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FARMERS' KNOWLEDGE AND THE DEVELOPMENT OF COMPLEX AGROFORESTRY PRACTICES IN SRI LANKA

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DEDICATION

This thesis is dedicated to my loving parents and also to my wife Yasasvi and daughter Sachini.

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ABSTRACT

The principal theme of this thesis stems from the failure of farming systems research and extension (FSR/E) methods to deliver agroforestry interventions that are widely adopted by farmers. The possibility of using a knowledge-based systems approach to augment conventional FSR/E methods in considering the improvement of complex agroforestry practices was, therefore, evaluated by sequential adoption of ICRAF's Diagnosis and Design Methodology and a novel knowledge-based systems approach. This was done on a case study basis in the Kandy district of Sri Lanka, where the traditional forest gardens are an important feature of land use. It has been previously suggested that analysis of an explicit record of farmers knowledge might be used to identify deficiencies constraining productivity and sustainability of agroforestry practices and hence develop appropriate research and extension strategies, this thesis records the first attempt to do this.

There were difficulties in applying conventional FSR/E methods to farming systems involving complex agroforestry practices, specifically because the classification at the level of the farming system did not result in identification of sufficiently homogeneous groups of agroforestry practices for the purposes of designing research and extension.

The extent to which a knowledge-based systems approach generated new information which changed what was known about farming practice from that available from a conventional diagnosis was explored and the knowledge-based systems methodology further developed and tested by:

- comparing alternative methods of testing representativeness of knowledge collected from a purposive sample of key informants against the distribution of knowledge in the whole farming community,
- exploring the validity of items of indigenous knowledge in an objective sense through experimentation to determine their scientific validity, and
- exploring the possibility of generating and introducing new knowledge to fill gaps identified through analysis of farmers' existing knowledge.

The findings of the research have implications for the role of knowledge-based methods in agroforestry research and extension which are discussed in the light of contemporary developments in approaches to research and development in agriculture and forestry more generally.

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LIST OF ABBREVIATIONS AND ACRONYMS

AAD	Agroecosystem Analysis and Development
AKT-1	Agroforestry Knowledge Toolkit-1
AKT	Agroforestry Knowledge Toolkit
ASC	Agrarian Services Centre
ASD	Agrarian Services Division
CGIAR	Consultative Group on International Agricultural Research
DBH	Diameter at Breast Height
D & D	Diagnosis and Design
FMRC	Farm Machinery Research Centre
FSR	Farming Systems Research
FSR/E	Farming Systems Research and Extension
GIS	Geographical Information Systems
GRSD	Galagedara Regional Secretary Division
IBL	Immature Brown Loam soil
ICRAF	International Council for Research in Agroforestry
IDS	Institute of Development Studies
IIED	International Institute for Environment and Development
IUFRO	International Union of Forestry Research Organisations
KGF	Kandyan Forestgarden
KHG	Kandyan Homegarden
LHG	Low Humic Gley soil
LUS	Land Use System
LUSs	Land Use systems
MAFP	Months after field planting
MAG	Months after germination
NGO	Non-Governmental Organisation
ODA	Overseas Development Administration
ODI	Overseas Development Institute
PRA	Participatory Rural Appraisal
RBL	Reddish Brown Latosolic soil
RRA	Rapid Rural Appraisal
RSD	Regional Secretary Division
VSO	Village Services Officer

LIST OF LOCAL NAMES[1]

Ande	Shared labour system adopted in cultivating lowland rice plots in Sri Lanka
Atthama	Land lease system adopted in cultivating lowland rice plots in Sri Lanka
Chena cultivation	A form of slash and burn agriculture
Goyigama	Main farming (cultivator) cast
Janasaviya	A social security scheme introduced by the Sri Lankan Government
Kandyan region	The area around Kandy; mainly district of Kandy and parts of districts Matale, Kegalle and Kurunegala
Pohora-gathiya	Soil nutrient content
Kamatha	Threshing floor
Midula	Open area around the house
Grama Seva Niladari	Village Services Officer

[1] Local terms related to pruning of trees are given in Appendix 8, also the local names of plant species in Appendix 2.

CHAPTER 1

INTRODUCTION

1.1 PURPOSE OF THIS CHAPTER

This chapter outlines the background to the present research study and provides the context for the remainder of the thesis. The principal theme of the thesis stems from the failure of farming systems research and extension (FSR/E) methods to deliver agroforestry interventions that are widely adopted by farmers (Sanchez, 1995). The possibility of using a knowledge-based systems approach (Walker *et al.*, 1995a) to augment conventional FSR/E methods in considering the improvement of complex agroforestry practices is evaluated by sequential adoption of ICRAF's Diagnosis and Design Methodology (D & D) (Raintree, 1990) and knowledge-based systems techniques on a case study basis in the Kandy district of Sri Lanka, where the traditional forest gardens are an important feature of land use. The present chapter, therefore, examines the methodological requirements for agroforestry research and extension and justifies the use of a knowledge-based systems approach as a means of bridging the gaps between these requirements and what is currently achieved by the adoption of conventional FSR/E methods. This leads to the development of the hypotheses, objectives and research strategy employed in the present study. Finally, a brief summary of the structure of the thesis and the criteria used to select the case study area are outlined.

1.2 BACKGROUND AND CONTEXT

Agroforestry practices have attracted a great deal of intellectual interest because of their potential contribution to the economic well being of rural populations in an environmentally sustainable way. Agroforestry refers to an integrated approach to land management and has been defined in many different ways in the literature. An early attempt to define agroforestry as it began to emerge as a science, viewed it as a sustainable land management system that increases overall production, combines agricultural crops, tree crops and forest plants and/or animals simultaneously or sequentially, and applies management practices that are compatible with the cultural patterns of the local population (Bene *et al.*, 1977).

This definition explicitly recognises the variety of biological components which may combine to form agroforestry practices and further identifies increase in productivity and sustainability of land while retaining cultural appropriateness as characteristics of agroforestry. Therefore, it gives evidence for recognition that a multiplicity of disciplines, such as agronomy, horticulture, forestry, livestock sciences, rural sociology and environmental conservation have to contribute in the development of agroforestry. However, with advancement of agroforestry as a science during the 1980s productivity, sustainability and adoptability began to be viewed as properties of a good agroforestry design rather than defining characteristics of what agroforestry was (Raintree, 1983b) and a narrow definition based only on the involvement of agricultural activities and trees on the same land such that there were significant economic and ecological interactions in time and/or space was adopted by ICRAF (Lundgren, 1982). At the same time Conway (1987) in proposing an agroecosystems analysis approach to rural research and development identified productivity, stability, sustainability and equitability as fundamental properties to examine during the analysis of complex agroecosystems.

More recently agroforestry has been viewed as both an interdisciplinary approach to land use and a set of integrated land use practices (Sinclair *et al.*, 1994). The approach embraces a systems focus and considers the interactions of people, trees, herbaceous plants and livestock within a production system. This definition thus separates the previous narrow view of agroforestry practices from a broader approach to research and development of whole farm systems and proposes the use of systems analysis in dealing with the complexity inherent in agroforestry while also giving explicit recognition to the human component in the functioning of the system. It is clear then that agroforestry systems are highly complex both because of the variety of biological components involved and their interactions and because of the human dimension in managing such complexity, making them extremely difficult to understand and evaluate.

