwill, W.J. (eds.), Rubber. Longman Scientific and Technical, Harlow, UK. pp. 125-164.

Pamplona, P. P. (1987). Rubber intercropping for smallholders. PCARRD Monitor, (Philippine Council for Agriculture, Forestry, and Natural Resources Research and Development) 15(9):8-9.

Penot, E. (1994). The non-project rubber smallholder sector in Indonesia: rubber agroforestry systems (RAS) as a challenge for the improvement of rubber productivity, rubber-based systems sustainability, biodiversity and environment. Working paper presented at the 1994 ICRAF annual seminar. ICRAF, 18 pp.

Penot, E. and Aswar, R. (1994). Rubber Clones Index in Indonesia. CIRAD-CP / Rubber Research Institute of Sembawa, Palembang. 401 pp.

Penot, E., de Foresta, H. and Garrity, D. (1994). Rubber Agroforestry Systems (RAS): Methodology For On-Farm Experimentation. Internal ICRAF document. ICRAF SE-Asia, Bogor, Indonesia.

Penot, E. (1995). Taking the 'jungle' out of the rubber: improving rubber in Indonesian agroforestry systems. Agroforestry Today, July- December 1995, pp. 11-13.

Penot, E. (1997a). From shifting agriculture to sustainable rubber complex agroforestry systems (jungle rubber) in Indonesia: a history of innovations production and adoption process. Paper presented at the ICRAF/Cornell University Workshop on Indigenous Strategies for Intensification of Shifting Cultivation in S.E. Asia, June 1997, Bogor, Indonesia.

Penot, E. (1997b). Which improved planting material for rubber agroforestry systems in Indonesia? Internal SRAP document, ICRAF S.E. Asia, Bogor, Indonesia. 11 pp.

Penot, E., Wibawa, G. and Komardiwan, I. (1998). Rubber Planting Material: Availability and Production in Jambi Province. Report of a study conducted for the World Bank Jambi Regional Development Project (JRDP), March 1998. 55 pp.

Penot, E. (1999). Prospects for conservation of biodiversity within productive rubber agroforests. In: Sist, P., Sabogal, C., and Byron, Y. (eds.), Proceedings of the International Workshop on Management of Secondary and Logged-Over Forests in Indonesia, 17-19 November 1997, Bogor, Indonesia, pp. 21-32. CIFOR.

Penot, E. (in press). Introduction to SRAP methodology and RAS concepts: summary of the preliminary results. In: Penot, E., Wibawa, G. and Williams, S.E. (eds.), Proceedings of the Smallholder Rubber Agroforestry Project (SRAP) Workshop, 29-30 September 1997, Bogor, Indonesia. ICRAF / CIRAD-TERA/TH.

Penot, E., Sunario, Akiefnawati, R. & Ilahang. (in press). Main agronomic results of RAS on-farm experimentation network in West Kalimantan. In: Penot, E., Wibawa, G. and Williams S.E. (eds.), Proceedings of the Smallholder Rubber Agroforestry Project Workshop, Bogor, 29-30 September 1997.

Pereira, A.V. and Pereira, E.B.C. (1987). Growth responses of rubber rootstocks to liming. Revista Brasileira de Ciencia do Solo 11 (3): 333-336.

Potash and Phosphate Institute (PPI). (1995). International Soil Fertility Manual. PPI, Norcross, USA. 117 pp.

Preechapanya, P. (1996). Indigenous Knowledge about the Sustainability of Tea Gardens in the Hill-Evergreen Forest of Northern Thailand. PhD thesis, University of Wales, Bangor. 286 pp.

Preisinger, H., Coelho, L.F., Siqueira, M.D. and Lieberei, R. (1994). Analysis of growth form types and floristic composition of the spontaneous vegetation in an agricultural test area near Manaus, Amazonas, Brazil. Angewandte Botanik 68 : 40-46.

Premakumari, D., Sherief, P.M. and Sethuraj, M.R. (1980). Lutoid stability and rubber particle stability as factors influencing yield during drought in rubber. Journal of Plantation Crops 8: 43-47.

Pretty, J.N. (1994). Alternative systems of inquiry for a sustainable agriculture. IDS Bulletin 25 (2): 37-50.

Pushparajah, E. and Chellapah, K. (1969). Manuring of rubber in relation to covers. Journal of the Rubber Research Institute of Malaya 21 (2): 126-142.

Pushparajah, E. and Tan, K.T. (1972). Factors affecting leaf nutrient levels in rubber. Paper presented at the Rubber Research Institute of Malaysia's Planters' Conference, Kuala Lumpur, 1972. pp. 140-154.

Pushparajah, E. (1983). Manuring of rubber (*Hevea*): current global practices and future trends. In: Proceedings of the Symposium of the International Rubber Research and Development Board, 12-14 May, 1983, Beijing. IRRDB.

Pushparajah, E. (1995). RRIM's achievements in production research and development from 1925 to 1995. Planter 71 (837): 571-587.

Putz, F.E. and Canham, C.D. (1992). Mechanisms of arrested succession in shrublands: root and shoot competition between shrubs and tree seedlings. Journal of Forest Ecology and Management 49: 267-275.

Rachman, A., Subagjo, H., Sukmana, S., Haryogyo, Kartiwa, B., Muti, A. and Sutrisno, U. (1997). Soil and agroclimatic characterization for determining alternatives to slash-and-burn. Paper presented at a Regional Workshop on Alternatives to Slash and Burn, 6-9 June, 1995, Bogor, Indonesia.

Rai, S.N. (1976). Eupatorium and weedicides. Indian Forester 102 (7): 449-454.

Raich, J.W., Riley, R.H. and Vitousek, P.M. (1994). Use of root ingrowth cores to assess nutrient limitations in forest ecosystems. Canadian Journal of Forest Research 24: 2135-2138.

Rajasekharan, P. (1989). Pineapple intercropping in the first three years of rubber planting in smallholdings: an economic analysis. Indian Journal of Natural Rubber Research 2(2): 118-124.

Rajasekharan, P. (1990). An economic study of cover crops in rubber smallholdings. Rubber Board Bulletin 25(3): 21-24.

Reis, E.L. and Cabala-Rosand, P. (1988). Eficiencia dos fertilizantes aplicados nas fases pre e pos sangria de seringueira. [Efficiency of fertilizer application during pre-and post-tapping phases of rubber.]. Revista Theobroma 18 (3): 189-200.

Richards, P. (1985). Indigenous Agricultural Revolution: Ecology and Food Production in West Africa. Hutchison & Co., London. 162 pp.

Richards, P. (1989). Agriculture as a performance. In: Chambers, R., Pacey, A., and Thrupp, L.A. (eds.) Farmer First, pp. 39-42. Intermediate Technology Publications, London.

Riegel, G.M., Miller, R.F. and Krueger, W.C. (1992). Competition for resources between understory vegetation and overstory *Pinus ponderosa* in Northeastern Oregon. Ecological Applications 21 (1): 71-85.

Rodrigo, V.H.L., Stirling, C.M., Teklehaimanot, Z. and Nugawela, A. (1997). The effect of planting density on growth and development of component crops in rubber / banana intercropping systems. Field Crops Research 52: 95-108.

Rosalina-Wasrin, U. *et al.* (1995). Vegetation characterization and monitoring: its contribution to alternatives to slash and burn practices. Paper presented at a Regional Workshop on Alternatives to Slash and Burn, 6-9 June 1995, Bogor, Indonesia.

Rowe, E.C., Hairiah, K., Giller, K.E., van Noordwijk, M. and Cadisch, G. (1999). Testing the safety-net role of hedgerow tree roots by ^{15}N placement at different soil depths. Agroforestry Systems 43 : 81-93.

RRIM (1993a). Control of noxious weeds. Annual Report of the Rubber Research Institute of Malaysia. p.36.

RRIM (1993b). Effects of weed species on the growth of young rubber. Annual Report of the Rubber Research Institute of Malaysia. p.27.

Rubber Research Institute of Malaya (1958). Rooting habit. Planters' Bulletin of the Rubber Research Institute of Malaya 39:120-128.

Said, I.B. (1997). Path of rubber technology flow from research to smallholders. Paper presented at the ANRPC Seminar on Modernising the Rubber Smallholding Sector, 8-10 July, 1997, Padang, Indonesia.

Samarappuli, L., Yogaratnam, N., Karunadasa, P. and Mitrasena, U. (1996). Root development in *Hevea brasiliensis* in relation to management practices. Journal of the Rubber Research Institute of Sri Lanka 77: 93-111.

Samaraweera, M.K.S.A. (1984). The effect of major nutrients on the physiology of latex production. Paper presented at the International Rubber Conference, on 75 Years of Rubber Research In Sri Lanka; September 1984, Colombo.