Due to the realisation of the importance of understanding complex farming practices, such as agroforestry, in the planning of rural development projects and the emergence of close interaction with local people as the most effective means of achieving this, new methodologies of research and development have been developed during the last decade. They include the Diagnosis and Design methodology developed by ICRAF, Agro-Ecosystem analysis by the International Institute for Environment and Development (IIED), Rapid Rural Appraisal (RRA) as promoted, for example, at Khon Kaen University, Thailand and the Institute of Development Studies (IDS) in Sussex, Participatory Rural Appraisal (PRA) as reviewed by the Overseas Development Institute (ODI), Peter Hildebrand's Sondeo, Robert Rhode's Farmer-back-to-farmer and Farming system research and diagnostic surveys at the CGIARs (Chambers and Ghildyal, 1985; Molnar, 1989). Similarly, ethnographical and anthropological approaches have also improved in terms of interacting and understanding local people for pragmatic as well as academic purposes (Werner and Schoepfle, 1987a; Werner and Schoepfle, 1987b). Such multidisciplinary approaches and methodologies have been extensively reviewed (McCracken *et al.*, 1988; Molnar, 1988; Cornwall *et al.*, 1994) and also analysed to identify the potential for agroforestry applications elsewhere (Asia-Pacific Agroforestry Network, 1994). Perhaps the most significant development in recent years has been a shift of emphasis towards greater participation by rural people in the process of development (Cornwall *et al.*, 1994). Participation, in this context, being associated with empowerment to make decisions rather than a more passive involvement through a process of consultation. This has been coupled with a recognition that farmers themselves are often competent experimenters (Richards, 1994) and hence increasingly explicit references to the importance of indigenous knowledge (Warren *et al.*, 1995).

Despite the perceived interest in agroforestry in Sri Lanka (MALF, 1995), most large (Government) research organisations have yet to realise the importance of using multidisciplinary approaches in agroforestry planning. Therefore, very little genuine research collaboration between scientists and, participation and knowledge of local people, have been used in agroforestry and community forestry research and development programmes (Carter *et al.*, 1994). Increase in the use of multidisciplinary methods in research and extension efforts, therefore, is highly relevant to agroforestry development in Sri Lanka. Such studies may increase the awareness of benefits of using appropriate methods in agroforestry research and extension. Very recently, the potential of using indigenous knowledge in promoting sustainable rural development in Sri Lanka was recognised at the national level (Ulluwisihewa *et al.*, 1994), but there is very little prospect of such knowledge being used without the development and application of appropriate methodologies to achieve this.

1.3 JUSTIFICATION

1.3.1 Methodologies for agroforestry research and extension

It has been observed that the adoption rates of designed agroforestry technology packages as promoted by conventional farming systems research and extension (FSR/E) methods have been low whereas farmers have often expressed interest in specific aspects of these packages (Kerkof, 1990; Buck, 1990; Bunderson *et al.*, 1990; Scherr, 1990) and may often have a sophisticated understanding of the underlying ecology of their farming practices (Richards, 1994; Thapa *et al.*, 1995). This has led to the suggestion that incremental changes to existing practices, which build on local knowledge and farmers incorporating new knowledge and technological elements into their systems are more likely to be successful than extending pre-fabricated technology packages (Anderson *et al.*, 1993).

To achieve this farmers require support in making decisions about the incorporation of trees in their farming systems based on sound ecological knowledge that adds to what they already know. In order to construct appropriate decision support tools and identify appropriate experimental research to provide knowledge required by farmers to effect change, it is necessary to document and evaluate what farmers know, identify gaps that constrain development of agroforestry practices and then provide knowledge that fills the gaps that were identified either from previous research findings or through new research. Such an approach can be identified as an incremental knowledge-based approach.

1.3.2 Farming Systems Research and Extension Methods

The obvious choice of an FSR/E methodology to use in the present study was the Diagnosis and Design methodology (D & D) developed specifically for agroforestry at ICRAF. This both typifies the FSR/E methods employed in the CGIAR sector (Simmonds, 1985) and incorporates features specifically designed to cater for the consideration of trees.

The underlying conceptual and theoretical framework, (Raintree, 1984) methodological guidelines and rationale of its application (ICRAF, 1983a; ICRAF, 1983b, Raintree, 1987; Hitinayake, 1992) and examples of the application (Hoek, 1983; Raintree, 1983a; Raintree, 1983b; Rocheleau, 1983; Hoekstra, 1984; Rocheleau and Hoek, 1984; Raintree and Rocheleau, 1987; Raintree, 1988; Scherr, 1990) have been discussed in great detail elsewhere.

The basic assumption underlying the D & D methodology is that agroforestry techniques are system rather than location-specific (Raintree, 1984). Therefore, the ultimate goal of the diagnosis and design methodology is to identify the agroforestry techniques which solve the problems identified in the diagnosis and realise the potentials of specific land use systems. Hence, the principal purpose of the D & D methodology is to guide technology generation and the research on which it is based. D & D focuses its analysis on the land use system in order to obtain a holistic view of the system in which the farmer operates. Further, it views the land use system as a combination of particular land facets with certain management. D & D is open-ended but structured to create a balance between the need to be holistic and at the same time progressively sharpen the focus of analysis by excluding irrelevant information. Due to this "optimal ignorance" nature of the methodology and the employment of multidisciplinary teams, as with other farming systems research and extension methods such as Sondeo (Hildebrand, 1981), the process of understanding rural realities is achieved rapidly. Essentially existing agroforestry technologies are 'matched' with the problem specification and system characteristics identified through the diagnostic procedure and then an iterative research and extension process followed, through which the diagnosis and technological intervention are continuously refined through a programme of adaptive research, typically involving a large on-farm research component.

A need for methodological development to D & D procedures can be identified in two main ways. Firstly, many of the original diagnoses done at ICRAF, even though in very different circumstances, resulted in similar recommendations many involving the introduction of alley cropping technologies which have subsequently been found to be inappropriate (Sanchez, 1995). This may reflect both failures in performance of the procedures, as has occurred with FSR/E methods more generally at both international and national levels (Biggs, 1995) and the fact that there were not many well-researched agroforestry technologies on the shelf to be matched with the problems and constraints identified through diagnosis. Secondly, as mentioned earlier, farmers have generally not adopted whole technology packages generated through the application of D & D procedures but have shown interest in some of the components of such packages (Buck, 1990).

1.3.3 Knowledge-based systems approach

1.3.3.1 Introduction

A novel knowledge-based systems approach has recently been developed to collect, and represent explanatory ecological knowledge underlying agroforestry practices and to identify gaps in farmers knowledge that constrain the development of the system and result in an explicit record of local ecological knowledge. This record is used as a basis for the identification of focused research or existing scientific knowledge that will fill gaps in knowledge thereby removing constraints (Walker *et al.*, 1994).

This approach was iteratively developed through fieldwork in a range of socio-cultural and agroecological conditions in the mid-hills of Eastern Nepal (Thapa, 1994), the Kandyan homegardens in Sri Lanka (Southern, 1994; Jinadasa, 1995), the semi-arid and degraded rangelands of Shinyanga region, Tanzania (Rosas da Costa, 1993; Kilahama, 1994), the indigenous tea gardens in the hill evergreen forest in the highlands of northern Thailand (Preechapanya, *in preparation*) and the Uttar Pradesh hills of India (Garde, 1992).

This research has established the existence of a sophisticated understanding of ecological processes underlying the management, by farmers, of their production systems. However, while it has been suggested that this can lead to identification of research and extension for improvement of those agroforestry practices only broad outlines of the sort of research that may be appropriate have been suggested (Thapa *et al.*, 1995). There is a need, therefore, both to refine the methodology and to extend its application to the research and extension phase to more fully evaluate its usefulness.

1.3.3.2 Key conceptual and theoretical features

Since the knowledge-based systems approach is a novel methodology, detailed discussion about its conceptual, theoretical and methodological features are available in recent publications elsewhere (Thapa *et al.*, 1995; Walker *et al.*, 1995a; Walker *et al.*, 1995b). The discussion here will, therefore, be limited to examination of the characteristics which make this methodology suitable for achieving an incremental knowledge-based approach to improving agroforestry practices.

(a) Explicit focus on use of local knowledge

Agroforestry involves managing interactions between species. Therefore, knowledge about interactions amongst plant species is essential in planning incremental improvements to existing agroforestry practices and for developing new ones. Most experimental research in agroforestry has, however, involved simple combinations of few species in regular arrangements, whereas long-established agroforestry practices such as Kandyan homegardens (Jacob and Alles, 1987) involve significant species diversity and complex arrangements and appear to have sustained productivity at low input levels. However, development and improvement of such agroforestry practices is currently limited by the inadequacy of understanding of ecological interactions amongst different plant species.

Evidence suggests that, because of a long history of managing production practices, including agroforestry, local people have developed useful understanding about the ecological interactions (Conklin, 1957; Baker *et al.*, 1977; Brokensha and Riley, 1980; Posey, 1985; Richards, 1985; Chandler, 1991; Barrow, 1992; Richards, 1994; Warren *et al.*, 1995). Similarly, many authors have asserted that farmer practices in tropical homegardens including Kandyan homegardens are ecologically rational through providing explanations to certain practices on the basis of scientific theory, using their own observations and informal inquiry (Michon, 1983; Fernandes *et al.*, 1984; Fernandes and Nair, 1986; Jacob and Alles, 1987; Soemarwoto, 1987). This suggests that local knowledge could be used in conjunction with scientific understanding of species interactions to improve existing agroforestry practices and develop new ones. Further, exploring local knowledge could uncover gaps and technically less sound areas of farmers' understanding and allow the identification of external knowledge to bridge such gaps

(Gladwin, 1980; Rocheleau, 1987; Bently, 1994). Also, indigenous ecological knowledge may often be distributed unevenly within and between communities so that collecting and representing this knowledge in a formal way may enable scientists and farmers to explore and use it as an encyclopaedic resource not previously available, with attendant issues of intellectual property rights and impacts on the balance of wealth and power within the community.

(b) Exploration of indigenous ecological knowledge

Exploring local knowledge systems underlying the management of agroforestry practices is a difficult task as it is culturally specific. Various authors have described ethnoscience or ethnography as an approach to "the study of a system of knowledge developed by a given culture to classify the objectives, activities and events of the universe" (Hardesty, 1977) and ethnoecology as "environments as understood by those who act within them" (Vayda and Rappaport, 1968). Furthermore, many authors have emphasised ethnoecology as an approach to exploring and understanding native conceptions and how they interact with the environment (Conklin, 1954; Frake, 1962; Posey, 1984; Brosius *et al.*, 1986). Therefore, it can be argued that ethnography can contribute to identifying concepts and methods to learn and record farmers' ecological knowledge about managing agroforestry practices. The knowledge-based systems approach has adopted many concepts and approaches from ethnography and anthropology for accessing people's knowledge seeking an 'emic' (Knight, 1980) rather than 'etic' explanation of farmer behaviour. Thapa (1994) argues that the approaches adopted in the knowledge-based systems methodology fall between cognivist and materialist approaches to ethnography (Werner and Scoepfle, 1987a) and are applied with an ethnoecological perspective. Their application has revealed that while some concepts appear culturally unique, much farmers' knowledge of practical relevance is surprisingly comparable, compatible and complementary to the professional knowledge used by research and extension workers derived from the western scientific tradition (Thapa *et al.*, *in press*).

(C) Practical use of knowledge

The knowledge collected here was required to be able to be used practically in agroforestry development. The knowledge-based systems approach, therefore, has adopted techniques used by knowledge engineers in the field of artificial intelligence to assist in the acquisition of knowledge, and subsequent automated reasoning with it that assists in handling of qualitative information in much the same way as computing power has revolutionised what can be done with numerical data (Kendon *et al.*, 1995).

1.3.3.3 Key methodological features

The knowledge-based systems methodology adopts an analytical approach to knowledge acquisition with the assistance of artificial intelligence techniques. Despite, numerous approaches and methods available for indigenous knowledge research, the information generated has been largely descriptive. Such descriptive information tends to be difficult to analyse, especially for purposes other than it was collected and, therefore, is of limited practical use. In the context of the present research the collected knowledge must be able to be rigorously evaluated to identify the gaps in the farmers knowledge which constrain the development of the system.

The computer software environment used in present research (AKT) was developed with the use of artificial intelligence techniques to facilitate systematic and objective recording of ecological knowledge from various sources, and then the storage and analysis of such knowledge (Walker *et al.*, 1995a). Due to the complex nature of agroforestry practices and the social, economic, biological and environmental interactions involved, knowledge held by farmers may be widely scattered amongst a range of sources. Furthermore, in the present research, there is an explicit intention to fill gaps identified in the farmers knowledge with relevant knowledge from existing scientific findings or through new research. This requires tools to combine knowledge from various sources which essentially requires a neutral representational framework within which knowledge from different sources can be held.

Expert systems incorporating artificial intelligence techniques have been commonly used especially in the fields of medicine and engineering and have also recently been considered in natural resource management (Muetzelfeldt, 1984; Jones, 1989; Warkentin *et al.*, 1990; Bennett, 1992; McGregor, 1992; Grinspan *et al.*, 1994). There have, however, only been the most rudimentary applications of expert systems in agroforestry (Warkentin, *et al.*, 1990) and indigenous knowledge more generally (Babu *et al.*, 1995 and because of the explicit focus on agroforestry development, the AKT knowledge-based systems approach has not adopted an expert systems model producing prescriptive output. Expert systems reason with knowledge to produce answers to specific and well defined types of questions as for example in medical diagnosis. However, development of such a system demands accurate definition of questions to be answered by the expert system. Those systems, therefore, are not appropriate for dealing with imprecise, incomplete and contradictory or uncertain information which often characterises the real world problems and understanding available about complex agroforestry practices.

The knowledge-based systems approach mainly focuses on dealing with qualitative information. This is because farmers knowledge is largely qualitative and their decisions are generally based on qualitative assessment in situations where precise, quantitative information is rarely available (Gladwin, 1980; Zabawa and Gladwin, 1995).

1.4 RESEARCH HYPOTHESIS

The above discussion reveals that a knowledge-based systems approach is suitable for applying to a highly focused domain, to collect in depth knowledge, whereas conventional FSR/E methods are geared to problem identification in a broader context. It seems sensible to suggest that ICRAF's diagnosis and design (D & D) methodology (ICRAF, 1983a and 1983b) developed on the lines of conventional farming systems research and extension may be appropriate for generating descriptions of actual practice and constraints on the farming system in order to identify prioritised areas for applying a knowledge-based systems approach. This research aimed to explore and evaluate such a strategy.

The overall hypothesis was, therefore, that an incremental knowledge-based approach had a useful and complementary role to that of conventional farming systems research and extension methods, in agroforestry research and extension.

1.5 RESEARCH OBJECTIVES

The overall objective of this study was to evaluate the role of a knowledge-based systems approach in agroforestry research and extension and to compare it with conventional farming systems research and extension methods to identify the strengths, limitations and complementarity of the two approaches with the overall aim of improving existing and developing new agroforestry practices.

Hence, ICRAF's D & D methodology was applied to identify land use problems, and their causes and to design solutions to problems and a novel knowledge-based systems approach (Walker *et al.*, 1994) was subsequently applied to collect and represent explanatory ecological knowledge underlying specific aspects of agroforestry practices and to identify gaps in farmers' knowledge that constrain development of the system and hence identification of research and extension that would fill these gaps and thereby remove constraints.

This framework allowed the following specific objectives to be addressed.

- To evaluate the appropriateness of conventional FSR/E methods for identifying and prioritising research and extension in relation to farming systems involving complex agroforestry practices and specifically whether classification at the level of the farming system results in identification of sufficiently homogeneous groups of agroforestry practices for the purposes of designing research and extension.

- To explore the extent to which a knowledge-based systems approach generated new information which changed the information base and perceptions about farming practice from that available from a conventional diagnosis and thus the extent to which the type of research and extension priorities that emerged were different.

  To further develop and test the knowledge-based systems approach by:

  - comparing alternative methods of testing representativeness of knowledge collected from a purposive sample of key informants against the distribution of knowledge in the whole farming community as a prelude to using knowledge as a basis for identifying research and extension priorities,
  - exploring the validity of items of indigenous knowledge in an objective sense through experimentation to determine their scientific validity,
  - exploring the possibility of generating and introducing new knowledge to fill gaps identified through analysis of farmers' existing knowledge.

1.6 THE CHOICE OF STUDY AREA

Choice of an appropriate case study area was critical for achieving the research objectives. After visiting and then evaluating the suitability of potential sites, Galagedara Regional Secretariat Division, Kandy, Sri Lanka was selected for the present study because of the following features.