Samsuddin, Z., Khir, M. and Impens I. (1978). Development of the leaf blade class concept for the characterisation of *Hevea brasiliensis* leaf age. Journal of the Rubber Research Institute of Malaysia 26: 1-5.

Schroth, G. (1995). Tree root characteristics as criteria for species selection and systems design in agroforestry. Agroforestry Systems 30: 125-144.

Schroth, G. (1999). A review of belowground interactions in agroforestry, focussing on mechanisms and management options. Agroforestry Systems 44 : 4-34.

Schueller, W., Penot, E. and Sunaryo. (in press). Rubber Improved Genetic Planting Material (IGPM) availability and use by smallholders in West Kalimantan. In: Penot, E., Wibawa, G. and Williams, S.E. (eds.), Proceedings of the Smallholder Rubber Agroforestry Project (SRAP) Workshop, 29-30 September 1997, Bogor, Indonesia. ICRAF / CIRAD-TERA/TH.

Seegers, S., Douwe Meindertsma, J. and Stoop, W. (1994). Setting research priorities in FSR&D programmes. In: Douwe Meindertsma, J. (ed.) Setting Research Priorities: Towards Effective Farmer-Oriented Research, pp. 15-31. Royal Tropical Institute, Amsterdam.

Sepien, A. bin (1980). Economics of high planting density on rubber smallholdings. Proceedings of the Rubber Research Institute of Malaysia Planters' Conference, Kuala Lumpur, 1979, pp. 82-92.

Sethuraj, M.R. (1985). Physiology of growth and yield in *Hevea brasiliensis*. Paper presented at the International Rubber Conference, Kuala Lumpur, 1985, 16 pp.

Sethuraj, M.R. (1992). Yield components in *Hevea brasiliensis*. In: Sethuraj, M.R. and Mathew, N.M. (eds.), Natural Rubber: Biology, Cultivation and Technology. Elsevier, New York. pp. 138-163.

Shaban, H.A.M.U. (1986). A new outlook for Malaysian smallholders in the light of the problems faced by rubber as the main crop. In: Osman, A.H. and Tan, G.S. (eds.) Proceedings of the ANRPC Seminar on the Progress and Development of Rubber Smallholders, 22-26 August, 1986, Palembang, Indonesia, pp. 131-140. ANRPC, Kuala Lumpur, Malaysia.

Shepherd, K., Swinkels, R. and Jama, B. (1994). A question of management: the pros and cons of farmer- and researcher-managed trials. Agroforestry Today 6 (4): 3-7.

Shepherd, K., Ndufa, J.K., Ohlsson, E., Sjogrens, H. and Swinkels, R. (1997). Adoption potential of hedgerow intercropping in maize-based cropping systems in the highlands of western Kenya. 1. Background and economic evaluation. Experimental Agriculture 33 : 197-209.

Shorrocks, V.M. (1965). Leaf analysis as a guide to the nutrition of *Hevea brasiliensis*. VI. Variation in the leaf nutrient composition with age of leaf and with time. Journal of the Rubber Research Institute of Malaya 19: 1-8.

Siagian, N. and Sumarmadji. (1989). Rumput makanan ternak sebagai alternatif penutup tanah pada tanaman karet yang muda. [Forage grasses as alternative cover crops for young rubber.] Bulletin Perkaretan 7 (3): 75-79.

Siagian, N. and Sunarwidi (1990). Peningkatan efisiensi melalui minimisasi pemeliharaan sepanjang jalur tanaman karet. [Increasing efficiency by minimising planting strip maintenance in rubber trees.] Buletin Perkaretan 8 (3): 73-76.

Sivadasan, C.R., and Nair, C.K. (1987). Rubber-cardamom intercropping. Rubber Board Bulletin 24(4): 21-22.

Simmonds, N.W. (1982). Some ideas on botanical research on rubber. Tropical Agriculture (Trinidad) 59: 2-8.

Simmonds, N.W. (1989). Rubber breeding. In: Webster, C.C. and Baulkwill, W.J. (eds.), Rubber. Longman Scientific and Technical, Harlow, UK. pp. 85-124.

Sinulingga, W., Tjitrosomo, H.S.S., Pawirosoemardjo, S. and Rumawas, F. (1989). Pengaruh beberapa penutup tanah terhadap intensitas dan viabilitas *Rigidoporus lignosus* pada tanaman karet. [Effect of several cover crops on the intensity and viabiliy of *Rigidoporus lignosus* on rubber trees.] Buletin Perkaretan 7 (1): 6-12.

Soong, N.K. (1976). Feeder root development of *Hevea brasiliensis* in relation to clones and environment. Journal of the Rubber Research Institute of Malaysia 24(5): 283-298.

Soong, N.K. and Yap, W.C. (1976). Effect of cover management on physical properties of rubber growing soils. Journal of the Rubber Research Institute of Malaysia 24: 145-159.

Southern, A. (1994). Acquisition of Indigenous Ecological Knowledge about Forest Gardens in Kandy District, Sri Lanka. MPhil thesis, University of Wales, Bangor. 152 pp.

Southorn, W.A. and Gomez, J.B. (1970). Latex flow studies. VII. Influence of length of tapping cut on latex flow pattern. Journal of the Rubber Research Institute of Malaya 23: 15-22.

Spek, L.Y. and van Noordwijk, M. (1994). Proximal root diameter as predictor of total root size for fractal branching models. II. Numerical model. Plant and Soil 164 : 119-127.

Sreenivasan, K.G., Ipe, C.V., Haridasan, V., and Mathew, M. (1987). Economics of intercropping in the first three years among newly replanted rubber. Rubber Board Bulletin 23(1): 13-17.

Statistical Services Centre. (1998). On-Farm Trials - Some Biometrical Guidelines. SSC Guidelines Series. The University of Reading, Reading. 13 pp.

Steen, E. (1984). Variation of root growth in a grass ley studied with a mesh bag technique. Swedish Journal of Agricultural Research 14: 93-97.

Steen, E. (1991). Usefulness of the mesh bag method in quantitative root studies. In: Atkinson, D. (ed.), Plant Root Growth: an Ecological Perspective, Blackwell Scientific Publications, Oxford, UK, pp. 75-85.

Stolle, F., Tomich, T.P., Chomitz, K.M. and Rosalina-Wasrin, U. (in press). Land-use changes in Sumatra. In: Penot, E., Wibawa, G. and Williams, S.E. (eds.), Proceedings of the Smallholder Rubber Agroforestry Project (SRAP) Workshop, 27-29 September, 1997, Bogor, Indonesia. ICRAF/CIRAD-TERA/TH.

Sumarmadji, Sunarwidi, Koswara, J. and Ismal, G. (1989). Adaptasi dua jenis kapolaga dan pengaruh pemberian bahan organik pada berberapa tingkat naungan karet. [Adaptation of two cardamom species and effects of organic matter application on rubber, under various levels of shade.] Bulletin Perkaretan 7:(3) 66-74.

Supriadi, M. (1994). Studi ahli teknologi pada perkebunan rakyat di Sumatera Selatan [Study of technology use by smallholders in South Sumatra]. Research Report APBN 1993/1994. Balai Penelitian Sembawa [Sembawa Rubber Research Institute], Palembang, Indonesia.

Swank, S.E. and Oechel, W.C. (1992). Interactions among the effects of herbivory, competition, and resource-limitation on chaparral herbs. Ecology 72 (1): 104-115.

Swinkels, R. and Franzel, S. (1997). Adoption potential of hegderow intercropping in the maize-based cropping systems of the highlands of western Kenya. 2. Economic and farmers' evaluation. Experimental Agriculture 32 (2): 211-223.

Taryoto, *et al.* (1995). Policy analysis of slash and burn practices: the case of three agroecological zones in Sumatra. Paper presented at a Regional Workshop on Alternatives to Slash and Burn, 6-9 June 1995, Bogor, Indonesia.

Templeton, J.K. (1968). Growth studies in *Hevea brasiliensis*. 1. Growth analysis up to seven years after budgrafting. Journal of the Rubber Research Institute of Malaya 20: 136-146.

Templeton, J.K. (1969). Partition of assimilates. Journal of the Rubber Research Institute of Malaya 21: 259-263.

Tennant, D. (1975). A test of a modified line intersect method of estimating root length. Journal of Ecology 63: 995-1002.

Teoh, C.H., Chung, G.F., Liau, S.S., Ghani, I., Tan, A.M., Lee, S.A. and Mohammed, M. (1985). Prospects of biological control of *Mikania micrantha* in Malaysia. Planter 61: 515-530.