- The farming system in the area involved a reasonably complex agroforestry practice, in the form of the Kandyan homegardens (Section 2.3).
- People in the area were highly involved in their farming practices as they were heavily dependent upon farming for their living. Hence, it was reasonable to expect that these farmers may have developed useful ecological understanding about managing interactions in Kandyan homegardens, and, therefore, be able to discuss the management of their gardens with researchers.

- There was a reasonably homogeneous cluster of villages at the site, populated by people of the same ethnicity, caste and religion operating farming systems in similar agroecological conditions.

A detailed description of the study area has been included where appropriate (Section 2.3 and 2.4)

1.7 STRUCTURE OF THE THESIS

The thesis is structured as follows.

Chapter 1 outlines the background and context to the research and states the research problem, hypothesis, objectives and justifies the research programme and choice of study area.

Chapter 2 describes the application of the diagnosis and design methodology, in the Galagedara Regional Secretariat division, Kandy, Sri Lanka for identifying land use problems, their causes and interventions to solve these problems identified.

Chapter 3 examines the effectiveness of land use system classification as a means of identifying sufficiently homogenous groups of agroforestry practices for research and extension purposes.

Chapter 4 describes the sequential application of knowledge-based systems methods to collect and represent explanatory ecological knowledge underlying specific aspects of agroforestry practices at the same site as the FSR/E diagnosis was done and attempts to identify gaps in farmers' knowledge that constrain development of the system.

Chapter 5 explores the validity of farmers' ecological knowledge by taking two fairly specific items of knowledge from Chapter 4 that were not in the scientific domain and subjecting them to experimental verification.

Chapter 6 explores the possibility of introducing new knowledge to the farming community using a case study approach involving gaps in knowledge identified through analysis of the farmers' knowledge system in Chapter 4.

The final chapter (Chapter 7) summarises the findings of the whole research programme and reappraises the role of knowledge-based systems and farming systems research and extension methods in agroforestry development in the light of the present research findings.

Unless specified all tables and figures in the following chapters derived from the authors' own work.

CHAPTER 2

APPLICATION OF FARMING SYSTEMS RESEARCH AND EXTENSION (FSR/E) METHODS

2.1 INTRODUCTION

The objective of this chapter is to explore the usefulness of farming systems research and extension (FSR/E) methods in the agroforestry domain through their application in a case study at the Galagedara Regional Secretary Division (RSD). As discussed earlier (Section 1.3.2) ICRAF's Diagnosis and Design (D & D) methodology represents a package of FSR/E techniques specifically designed for planning agroforestry research.

As discussed in the many publications about the D & D methodology, its primary aim is to identify land use problems and design appropriate model solutions. This results in recommendations of model solutions for specific locations which are then extended as technology packages (ICRAF, 1983a; ICRAF, 1983b). The intention of the D & D methodology, is therefore, to assist researchers and project managers in matching possible agroforestry interventions to different land users and land use constraints, in a particular area.

2.2 FIELD METHODOLOGY

The conceptual, theoretical and methodological framework of the D & D methodology was summarised earlier (Section 1.3.2). The general methodological approaches and guidelines of ICRAF D & D methodology were used in this research investigation and are well documented elsewhere (ICRAF, 1983a; ICRAF, 1983b; Raintree, 1983a; Raintree, 1983b; Raintree, 1990), hence the methodological section here simply describes the actual methods used in this field study. The Galagedara RSD, Kandy, Sri Lanka was chosen for the reasons discussed earlier (Section 1.6).

Diagnosis and design methods were applied in three phases denoted in accordance with the literature as: prediagnostic, diagnostic and technology design. Discussion of the field methodology follows this structure.

2.2.1 Prediagnostic stage

2.2.1.1 Planning the study

The D & D exercise was conducted by the researcher and limited to a period of eight weeks.

Meetings with the Extension Officers of the Galagedara Agrarian Services Centre (ASC) and the Agrarian Services Committee, (consisting of farmers who represented the agricultural community of the area) were held at the ASC. During these meetings the nature and objectives of the study were briefly explained and their assistance was requested in carrying out the study.

Meetings (lasting one to one and a half hours) were held with the extension officers at Galagedara ASC on three Wednesdays during the study. During these meetings the results of the prediagnostic and diagnostic analysis, and technology design stages were discussed.

2.2.1.2 Prediagnostic survey

A survey was carried out to collect background information on the study area and to develop a rapport with the farmers, and the village and regional level Government Officials involved in agricultural development in the area. The following methods and tools were used:

(i) Secondary information was collected from the records of the Galagedara Regional Secretary's office (GRSO, 1993) and the Galagedara ASC (GASC, 1993), publications (IRDP, 1990) and maps (Department of Agriculture, 1980; Department of Agriculture, 1988) which contained the bio-physical and socioeconomic information for the area.

(ii) Reconnaissance visits were made to the study site to assist in the interpretation of secondary information, and to collect supplementary information through direct observation of environmental features and land use patterns. Thus, each of four Agrarian Services Divisions (ASDs) were visited twice and three to four hours were spent in the site during each case.

(iii) Interviews with qualified informants, including rural development planners at the Regional Secretary's office, agricultural extension officers at the ASC, the Agrarian Services Committee and Village Services Officers (*Grama Seva Niladari*) were also held during those visits (Table 2.1).

Table 2.1 Details of the interviews with qualified informants.

Informant	Regional office	Number from each category
Regional secretary	Regional Secretary's' office, Galagedara	1
Regional development officers	Regional Secretary's' office, Galagedara	2
Agrarian Services Officer	Agrarian Services Centres- Galagedara, Hataraliyadda, Weliwita and Aludeniya	4
Extension officer / Export Agricultural Crops	Agrarian Services Centre, Galagedara	1
Agricultural Instructor	Agrarian Services Centre, Galagedara	1
Tea Inspector	Agrarian Services Centre, Galagedara	1
Rubber Instructor	Agrarian Services Centre, Galagedara	1
Coconut Development Officer	Agrarian Services Centre, Galagedara	1
Livestock officer	Regional Secretary's office, Galagedara	1
Agrarian Services Committee members[1]	Different villages	12
Village Services Officers	Different villages	8

[1] Farmers nominated to represent the Village Agricultural Committees (which consisted of all farmers in the village) at the Agrarian Services Centre.

2.2.1.3 Prediagnostic analysis

Interpretation and analysis of the prediagnostic survey data produced a description of the following topics:

(i) the socioeconomic environment of the area

(ii) the climate and land use in the area, and

(iii) the main land use systems in the area and their constraints.

The following procedure was adopted to identify the land use systems:

This information was used to identify the biophysical and socio-economic criteria most appropriate for differentiating land use systems within the Galagedara RSD. These were:

(a) main land use practices in the households,

(b) main sources of food and cash supply of the household, and

(c) main employment of members within households.

These criteria were used to differentiate the main land use systems, so that they represented groups of holdings that were sufficiently similar to be classified together for the purpose of targeting research and extension. The discussions with qualified informants and direct observations made during reconnaissance visits were particularly useful in making a preliminary assessment of their problems.

(iv) Selection of priority land use system

One land use system was selected for further investigation on the basis of the following criteria:

- severity of problems; that is, the land use system which was most severely constrained,
- regional representativeness; that is, the land use system which covered the highest proportion of land and of the farming community, and

- potential for an agroforestry approach to the improvement of the land use system.

2.2.2 Diagnostic stage

2.2.2.1 Diagnostic survey

A field survey was carried out in the selected land use system in order to identify common strategies and problems. Sample diagnostic farm survey guidelines (ICRAF, 1983a; ICRAF, 1987b) and farm level D & D survey data recording forms (ICRAF, 1983b; ICRAF, 1987a) adapted for the present study were used to conduct the diagnostic survey and are reproduced in Appendix 1. Diagnostic interviews and direct field observations were used for the collection of diagnostic information. Semi-structured and informal approaches were used when conducting interviews.