Thaler, P. (1996). Relations Entre Developpement Racinaire et Developpement Aerien: Modelisation de l'Influence de la Disponibilite en Assimilats Carbones sur l'Architecture Racinaire d'*Hevea brasiliensis*. PhD thesis, Universite Montpellier II Science et Techniques du Languedoc. 142 pp.

Thomas, T.H., Willis, R.W., Bekorowajnyj, P.G., Sangkul, S. and Ng, A.P. (1993). A compendium of technical overviews for the BEAM spreadsheet models: TANZMOD, RRYIELD, POPMOD and ROWECON4. The BEAM Project, School of Agricultural and Forest Sciences, University of Wales, Bangor, UK.

Tilman, D. (1985). The resource-ratio hypothesis of plant succession. American Naturalist 125: 827-852.

Tilman, D. (1987). On the meaning of competition and the mechanisms of competitive superiority. Functional Ecology 1: 304-315.

Tilman, D. (1988). Plant Strategies and the Dynamics and Structure of Plant Communities. Princeton University Press, Princeton, New Jersey, USA. 360 pp.

Tomich, T.P. (1991). Smallholder rubber development in Indonesia. In: Perkins, D.H. and Roemer, M. (eds.) Reforming Economic Systems in Developing Countries, pp. 249-269. Harvard University Press, Cambridge, Massachusetts.

Tomich, T., van Noordwijk, M., Vosti, S. and Witcover, J. (1998). Agricultural development with rainforest conservation: methods for seeking best bet alternatives to slash-and-burn, with applications to Brazil and Indonesia. Journal of Agricultural Economics 19: 159-174.

Torquebiau, E. (1984). Man-made dipterocarp forest in Sumatra. Agroforestry Systems 2: 103-128.

Tripp, R. (1989). Farmer Participation in Agricultural Research: New Directions or Old Problems? Institute of Development Studies, Brighton, UK. 35 pp.

USDA (United States Department of Agriculture) (1975). Soil Taxonomy. United States Department of Agriculture Soil Conversion Service Agricultural Handbook No. 436. Government Printer, Washington.

Vaast, P. (1988). Presentation des systemes de regeneration cacaoyere en milieu paysan au Togo. In: Proceedings of the Proceedings of the 10th International Conference on Cocoa Research, Santo Domingo, Dominican Republic, pp. 63-69.

van Gelder, A. (1950). Belvolkingsrubber Cultuur [Smallholder Rubber Systems]. In: van Hall, C.J.J. and van de Koppel, C. (eds.) De Landbouw in de Indische Archipel. [Land Use in the Indonesian Archipelago]. pp. 427-475. Van Hoeve, Gravenhage. [Trans. M. van Noordwijk.].

van Noordwijk, M., Spek, L.Y. and de Willigen, P. (1994). Proximal root diameter as predictor of total root size for fractal branching models. I. Theory. Plant and Soil 164 : 107-117.

van Noordwijk, M. and Purnomosidhi, P, (1995). Root architecture in relation to tree-soil-crop interactions and shoot pruning in agroforestry. Agroforestry Systems 30: 161-173.

van Noordwijk, M., Tomich, T.P., Winahyu, R., Murdiyarso, D., Partoharjono, S. and Fagi, A.M. (1995a). Alternatives to Slash-and-Burn in Indonesia, Summary Report of Phase 1. ASB-Indonesia Report Number 4. ICRAF, Bogor, Indonesia. 154 pp.

van Noordwijk, M., van Schaik, C.P., de Foresta, H. and Tomich, T.P. (1995b). Segregate or integrate nature and agriculture for biodiversity conservation? Paper presented at the Biodiversity Forum, 4-5 November, 1995, Jakarta, Indonesia.

van Noordwijk, M., Lawson, G., Soumare, A. Groot, J.J.R. and Hairiah, K. (1996). Root distribution of trees and crops: competition and/or complementarity. In: Ong, C.K. and Huxley, P. (eds), Tree-Crop Interactions: a Physiological Approach, CAB International, Wallingford, UK. pp. 319-364.

van Noordwijk, M. and Ong, C.K. (1999). Can the ecosystem mimic concept be applied to farms in African savannahs? Agroforestry Systems 45: 131-158.

Vandermeer, J., van Noordwijk, M., Ong, C., Anderson, J. and Perfecto, Y. (1998). Global change and multi-species agroecosystems: concepts and issues. Agriculture, Ecosystems and Environment 67: 1-22.

Waidyanatha, U.P.D., Wijesinghe, D.S. and Stauss, R. (1984). Zero-grazed pasture under immature *Hevea* rubber - productivity of some grasses and grass-legume mixtures and their competition with *Hevea.* Tropical Grasslands 18 (1): 21-26.

Watson, G.A., Wong, P.W. and Narayanan, R. (1964a). Effects of cover plants on soil nutrient status and on growth of *Hevea. III.* A comparison of leguminous creepers with grasses and *Mikania cordata*. Journal of the Rubber Research Institute of Malaya 18: 80-95.

Watson, G.A., Wong, P.W. and Narayanan, R. (1964b). Effects of cover plants on soil nutrient status and on growth of *Hevea IV.* Loss of nitrate-nitrogen and of cations under bare soil conditions. A progress report on results from a small-scale field trial. Journal of the Rubber Research Institute of Malaya 18: 161-74.

Watson, G.A. (1989a). Climate and soil. In: Webster, C.C. and Baulkwill, W.J. (eds.), Rubber. Longman Scientific and Technical, Harlow, UK. pp. 125-164.

Watson, G.A. (1989b). Field maintenance. In: Webster, C.C. and Baulkwill, W.J. (eds.) Rubber, pp. 245-290. Longman Scientific and Technical, Harlow, UK.

Watson, G.A. (1989c). Nutrition. In: Webster, C.C. and Baulkwill, W.J. (eds.), Rubber. Longman Scientific and Technical, Harlow, UK. pp. 291-348.

Webster, C.C. (1989a). Preparation of land for planting and replanting. In: Webster, C.C. and Baulkwill, W.J. (eds.) Rubber, pp. 165-194. Longman Scientific and Technical, Harlow, UK.

Webster, C.C. (1989b). Propagation, planting and pruning. In: Webster, C.C. and Baulkwill, W.J. (eds.), Rubber. Longman Scientific and Technical, Harlow, UK. pp. 195-244.

Webster, C.C. and Paardekooper, E.C. (1989). The botany of the rubber tree. In: Webster, C.C. and Baulkwill, W.J. (eds.), Rubber, pp. 57-84. Longman Scientific and Technical, Harlow, UK.

Weischet, W. and Caviedes, C.N. (1993). The Persisting Ecological Constraints of Tropical Agriculture. Longman Scientific and Technical, Harlow, UK. 319 pp.

Werner, S. (1999). The impact of management practices on species richness within productive rubber agroforests of Indonesia. In: Sist, P., Sabogal, C., and Byron, Y. (eds.) Proceedings of the International Workshop on Management of Secondary and Logged-Over Forests in Indonesia, 17-19 November 1997, Bogor, Indonesia, pp. 33-44. CIFOR.

Werner, S. (in press). Useful plants and management of traditional rubber agroforestry systems in Indonesia. In: Penot, E., Wibawa, G. and Williams, S.E. (eds.) Proceedings of the Smallholder Rubber Agroforestry Project (SRAP) Workshop, 29-30 September, 1997, Bogor, Indonesia. ICRAF/CIRAD-TERA/TH.

Whitby, S. (1919). Variation in *Hevea brasiliensis*. Annals of Botany 33: 313-21.

Whitten A.J., Damanik, S.J., Anwar, J. and Hisyam, N. (1984). The Ecology of Sumatra. Gadjah Mada University Press, Yogyakarta (Indonesia). 583 pp.

Wibawa, G. and Gunawan, A. (1997). Study of *Hevea*-based intercropping system functioning: C. Effect of farmers' cropping system and some socio-economic factors on rubber growth. Paper presented at STD III Meeting in Sembawa Rubber Research Institute, 8-9 July 1997, Palembang, Indonesia. 22 pp.

Wibawa, G. and Rosyid, M.J. (1997). Study of *Hevea*-based intercropping system functioning: B. Effect of rubber growth on upland rice yield and its components. Paper presented at STD III Meeting in Sembawa Rubber Research Institute, 8-9 July 1997, Palembang, Indonesia. 10 pp.

Wibawa, G. and Thomas (1997). Study of Hevea based intercropping system functioning: A. Effect of different intercrops on rubber growth. Paper presented at STD III Meeting in Sembawa Rubber Research Institute, 8-9 July 1997, Palembang, Indonesia. 25 pp.