Twelve were randomly selected from the 114 Village Services Officers' (VSO) divisions found in the Galagedara, Hataraliyadda and Weliwita ASC areas (Figure 2.1) because those areas were typical of the Mid Country Wet Zone climate of Sri Lanka (Section 2.3.3). A full day was spent in each of the divisions to minimise travelling between different parts of the region and so to maximise time with farmers. More time was spent on the farms representative of the target land use system than other farms. Six farmers were visited in each VSO division. This was considered to be the number of farmers that could realistically be interviewed during a single day and likely to be enough to allow a general picture of land use characteristics to be ascertained. Therefore, a total of 72 farmers from the selected land use system were interviewed for the purpose of this investigation . This was efficiently carried out by walking in a circular route through the village and visiting farms that were selected by drawing random numbers.

The objectives of the diagnostic survey were as follows:

(i) to identify land user objectives and strategies; that is, output subsystems,

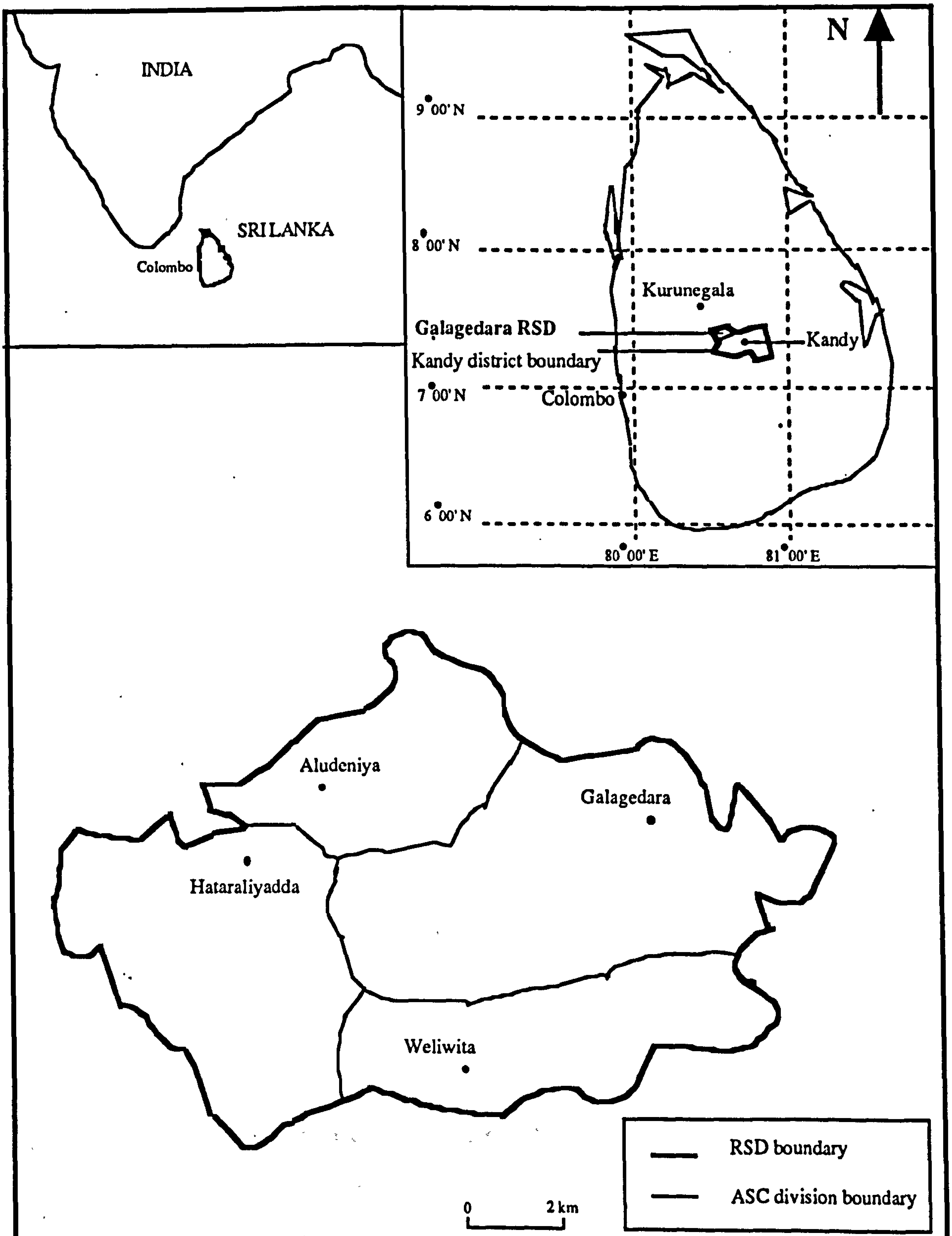

Figure 2.1 Location of the Galagedara RSD.
(Source: IRDP, 1990)

(ii) to evaluate the performance of output subsystems and identify problems by defining gaps between potential and actual performance, and

(iii) to determine the constraints that limited the performance of subsystems.

2.2.2.2 Diagnostic analysis

The following activities were undertaken during the final diagnostic analysis:

(i) field data were analysed and this information (that is key constraints and causal relationships) was then incorporated into structural models (i.e. node and link diagrams) to identify intervention points that would improve system performance, and

(ii) suggestions were made for interventions to solve the problems that had been identified.

2.2.3 Design stage

Based on the design specifications identified during the diagnostic analysis, potential interventions were identified (by the researcher) and those were matched with the site characteristics and problem and then screened to see if other constraints were violated.

2.3 PREDIAGNOSTIC INFORMATION

2.3.1 Socioeconomic status

The Galagedara RSD covers an area of about 109 square kilometres and in 1990 had a population of 66 142 (the mean population density was 606 people per square kilometre) and was growing at a rate of 1.7 % per annum (IRDP, 1990). Mean land holding size was 0.58 ha, and the mean family size was 4.8 with a dependency ratio[1] of 2.5. Ethnically about 93 % of the community are Sinhala and the balance consisted of Moors and Tamils. Buddhists form the main religious group, and make up about 92% of population while the remainder consists of Hindus, Muslims and Christians. About 21 % of the population between the ages of 15 and 55; that is, the work force, was fully employed in agriculture while another 44 % was at least partly involved (IRDP, 1990; GASC, 1993).

About 55 % of the villages had access to public transport. There were 65 rural credit institutions and 26 post offices found in the region. There were two medium-sized towns within the area and the distance from the centre of the area to the closest cities of Kandy and Kurunegala was 18 km and 24 km respectively. There were 46 schools with an average student / teacher ratio of 18. There were also three hospitals, 15 government clinics and 47 other clinics available in the region. Most parts of the area are semi-rural. About 63 % of the population received food aid from the government because of low income (that is, when monthly cash income falls below Rs. 700).

Although there were many health, education, post and telecommunication and marketing centres in and around the area, the main infrastructural barrier to development lay in the inadequate road network and transport facilities. The few main roads (4.17 km) and several minor roads (57.35 km), in the area were not sufficient for the transport of produce to the main town centres. Public transport services existed only in and around the main town centres and roads, leaving the remote areas isolated. Because of the hilly terrain and poorly maintained roads it was difficult for people to use bicycles for transport.

2.3.2 Land use history of the area

During the colonial administration (before 1948) a large proportion of uplands in the region were converted to tea (*Camellia sinensis*) and rubber (*Hevea brasiliensis*)

1 dependancy ratio= total population / employed population

plantations under the Waste Land Ordinance (Perera, 1992; MALF, 1995). As a result most of the traditional villages became very small. Local people who were employed by the government became rich and influential. This new elite bought land from poor farmers in the region. They also planted some of their land with plantation crops using the subsidy schemes that operated during this period. Today, holdings of the local rich class have become relatively small (typically 1-2 ha) because of land fragmentation (GRSO, 1993).

The equitability of land ownership thus decreased and population pressure for land among less wealthy households became very intense. Some of the less wealthy became hired labourers on the farms of the local elite. Some of the farmers in the area migrated to settlement schemes, which were established in the less populated dry zone of Sri Lanka after independence in 1948 (Perera, 1992). Village expansion schemes started in the early 1950's, with the aim of alleviating some of the pressure for land (Perera, 1992). This involved government purchasing of parts of the large private estates and the subsequent distribution of land amongst low income families so that each family owned between 0.25 ha and 0.50 ha.

Before the introduction of plantation crops (mainly rubber) to the area in the 1930s, the middle and upper parts of the hills were covered with jungle, where the farmers practiced "*chena*" cultivation, a form of slash and burn agriculture (Silva, 1992; GRSO, 1993) and planted annual crops such as finger millet (*Eleusine coracana*), upland rice (*Oryza sativa*), mustard (*Brassica nigra*), and vegetables. In addition to food, this land also provided timber for the requirements of the local population.

People lived in homegardens located in the lower parts of the hills and also planted lowland rice on the flood plains below these gardens. Until about 1950 Kandyan homegardens (KHGs) were mainly planted with both annual and perennial food crops such as coconut (*Cocos nucifera*), arecanut (*Areca catechu*), *kitul* (*Caryota urens*), jak (*Artocarpus heterophyllus*), bread fruit (*Artocarpus altilis*), cassava (*Manihot esculenta*), yams (*Dioscorea* species), sweet potato (*Ipomoea batatas*) and vegetables. Among the spice crops only pepper (*Piper nigrum*) was planted on a small scale. Because of the increase in the price of spices in the mid 1950s the proportion of spice crop cultivation in the KHGs increased at the expense of other food crops (GRSO, 1993).

2.3.3 Climate

The study area can be divided into two distinct climatic and land use types: (i) the Northwestern parts of Galagedara RSD has a climate and land use typical of the Low Country Intermediate Zone where coconut and lowland rice is typically grown, and (ii) the remainder of Galagedara RSD which is wetter and falls within the third region of Mid Country Wet Zone[1] of the agro ecological map of Sri Lanka (Department of Agriculture, 1980) where tea, rubber and KHGs are mainly found (Table 2.2).

Table 2.2 Different climatic regions of Galagedara RSD.

Characteristics	Wet areas	Dry areas
Climate	Climate typical of Mid Country Wet Zone of Sri Lanka	Climate typical of Low Country Intermediate Zone
Mean daily minimum temperature Mean daily maximum temperature Average temperature	20.0°C 28.7 °C 24.3 °C	23.9°C 29.9 °C 27.0 °C
Rainfall range Dry season (s)	2000-2500 mm a^{-1} January-February	1500-1999 mm a^{-1} January-March and July-August
Elevation	182-333 m	100-182 m
Predominant soil groups	Reddish brown latosolic and immature brown loams	Reddish brown earth and low humic gley
Slope	Moderately sloping (8-30%)	Gentle (3-8%)
Regional representativeness	Galagedara, Hataraliyadda and Weliwita ASC areas	Aludeniya ASC area which borders the Kurunegala District
Main land use types	Rubber, lowland rice, KHGs and tea	Coconut, lowland rice and homegardens

Source: Department of Agriculture, 1980; Department of Agriculture, 1988; IRDP, 1990; Department of Agriculture, 1993

[1] WM3

It was decided to focus on the wetter part of the Galagedara RSD because it was typical of the Mid Country Wet Zone climate of Sri Lanka and covered 75 % of Galagedara RSD. The rainfall of the wetter part of Galagedara RSD is high throughout the year but shows two peaks during April to June and October to December (Figure 2.2). The total rainfall ranges from 2000 to 2500 mm a^{-1}. The climate and soil are ideal for perennial tree crop plantations. The topography of the area is highly variable and hence terrain can be steeply dissected, hilly, rolling or undulating. Soil erosion was significant in the areas with sloping terrain due to the presence of highly erodable immature brown loam soils and medium intensity rains. The soils are sandy clay loam in texture. Low humic gley soils which are imperfectly drained are found on the valley bottoms. There are no major irrigation schemes in the area and hence most of the land is rainfed. Within the region, there are four small streams, their source being in the small mountains in the area.

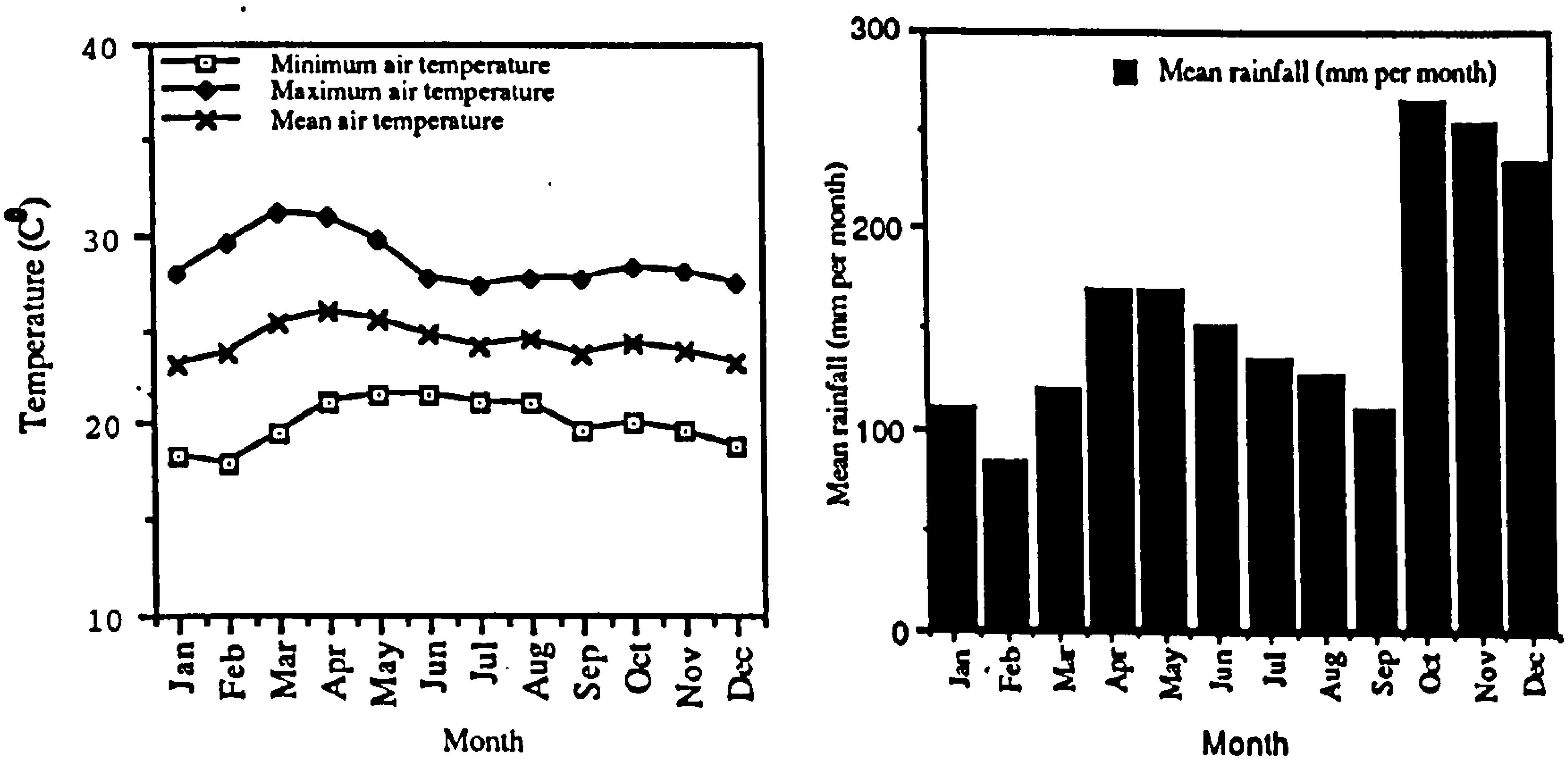

Figure 2.2 Meteorological data for wetter parts of Galagedara RSD.
(Source: Department of Agriculture, 1993)

Key: Figures averaged over 10 years.