Wibawa, G., Penot, E. and Williams, S.E. (in press). Preliminary results of rubber agroforestry systems (RAS): on-farm experimentation in Jambi Province. In: Penot, E., Wibawa G. and Williams, S.E. (eds.), Proceedings of the Smallholder Rubber Agroforestry Project (SRAP) Workshop, 29-30 September 1997, Bogor, Indonesia. ICRAF / CIRAD-TERA/TH.

Wickremasinghe, S.I., Yapa, P.A.J. and de Soyza, T.V.W. (1987). Accumulation of free proline in bark and latex of *Hevea brasiliensis* affected by brown bast. Journal of the Rubber Research Institute of Sri Lanka 67 : 9-17.

Wijayakusuma, P.M.H. (1995). Tanaman berkhasiat obat di Indonesia. [Medicinal plants of Indonesia] Pustaka Kartini, Jakarta, Indonesia. 148 pp.

Williams, S.E. (1995). Traditional management practices and indigenous knowledge on establishment of jungle rubber gardens: a group interview. Internal ICRAF report, ICRAF-S.E. Asia, Bogor, Indonesia. 8 pp.

Williams, S.E. (1996). Preliminary survey on rubber yields in mature agroforests in Muara Buat. Internal ICRAF report. ICRAF-S.E.Asia, Bogor, Indonesia. 10 pp.

Williams, S.E. (in press) Below-ground interactions in an immature RAS 1-type agroforestry system. In: Penot, E., Wibawa, G. and Williams S.E. (eds.), Proceedings of the Smallholder Rubber Agroforestry Project Workshop, Bogor, 29-30 September 1997.

Williams S.E., Wibawa, G. and van Noordwijk, M. (in press). Rubber roots shift to the subsoil when there are intercrops. In: Penot, E., Wibawa, G. and Williams, S.E. (eds.), Proceedings of the Smallholder Rubber Agroforestry Project (SRAP) Workshop, 29-30 September, 1997, Bogor, Indonesia. ICRAF/CIRAD-TERA/TH.

Wilson, J.B. (1988). Shoot competition and root competition. Journal of Applied Ecology 25: 279-296.

Woods, P.V., Nambiar, E.K.S. and Smethurst, P.J. (1992). Effect of annual weeds on water and nitrogen availability to *Pinus radiata* trees in a young plantation. Forest Ecology and Management 48: 145-163.

Wycherley, P.R., and Chandapillai, M.M. (1969). Effects of cover plants. Journal of the Rubber Research Institute of Malaya 21: 140-57.

Yew, F.K. and Pushparajah, E. (1984). Plant tissues as indicators of soil nutrient availability for *Hevea*: glasshouse evaluations. Journal of the Rubber Research Institute of Malaysia 32 (3): 171-181.

Yogaratnam, N., Perera, A.M.A. and De Mel, G.J. (1984). Management of ground covers for optimum production. In: Proceedings of the International Rubber Conference: 75 Years of Rubber Research in Sri Lanka, September, 1984, Colombo, I (I). pp. 521-527. Rubber Research Institute of Sri Lanka, Agalawatta, Sri Lanka.

Yogaratnam, N., Silva, F.P.W. and Weerasuriya, S.M. (1984). Recent developments in the nutrition of *Hevea* in Sri Lanka. In: Proceedings of the International Rubber Conference: 75 Years of Rubber Research in Sri Lanka, September, 1984, Colombo, I (I). pp. 207-247. Rubber Research Institute of Sri Lanka, Agalawatta, Sri Lanka.

Young, A. (1976). Tropical Soils and Soil Survey. Cambridge University Press, Cambridge. 468 pp.

Zain, Y.M. (1986). Effective transfer of technology towards independent smallholders- a Malaysian experience. In: Osman, A.H. and Tan, G.S. (eds.) Proceedings of the ANRPC Seminar on the Progress and Development of Rubber Smallholders, 22-26 July, 1986, Palembang, Indonesia, pp. 107-114. ANRPC, Kuala Lumpur, Malaysia.

Zainal, E., Mahmud, A.W., Mokhtaruddin, A.M., and Gulam, H. (1992). Management of sloping lands for sustainable agriculture in Malaysia. In: Sajjapongse, A. (ed.), Technical Report on the Management of Sloping Lands for Sustainable Agriculture in Asia. Network Document No. 2, IBSRAM, Bangkok, Thailand.

APPENDIX 2.1

PRELIMINARY SURVEY ON RUBBER YIELDS IN MATURE AGROFOREST
MUARA BUAT VILLAGE
DECEMBER 1996

AIMS

The aims of this preliminary survey were:

- To gather baseline information on rubber gardens, and farmers' tapping practices
- To explore the farmers' knowledge/ideas about rubber yield and its variation
- To assess farmers' ease in articulating these concepts
- To identify classes of farmers who were most knowlegeable about yield variation

This information was elicited in order to assess the feasibility of a proposed competition study in the mature rubber agroforest, and specifically, whether latex yields from individual trees could be used as an indicator of tree productivity in that proposed study. In addition, the information would be used to formulate a later detailed, structured questionnaire on yields from and management of the rubber agroforests.

BACKGROUND INFORMATION

- Almost all the families in Muara Buat rely in part or wholly on rubber as their source of income.
- A rubber garden is called a 'kebun karet'. Throughout this report, the term 'kebun' is used to describe rubber gardens.
- A system of share-tapping exists, called 'bagi tiga', where a tapper has an agreement with a kebun owner, and when the latex is sold, the tapper receives two thirds of the cash, and the owner one third.

FARMER CLASSIFICATION

A classification of people involved in establishment and tapping of rubber kebuns was developed from personal observations and discussions with Isabelle Clement, an anthropology research student (ORSTOM/ICRAF), also living in Muara Buat.

1. Young men (married or unmarried)
a) those who tap in their parent's kebun with income being used for family household expenses, and any surplus as 'pocket money'.
b) those who share-tap for other kebun owners outside the family.

2. Middle-aged men (usually with their own family)
a) those who tap in their parent's kebun, either under a bagi tiga system, or where they keep all the income themselves (this may be thought of as an advance of their inheritance).
b) those who tap in their own kebun, whether this was inherited from their parents or established themselves.
c) those who share-tap for other kebun owners; some may have established their own kebuns, but these are not yet in production.

3. Older men
These are usually too old to tap rubber themselves, they own a number of kebuns (inherited or established themselves) and employ other people as share-tappers.

4. Middle aged women (usually with their own family)-a minority
a) those who tap in their own kebun, often as their husband has off farm employment.
b) those who share-tap for other kebun owners.

METHODOLOGY

A small sample was taken, consisting of one informant from categories 1a, 2b, 2c and 4a. Semi-structured interviews were conducted informally, and were based around some core questions, but the interviews often developed into open-ended discussion.

INTERVIEWS

### Informant 1: Marten		Category 1a

Background information

Kebun establishment in Muara Buat: About 5 years ago, people began to establish new kebuns with a much greater frequency than before. Since then there is less rice being grown, and people rely more on income from rubber to buy rice. The reason is that there has been a sharp increase in off-farm employment, and many men from the village are working away. For example, in the upland rice fields ('ladang kering'), the area cultivated per year is now 0.5 ha/family, compared with 1 ha previously, as the majority of the work is now done by the wife, with only limited help from the husband.

Pests: there has been an increase in problems from pests in his lifetime, especially pigs, probably due to the decrease in tiger population.

Sale of kebuns: this practice is declining, as people realise how much work goes into their establishment, especially taking into account the fact that if people want to establish new kebuns now, the only free/available land is far from the village. Previously, kebuns would be sold for cash to cover an expense like a wedding party.

Kebun

Age: 'Old'. He mainly taps the self seeded progeny of the original trees.
Current management: slashing the understorey of the garden (he personally has cut all the vegetation, but recognises that other farmers do select particular trees to keep). The reason for this is that during rainy season, the other vegetation drips on and causes the tapping panel to be wet, and this is dangerous, because if you then tap, a few days later the tree does not give any latex. Large trees are ring barked, because they then die slowly, decay, and fall when dead and decomposing; this does not cause damage to rubber trees in the vicinity.
No. of trees in kebun: 200-250.
All trees tapped each tapping day?: yes.
No. of days tapping per week: Four. Saturday, Sunday, Tuesday, Wednesday. Monday is a rest day, Thursday the latex is sold (market day), Friday he goes to the mosque.
Time of tapping (actually cutting): 7 am-9 am.
Collection: rest first then collect, usually finished by 12 noon. Sometimes the latex is left in the cup one day, and collected with the next day's yield. In this case the 'cup lumps' are arranged in the wooden coagulating trough, and the liquid latex poured over to fill the matrix. Then acid is added for coagulation into a slab of rubber. The price obtained for a slab made in this way is the same as if the slab was entirely made from liquid latex, and of course the labour involved in collecting is effectively halved.
Yield per tapping day: 15-20 kg.

Yield variation

Time of day: best yield when there is still dew around (about 6 am), the air is wet and it is cooler. As it gets clearer, and the sun comes out, the latex dries on the cut faster, and latex won't come out any more.
Rain: cannot tap. The panel is wet, the latex is not channelled into the cup, and floods down the bark below.
Rainy season: yields per week are lower because of loss of tapping days.
Dry season: yields per week are higher (4 full days tapping), but the yield per tapping is slightly less.

Tapping more intensively (5 days per week): yield per tapping decreases, the week's yield is only marginally higher than the weekly yield from 4 days tapping. Therefore not worth the extra effort.
Causes of dry trees: too much tapping, and also tapping in the rain.
Differences in yield between trees at different slope position: He thinks none. HOWEVER, as tappers start at the bottom of the hill to tap, and work up the slope, the last trees to be tapped are at the top of the hill, and the yield is generally less. He attributes this to the fact that it is later in the day, and yield always decreases later in the day.
Tree size: 2 trees can be the same size, but one can yield less than the other.
Closeness of neighbours: if 2 or 3 trees are close together, there is no problem. But maybe if 15 or 20, maybe a problem then. Sometimes the trees close together have latex flows that stop very quickly. He has seen very old trees (usually not so good yielding), at the top of a hill, with wide spacing that are giving better yield than younger trees (usually better yielding), at the bottom of a hill, because these trees are planted very close together.

Informant 2: Pak M. Noor **Category 2b**

Background information

Informant: Very reliable, has planted 0.5 ha clonal rubber (SRAP project farmer), Secretary of village, and holds various other posts of responsibility.

His kebun was inherited from his father, and he and his younger brother tap there.

Kebun

Age: Approximately 40 years old, planted by his grandfather. There is one original tree left, the rest that are tapped now are naturally regenerated seedlings, and also seedlings deliberately planted in suitable gaps. These seedlings were either collected from within the rubber agroforest or seeds planted in polybags and planted out after one year.
Current management: Slashing of tapping paths, occasional planting of new seedlings.
Enrichment planting of new seedlings: in the established agroforest he recognised that both above-ground and below-ground competition were delaying the growth of seedlings, but below-ground effects could be overcome by addition of fertiliser, whereas shading was very hard to overcome.
Number of trees in kebun: Approximately 300 (150 tapped by him, 150 by his brother). 2 ha in total area, from very steep slopes, to relatively flat land.
All tapped each tapping day?: Yes.
No. days tapping per week: Four. Maybe only 2-3 days in rainy season.
Time of tapping: early morning, start about 6.30 am.
Collection: Every second day of tapping, as less work involved.
Yield per tapping day: 25 kg maximum, 20 kg if rainy season.

Yield variation

Time of day: Early morning, yields get less later in the day.
Rain: Too dangerous to tap if raining as the water stops the latex plugging on the cut, and so the latex doesn't stop coming out. The tree can become dry and die. Also the bark can become 'busuk' (soggy, decayed). Plus the stemflow can wash the latex all over the panel, and out of the cup.
Rainy season: Less tapping days, therefore less weekly yield. Also, if he has tapped, and it looks as though it may rain later on, he is forced to collect the latex quickly, maybe before the dripping has actually stopped, so some yield is lost. If it rains after 3 pm there is no problem, as autocoagulation of the latex has already occurred in the cup. Some people will add acid to ensure quick coagulation in the cup, and thus avoid the possibility of rain washing out the latex. However this is expensive.
Dry season: No problem, 4 tapping days per week, however the yield is slightly lower per tree than in the rainy season.
Tree size/age: When opening trees for tapping, he thinks that age is more important than size (and that seedling trees differed from clones in this respect). Test tapping is carried out,

and water content of latex assessed by eye. After 12 years of age, most trees can be tapped, and much less water is present.
Opening for tapping: He always starts tapping the panel on the same side of the tree as its lowest branch, as there is more latex here than on the other side. He classifies a tree around 15 years old as young, and only makes one cut (equivalent to 1/4 spiral) because 2 cuts (1/2 spiral) is too long, and can stress the tree too much. Also the bark can be more easily damaged, and a greater danger of "ulat" (caterpillars/maggots?) entering, which ruin the bark. At about 20 years old, the tree is old enough to stand 2 cuts in the bark.
Position on panel: More latex at the bottom than at the top.
Tapper: He, as the owner of the trees, takes a very thin amount of bark each tapping, so that each panel (say of a 15 yr old tree) lasts 4 years. He looks after his trees, as he knows if you treat them well, they can last a long time (also why he doesn't practice upward tapping any more). However, share-tappers tend to get a higher yield per tapping, as they remove a lot more bark, they have interest in short term profits only.
Dry trees: He knows a tree that was tapped for 2 years, but the following 3 years has been dry. Also, 1 tree, 28 years old that had never been able to be tapped, as it was giving no latex. In fact he removed a square of bark 3 x 6 cm, and only water came out.
Red/yellow varieties: Red- reddish, thick bark, leaves dark green, and wide in shape. Give lots of latex, and safe to make extra cuts in addition to the one V cut. On tapping, latex comes out quickly and flows a long time. Yellow- yellowish, thin bark, leaves small and narrow in shape. Gives less latex, can only use one V cut, and some trees, after 2 successive tappings still have not produced one full cup of latex.

Informant 3: Pak Effendi **Category 2c**

Background information

Informant: Has been tapping rubber for 6 years. He used to tap in Laman Panjang (2 villages away), but it was too far, so found a kebun closer to Muara Buat instead. Owns a 'warung' (coffee shop), has also planted 0.5 ha of young rubber (SRAP project).
Rubber quality: slab from Muara Buat is usually 60% rubber. Price on average is 850 Rp/kg. It used to be 1000 Rp, and even reached 1200 Rp at one time.
Classification: 75% of people tap for others. 30% of people own productive rubber kebuns. 80% of people have planted their own kebuns (this includes Category 3).

Kebun

Owner: Someone from Desa Buat (next village).
Distance from village: 10 minutes walk.
How long informant has tapped there: 4 months.
Age: 25 years, plus spontaneously regenerated trees (7, 8, 10 years old)
Current management: maintaining clear paths only. Half the kebun has had all understorey slashed, other half has lots of secondary forest regrowth.
Number of trees in kebun: 400
All tapped each tapping day?: No, only the 200 in the cleared area. These will be rested after 1 year tapping, and the other half of the plot slashed and tapped.
No. days tapping per week: Four.
Time of tapping: 6.30 - 10.30 am.
Collection: 1.5 hours.
Yield per tapping day: 17 kg.
Tapping cut: V-shaped.

Yield variation

Time of day: high yield early morning, trees quickly dry up in the late morning. 5 years ago a few people tapped at night (8 pm), yields were higher (trees dripped until the morning), but people were scared to be in the kebun at night.
Rain: if raining, or even heavy rain the night before the bark is wet and the flowing latex just fans out over the bark and is lost. Plus the fact that the cut area can go bad ('busuk'). Plus if the latex is wet (from rain), it won't coagulate.
Rainy season: less days for tapping, therefore yield reduced per week.

Dry season: No problem, better yield per week.
'Wintering': time of rubber leaf fall and regrowth (1 month per tree, between May and August)-less yield per tree.
Tapping more intensively: After 2 days, the yield of a tree is reduced, so a rest day is needed. In theory, a tree could be tapped every day for 3 months, but that is the absolute maximum, and must be rested after that. Tapping is more intensive than usual at certain times of the year e.g. before Lebaran, and before the rice harvest, after the harvest from the previous year has run out.
Differences in yield at different slope position: better at bottom, near water. Dampness of soil is most important. Also at tops of hills there is more risk of wind damage.
Tree size: the bigger the tree, the better the yield (when comparing original trees with mixed age, naturally regenerated ones).
Tree morphology: trees with dense crowns, i.e. lots of leaves and branches, give more latex than trees of the same size and age that have sparse crowns (they will grow faster too) Some people recognise this and induce branching by cutting the stem at 3m. Therefore important not to plant trees too close together, as the tree will grow up instead of out. Tree branching from ground level (i.e. 2 stems) is apparently not a problem. If trees are the same size, age, and have the same amount of branches, the yield will be the same too.
Tree age: trees will die after 35 years, but before that, they are still producing a lot of latex. If trees are still young, when test tapped, there is more water than latex.
Tree size and tree age: his example-there are 2 trees, the same size, one 5 years old, the other 7 years old. The 5 yr old will have watery latex, the 7 yr old more concentrated latex. and if there was one 10 years old, this would be better still. Therefore opening for tapping depends on age, not size.
Red/yellow varieties: Red is better than yellow. Red trees have thicker, harder bark. However, they give the same yield, although latex from red trees is heavier. There are less red trees than yellow trees.
Also 'white' trees- these are still young, under 10 years of age.