2.3.4 Land use

The uplands in the area consist of rubber, tea and KHGs (Table 2.3). The KHGs contain a large number of tree and crop species used for the production of spices, food, beverages, timber and multi-purpose trees grown around homesteads (Jacob and Alles, 1987). The valley bottoms were mostly used for lowland rice. The upland to lowland ratio of the area was about eight to one (IRDP,1990). About 80 % of the land area was occupied by holdings of less than 4 ha in size which are categorised as small holdings (GRSO, 1993). This type of land use is typical of the steep and undulating lands of the Mid Country Wet Zone of Sri Lanka.

Table 2.3 Land use in the wetter parts Galagedara RSD area.

Land use	Small holdings (ha)	Estate sector (ha)	Total extent (ha)
Rubber	2044 (96 %)	96 (4 %)	2284 (30 %)
Homegardens	2276 (100 %)	-	2276 (30 %)
Lowland rice	1330 (100 %)	-	998 (13 %)
Tea	454 (68 %)	211 (32 %)	665 (9 %)
Cultivable land	-	-	485 (6 %)
Protected areas[1]	-	-	731 (10 %)
Buildings	-	-	170 (2 %)
Total	6104 (80 %)	307 (4 %)	7609 (100 %)

Source: IRDP, 1990; GASC, 1993

A schematic presentation of the general land use pattern in the wetter parts of Galagedara RSD is given in Figure 2.3. The majority of people and hence the concentration of KHGs are in the mid and lower parts of the hills especially alongside the main roads. This can be attributed to easy access to main roads and better availability of water in the lower parts. There is no scarcity of water throughout the year for the people settled near flood plains and on the lower slopes as they can obtain water from bore holes. However, people settled in the mid and upper parts of hill land have to come down to these bore holes for water during dry months.

[1]protected areas were mostly covered with natural forests

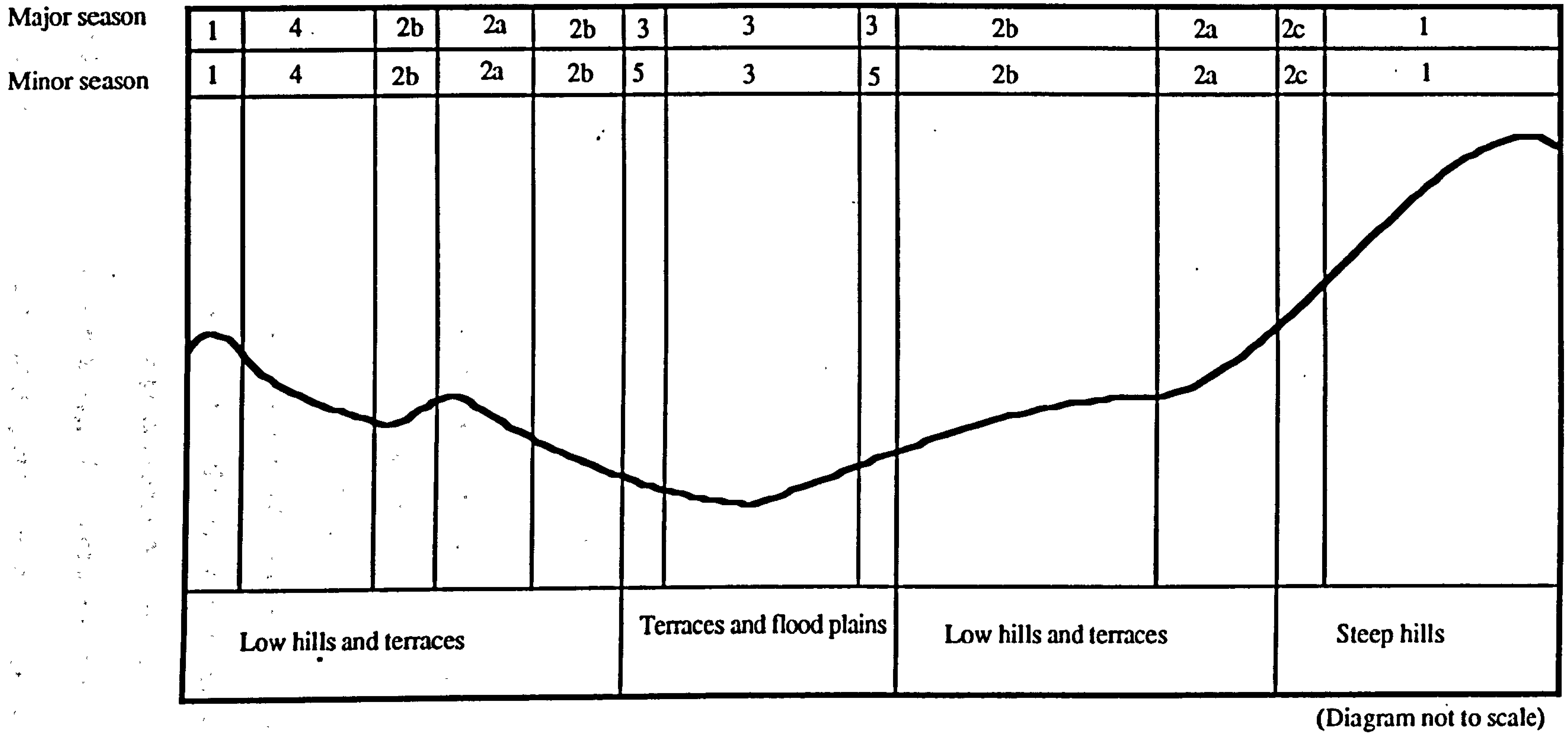

Figure 2.3 Schematic presentation of the general land use pattern in the Galagedara RSD, during the major and minor growing seasons.

Key: 1. Sub-montane evergreen forests: these were areas reserved for watershed protection but were in a degraded state as a result of illegal felling and fires.
2a. KHGs: there was a scarcity of water for people especially during dry months because of the lowering of the water table but this did not affect the growth of common crop species such as nutmeg, clove, tea, coffee, cocoa and pepper or timber trees.
2b. KHGs: water can be obtained from bore holes throughout the year.
2c. KHGs: similar to those on 2a but an illegal encroachment into a protected area.
3. Lowland rice
4. Rubber
5. Rice fallow

Over 394 illegal settlements have been recorded in the area (IRDP, 1990). These are found in the reservation areas, such as mountain tops, steep areas bordering roads and alongside small streams. Some of these settlements have planted KHGs. Vegetation cover in the protected areas has degraded considerably as a result of illegal fellings and fires, and the loss of vegetation cover has caused adverse effects on the hydrology of these catchments (Salati *et al.*, 1983).

2.3.5 Major land use systems and their constraints

The key characteristics of the common land use systems found in the wetter parts of Galagedara RSD are given in the Table 2.4. Spice growers, tea and rubber small holders were distinguished in land use systems I, II and III respectively. Over 75% of their food and cash income was provided from their farms. Cash income in land use system I, was only moderate at the time of survey but had been high as in the land use systems II and III until spice prices fell in the early 1990s. In all systems most adult males in the household were working as full time farmers on their farms. However, approximately 50 % of the younger males were employed off-farm to provide some additional income to the household. Most still worked on their farms part-time during peak work periods. Adult female members were mostly involved in domestic activities. These included cooking, looking after children, collecting firewood, cleaning and work in the paddy fields and homegardens, such as planting, weeding and drying the harvests. The women very rarely did off-farm jobs. Children up to age 18 were mainly engaged in educational activities and played a very small or no part in domestic or farming activities. The living standards of households in those categories were moderately high.

Because of the involvement in off-farm work very little family labour was left to work and manage the farms. The uplands were managed mostly with family labour and some hired labour during the peak labour demanding seasons or when the prices of farm produce was high. The lowland rice fields of the land use systems I and III were managed according to the "*aththama* system" or the "*ande* system". Under the *aththama* system farmers of different households form small groups of 5-15 people and help each other with labour intensive farming practices. The rice fields that were too large to be managed with family labour were managed under the "*ande* system". In this system an "*ande*" labourer will undertake all cultivation practises whilst the land owner provides the inputs. The harvest is then shared equally among them.