Other comments

The biggest area of young rubber in Muara Buat is around Sungei Duyung Besar, (an old ladang area) approximately 5 years old.
The future: there will come a time when there is not enough rubber to provide tapping jobs for the younger generation of Muara Buat. They may be forced to work (off farm) e.g. in Jambi, or go to other villages further up the valley, where there is more available land, to work as tappers, or in the case of Tagan (between Laman Panjang and Senamat Ulu), there is free land available to be "borrowed" for making 'ladang' (upland rice fields), but there, no property claims may be made.
Clonal rubber : if you want returns in the near future, clonal rubber is good. In comparison, planting local rubber, is seen more as an investment for the longer term future, which will more likely benefit your children/grandchildren. There is a lot of work involved with clonal rubber, and it can die quickly if there are too many weeds, and if not fertilised. He knows of only one person in Muara Buat who grafted clones from the Bandes (Government budwood garden) project; many of the other farmers were afraid the technology would not work, and their investment of labour and time would be lost.
Cinnamon: this is not as successful here as in Kerinci, where the climate and soils are better (from volcanic origins). In fact, the trees here only produce seed after 7 years, after using a lot of fertiliser. Otherwise they do not set seed until 20 years old.

Informant 4: Ibu Darnice **Category 4a**

Background information

This has been the only female tapper contacted so far, and she did not seem to be comfortable about answering questions which required her personal observations/opinions. She was happier talking just about her activities. More rapport needs to be built up, so she is more at ease before any more detailed questions are asked.

She is married, but her husband has off-farm work, and to support their 5 children she taps in their own kebun.

Sale of rubber: she is not tied to any particular middleman, and can choose the one offering the best price. There are 4 middlemen from, and operating in Muara Buat. Sometimes, if people aren't able to tap in a week, they can borrow money from the middleman. However, when they do have rubber to sell, they are under obligation to sell to that particular middleman, to cancel the debt, and sometimes receiving a lower price per kg of slab. One particular middleman will also accept payment of debts in other terms, e.g. fish, cinnamon or rice.

Kebun

Age: "Very old", many trees seem to be near the end of their productive life, and already have been tapped quite high up the bark. They bought the kebun 16 years ago when it was already "old". They themselves planted new seedlings in any available space.
Current management: paths between trees slashed. Last year, some cinnamon planted at the periphery, and in gaps, however growth of this has not been good.
Number trees in kebun: don't know.
All tapped each tapping day?: yes.
No. days tapping per week: 6 days a week are possible (Thursday the rubber is sold at market), However, usually about 3 days per week.
Time of tapping: 7 am start, about 11.30 am finish.
Collection: 2 days yield is left in the cup, and on the 3rd day of tapping, all is collected.
Yield per tapping day: Last week, 3 days work gave 14 kg.

Yield variation

Tree age: Older trees are best yielders.

APPENDIX 3.1

RUBBER ROOTS SHIFT TO THE SUBSOIL WHEN THERE ARE INTERCROPS

Sandy Williams[1]*, Gede Wibawa*[2]*, Meine van Noordwijk*[3]

[1] University of Wales, Bangor, UK [2] Indonesian Rubber Research Institute, Sembawa Research Station, [3] ICRAF, S.E. Asia, Bogor

Introduction

Rubber (*Hevea brasiliensis*) is well suited to acid soils and can provide farmer income on soils where continuous food crop production is not feasible. Rubber can be grown under a range of management intensities, ranging from 'plantations' to 'jungle rubber'. In the early stages various intercrops are used by farmers. Wibawa and Thomas (1997) in a trial at the Indonesian Rubber Research Institute showed large differences in tree diameter and height with different intercrops. The data suggest that this effect is based on competition for water and possibly nutrients between the rubber and the intercrops. If so, shifts in overall shoot: root ratio can be expected, but competition may also have an effect on the distribution of rubber roots over the profile. Schrot (1995) suggested that intercropping can be used to modify the root distribution patterns in agroforestry, but data to show this effect are scarce. We collected data on rubber roots with different intercrops and tested a new method of analysing tree root systems (van Noordwijk and Purnomosidhi, 1995) for its potential application to rubber.

Materials and methods

Observations were made in May 1997 in the 'STDIII Intercropping Experiment' at the Sembawa research station (Palembang, S. Sumatra), when the rubber trees (clone BPM 24) was 39 months old (planted in December 1993). The experiment was designed as six treatments in three blocks, with one replicate per block. Each plot contained 56 rubber trees, planted at 6.7 x 3m spacing, which represented a density of 500 trees/ha, plus an intercrop. We focussed our observations on treatments A, D and F, representing the best, an intermediate and the worst above-ground growth respectively:

A. Clean weeded: no intercrop, clean weeded every two months with a hoe.
D. Pineapple: planted in four rows, 1m from rubber trees, weeded every two months with a hoe.
F. Imperata cylindrica: manually weeded in 50 cm radius from rubber trees with a hoe.

Proximal Root Study: Two trees from each replicate were excavated, i.e. six trees per treatment. The methods are described by van Noordwijk and Purnomosidhi (1995) and involved measurement of the diameters of proximal roots, their classification by horizontal and vertical orientation, and measurement of stem diameter at 1 m. From these parameters, a tentative index of root competitiveness was calculated.

Fractal Branching Study: The fractal characteristics of the root branching patterns were also assessed by measurement of length of links between branching points and the diameter of each subsequent branch. One tree was excavated, from the edge of the bare soil treatment, bordering on an area of legume cover crop. Measurements of root diameter were made with calipers, and of stem diameter and larger roots with a tape. Data on individual branching points were analyzed to test whether the rules for change and allocation of root diameter upon branching depend on current root diameter.

Results

Test data show that the basic assumptions for fractal branching pattern hold, and thus that proximal root diameter can be used as indicator of total size of the branched root system. Results for the proximal roots are shown as the means of the six excavated trees per treatment (Table 1).

Table 1. Root and stem characteristics of 39-month old rubber trees with three types of intercrop

Intercrop	No. Horiz. Roots	No. Vert. Roots	% Horiz. Roots[1] (Dsqs)	Stem Dsq (cm^2)	Shoot/Root Ratio[2] (Dsqs)	Index[3] of Root Competitiveness
A. Clean Weeded	19.8	8.7	60.7	74.8	0.46	0.76
D. Pineapple	18.5	5.7	34.1	38.4	0.23	1.64
F. Imperata	22.3	4.5	23.7	13.9	0.28	1.20
F-probability	NS	NS	0.008	<0.001	0.022	NS
S.E.D.[4]	4.6	2.7	10.1	8.1	0.074	0.80

1. Percent Horizontal Root Diameter Squares $= 100 * \Sigma D_{hor}^2 / (\Sigma D_{hor}^2 + \Sigma D_{ver}^2)$

2. Shoot/Root Ratio (Diameter Squares) $= \Sigma D_{stem}^2 / (\Sigma D_{hor}^2 + \Sigma D_{ver}^2)$
3. Index of Root Competitiveness $= D_{stem}^2 / \Sigma D_{hor}^2$
4. S.E.D. = standard error of differences between means

The substantial effects of the intercrops on stem diameter was not reflected in total root cross sectional area (or diameter squares). The shoot: root ratio (on the basis of cross sectional area) was significantly lower for the rubber with intercrops than in the clean-weeded plots.

Allocation to horizontal and vertical roots can be considered in terms of the numbers of both types of roots, and also by their size, as calculated by summing the diameter squares of each root. The numbers of horizontal and vertical roots were not significantly influenced by the intercrop, but the percentage of horizontally oriented roots showed a positive trend with increasing severity of competition: 69% (A), 77% (D), 83% (F). The percentage of total root cross sectional area in horizontally oriented roots, by contrast, decreased in the same sequence: 61% (A), 34 % (D), 24 % (F). So, through A to F, more horizontal than vertical roots are produced, however the total size of the horizontal root system relative to the total size of the vertical root system decreases. The 'Index of root competitiveness' showed no statistically significant differences.

Conclusion

In the clean-weeded plots (C) the shoot-root ratio is considerably higher than in the intercropped plots D and F. Competition with intercrops, especially Imperata, also lead to a shift from horizontal to vertically oriented root cross-sectional area. We conclude that an increase in below ground competition results in preferential allocation within the root system to roots rather than shoots and to roots exploiting lower soil layers rather than roots in upper soil layers. Also, for root in the upper soil layers, there is a preferential allocation to more numerous, but smaller sized roots.

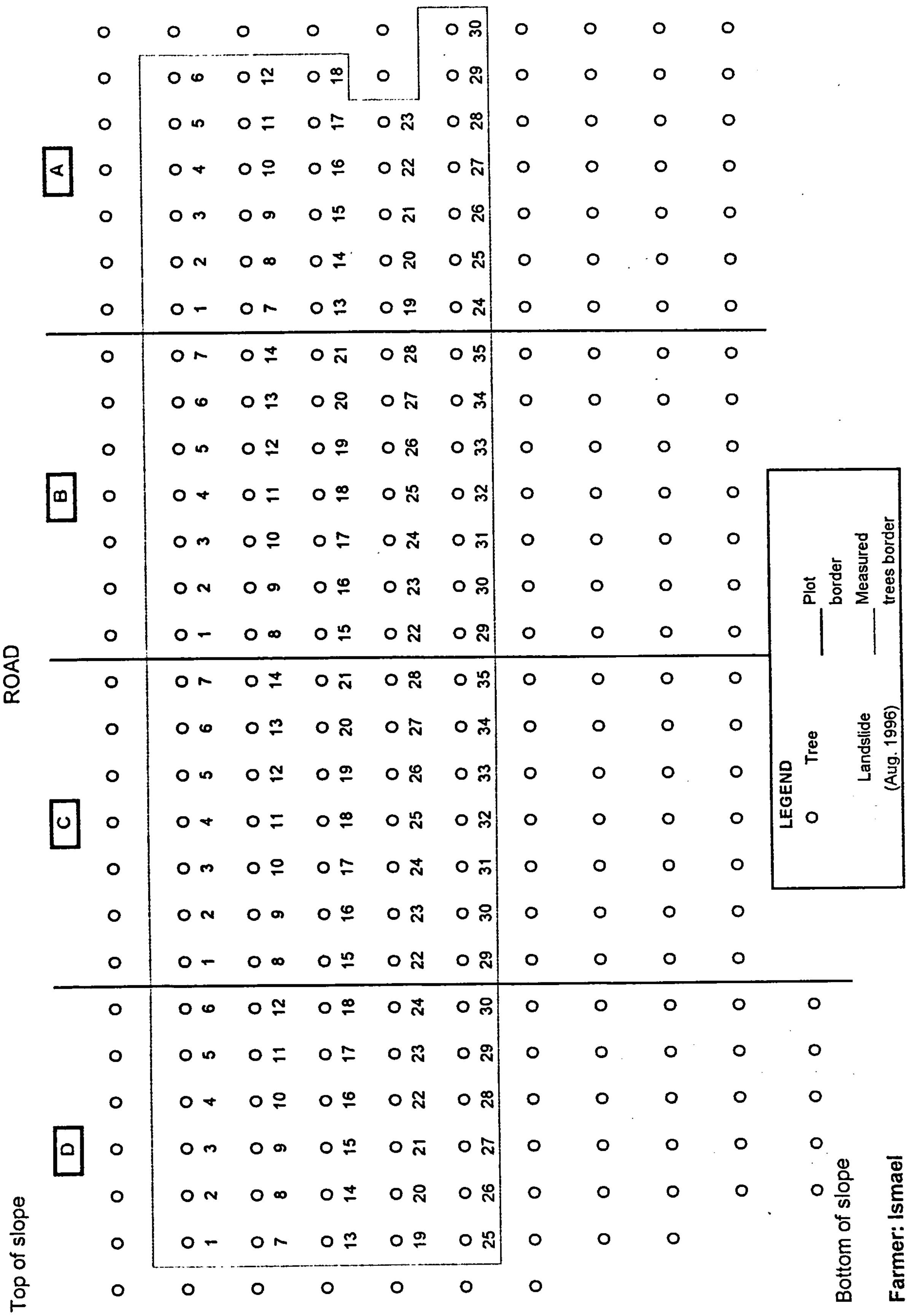
References

Schroth, G., 1995. Tree root characteristics as criteria for species selection and systems design in agroforestry. Agroforestry Systems 30: 125-144

van Noordwijk, M. and Purnomosidhi, P., 1995. Root architecture in relation to tree-soil-crop interactions and shoot pruning in agroforestry. Agroforestry Systems 30: 161-173.

Wibawa, G. and Thomas, 1997. Study of Hevea based intercropping system functioning: A. Effect of different intercrops on rubber growth. Paper presented at STD III Meeting in Sembawa Research Station, 8-9 July 1997. Palembang, Indonesia.

APPENDIX 5.1

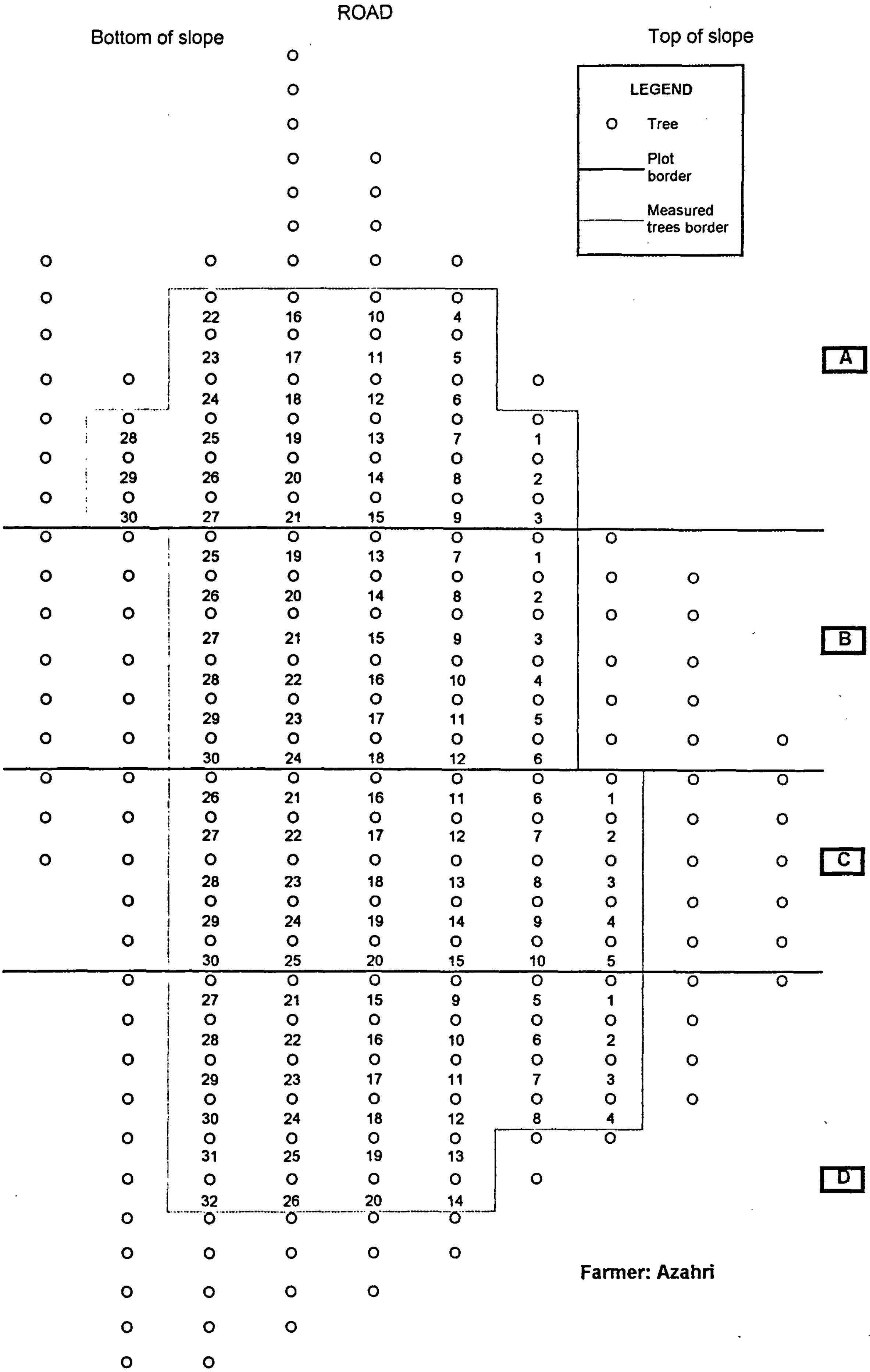

ROAD
Top of slope
Bottom of slope
A
B
C
D
LEGEND
Tree
Plot border
Measured trees border
Landslide (Aug. 1996)
Farmer: Ismael

a

b

Plate 5.1 Experimental field of Pak Ismael: a) Four months after planting (plot D in foreground, plot A in background); b) twenty one months after planting (plot B).

APPENDIX 5.2



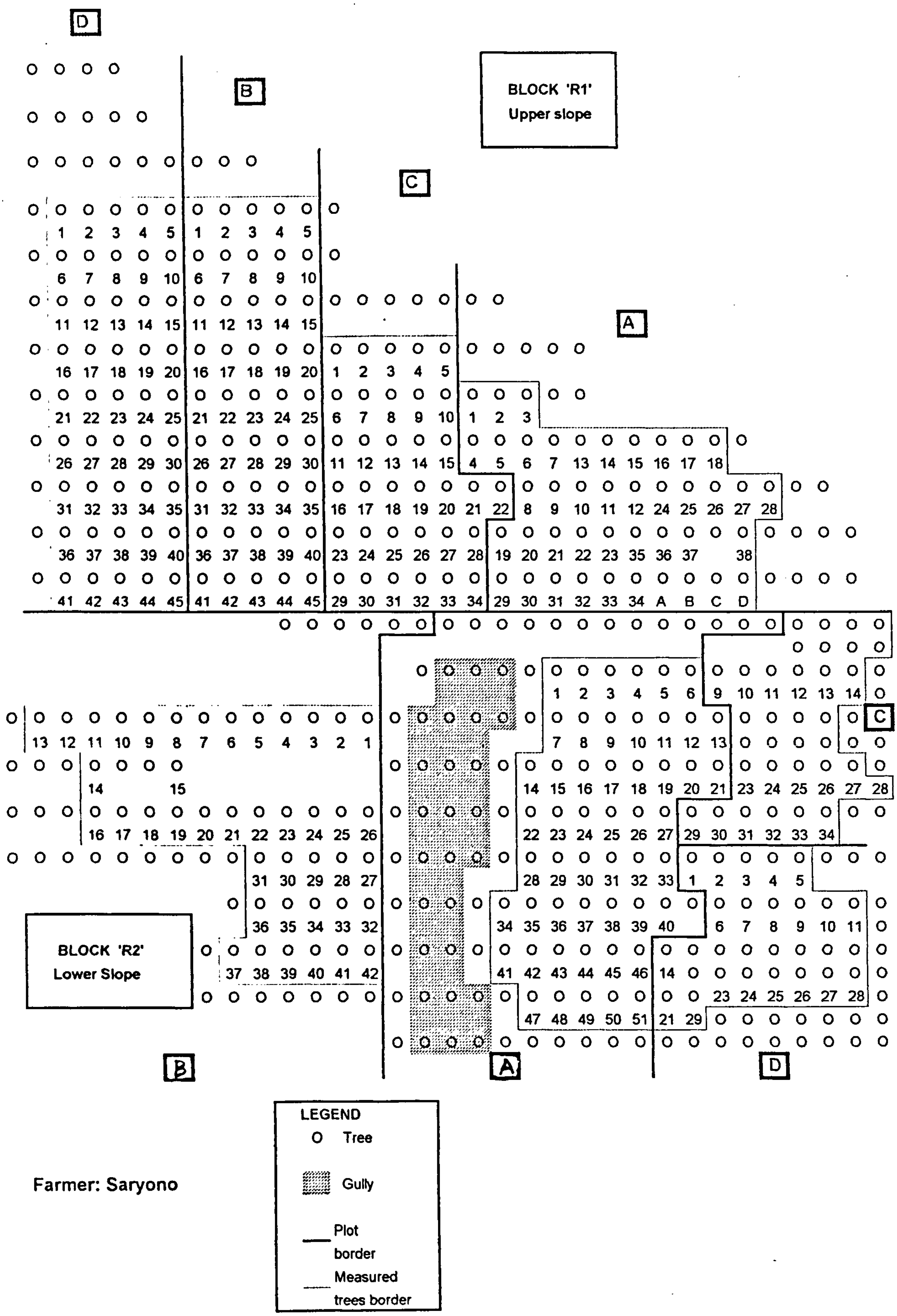
Farmer: Azahri

a

b

Plate 5.2 Experimental field of Pak Azahri: a) Four months after planting (plot A on the left , plot D on the right); b) twenty one months after planting (plot A on the right, plot B with secondary forest regrowth on the left).

APPENDIX 5.3



Farmer: Saryono

a

b

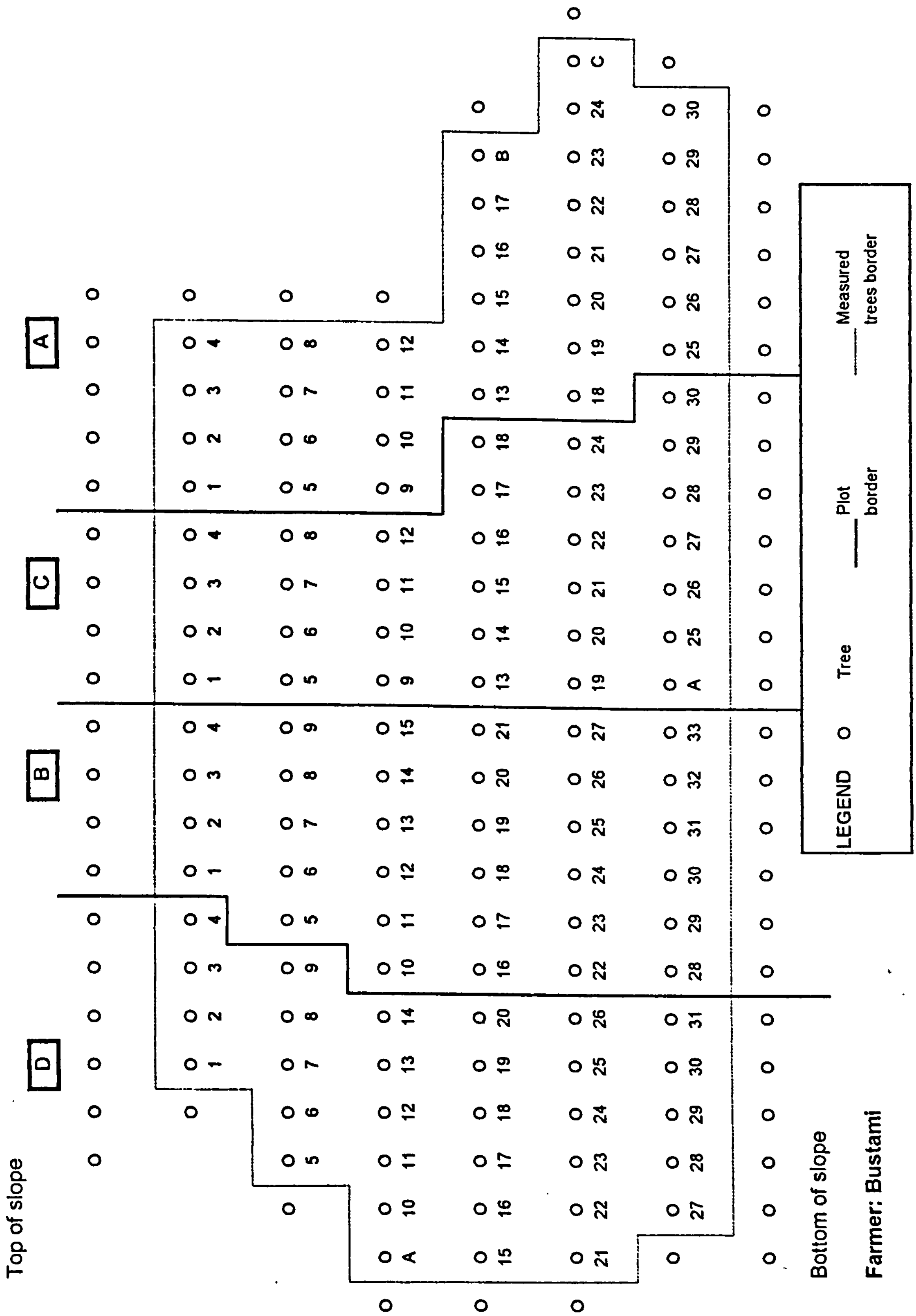
Plate 5.3 Experimental field of Pak Saryono, Block R1 a) Four months after planting (plot B in foreground, plot D in background); b) twenty one months after planting (plot B in foreground, plot D in Background)

a

b

Plate 5.4 Experimental field of Pak Saryono, Block R2 a) Four months after planting (plot D in foreground, plot C in background); b) twenty one months after planting (plot D in foreground, plot C in background)

APPENDIX 5.4


Top of slope
A
B
C
D
Bottom of slope
Farmer: Bustami
LEGEND
Tree
Plot border
Measured trees border

a

b

Plate 5.5 Experimental field of Pak Bustami, a) Four months after planting (plot C); b) twenty one months after planting, showing repeatedly damaged rubber tree which had only attained a height of twenty centimetres.