Land users in the fourth category owned about 0.10-0.40 ha of KHG. Some of them also cultivated lowland paddy fields of about 0.1-0.4 ha under the *ande* system, which were owned by large land owners. Some of the uplands had been given by the government to landless people under village expansion schemes. This land did not produce a sufficient income for the household. Although there was no permanent off-farm employment they were able to work as hired labourers on nearby farms, sawing timber and uprooting rubber trees. In addition to performing domestic activities some women also earned extra cash by working as hired labourers in groups during peak labour seasons, planting and weeding in the rice fields and harvesting in the farms. Cash income of households was very low and earnings were mainly from off-farm employment. People in this land use system were amongst the poorest in the region. They received benefits from social security schemes, introduced by the Government of Sri Lanka, in the form of "food stamps" and "*Janasaviya*" schemes, which provide essential food items free of charge on a monthly basis, and grants to start self employment.

The household members in land use system V were employed full time off-farm and a single household owned about 0.1 ha of homegarden. Homegardens tended to be simple in structure and management intensity of land was variable. The members of this category were wealthy because they had secure full time off-farm employment. Their cash income was high and they lived close to the main townships, along the main roads. About 50 % of them were Muslims of whom over 90% were involved in trade (GASC, 1993).

Other than those main categories there were large land owners, who had over 4 ha of upland planted with rubber or tea and facilities for processing the harvests. These estates were managed using a resident permanent labour force, known as "estate labour".

Table 2.4 Key characteristics of main land use systems (LUSs) in the wetter parts of the Galagedara RSD.

Characteristic	LUS-1 Spice growers	LUS-2 Tea small holders	LUS-3 Rubber small holders	LUS-4 Hired labour force	LUS-5 Traders, Government and private sector jobs
Main source of cash income	KHG: sale of spices, cocoa, coffee and timber	Green tea leaves	Rubber latex	-Off-farm jobs-	
Other sources of income	Some members in the household do off-farm jobs on a full-time or part-time basis			KHG-sale of spices and timber	None
Level of cash income	Moderate	-High-		Low	High
Source of labour for managing different components	Rice land-*aththama* or *ande* labour KHG-family labour	Tea-family and hired labour	Rubber-family and hired labour rice land-*aththama* or *ande* labour KHG-family labour	KHG-family labour	KHG-family labour
Main employment	-Farming-			Waged labour work: timber harvesting and sawing, agricultural labour work	Jobs which earn high income: trade, government and private sector jobs
Geographical distribution	Mostly in the Galagedara ASD	Mostly in the hilly and cooler parts: Kolugala, Tismada, Alagalla	Mostly in the Hataraliyadda ASD	Settlement schemes and other parts of the Galagedara RSD	Townships and along the main roads
Land use practices	Lowland rice large KHGs planted mainly with spices, cocoa, coffee	Tea small holdings small KHGs	Rubber small holdings-lowland rice-small KHGs	Small KHGs	Very small KHGs
Farm size	-Large (about 1-2 ha)-			Small (0.1-0.4 ha)	Very small (about 0.1 ha)

The general problems of different land use systems which were identified during the prediagnostic survey are given in the Table 2.5.

Table 2.5 Main problems and agroforestry potentials of different land use systems as articulated by farmers.

Land use system	Main problems
I	1. Decrease in cash income because of the low prices of main cash crops including clove, nutmeg, pepper and coffee 2. Decrease in crop yields due to damage of rice, banana and tuber crops by wild boars, and coconut, cocoa and other fruits by giant squirrels, red monkeys, common squirrels and birds 3. Low yields from rice lands because of: • low water availability, during the minor growing season, • poor soil conditions inherent to the region, and • scarcity of family labour and draught buffaloes for land preparation and, hired labour for planting rice plants causing delay in planting. 4. Feeding problems associated with keeping cattle
II	1. Low returns from tea because of the following reasons: • produce sold as green leaves as no processing facilities available • low price received for green leaves as it is decided by the estates 2. Decreased soil fertility as a result of inadequate soil conservation measures leading to soil erosion 3. Drought hazards are high during the years of poorly distributed rainfall because of lack of shade tree cover 4. Scarcity of labour for plucking tea leaves because of a decrease in family labour caused by increasing recourse to off-farm employment
III	1. Farmers receive low returns from rubber because: • most farmers sell their produce as unprocessed latex because they have no processing facilities • the low price received for the latex is decided by the estates. 2. There has been a decrease in skilled labour for tapping latex due to other job opportunities in the area and social security schemes.
IV	1. Insecurity of jobs 2. Seasonal job scarcities 3. Regional job scarcities 4. Scarcity of land
V	This group does not depend on the homegarden for meeting their basic household needs. They do not have any serious land use problems. They grow ornamental and medicinal plants, fruit trees, relishes and domestic vegetables on a very small scale.

2.3.6 Selection of priority land use system

Land use system I (Lowland rice and KHGs) was selected as the priority system for research for the following reasons.

(i) Most farmers in the land use system I were full time farmers and their food and cash income was derived from their farms. The farms were large enough to provide cash and food to meet their needs, and because of these reasons the farmers in this category were dedicated to farming. Hence, it was more likely that agroforestry interventions would have the potential to improve the performance of the system. Approximately 25 % of the farming community of the region consisted of farmers in this land use system (GASC, 1993). These farmers have been affected by the recent fall in spice prices and as a result are faced with a substantial reduction in cash income.

(ii) The farmers in the land use systems II and III were much less affected by the fall of spice prices, because they were small holders of rubber or tea. Present prices of tea and rubber are reasonably high.

(iii) The farmers in the land use systems IV and V were not full time farmers. They were less dependent upon their farms for cash income. Also, the extent of farms in the land use system IV and land use system V were not adequate to provide a living for the family. Therefore, they had only a casual interest in farming activities.

2.4 DIAGNOSTIC INFORMATION - "LOWLAND RICE-KANDYAN HOMEGARDEN SYSTEM"

The following section focuses on the strategies adopted and constraints which limit the performance of the land use system I. The information was mainly from the diagnostic survey carried out by the researcher in the Galagedara, Hataraliyadda and Weliwita Agrarian Services Division areas of the Galagedara RSD (Section 2.2.2.1) but information from secondary sources such as records of Central (Department of Agriculture, 1993) and Regional (GASC, 1993) Government institutions related to agriculture development and general administration (GRSO, 1993), reports of natural resource and socio-economic surveys carried out in the area (IRDP, 1990), and maps about the area (Department of Agriculture, 1980; Department of Agriculture, 1988) were occasionally used to support the findings of the diagnostic survey and are referenced to their sources.

2.4.1 Farm resources

A single household owned from 0.1 to 0.4 ha (mean=0.33 ha) of paddy and from 0.6 to 1.0 ha (mean=0.85 ha) of multilayered tree garden (KHG) dominated by coffee (*Coffea arabica*), cocoa (*Theobroma cacao*), spices (including pepper, clove (*Syzygium aromaticum*) and nutmeg (*Myristica fragrans*)), timber and fruit trees. The typical family size was from 4 to 6 (mean=5.1) and about 26% of households included extended families; that is, grand parents were also living with the family.

2.4.2 Farmers' objectives

The main objectives of farmers (their major output subsystems) were identified during the diagnostic survey as:

- food: crops and animal
- cash
- energy
- shelter (housing)

2.4.3 Farmer strategies

The following section describes the strategies used by farmers to meet their objectives. Also discussed are the problems and causes of the problems that limited the farmers in achieving these objectives.

2.4.3.1 Food subsystem (crops)

The different food items consumed and the various sources from which they are obtained by the household are shown in the Table 2.6.

Table 2.6 The source and variety of food items consumed within the household.

Source	Food items consumed
Rice land	Rice (the staple food)
Homegarden	Fruit: jak, avocado, mango, *anoda*, *rambutan*, pineapple, *durian*, *beli* Tuber: *kiri-ala*, yam, *hulan-kiriya* Leafy vegetables: *katuru-murunga*, spinach, *pavetta*, *anguna*, *koppa-kola*, *kohila*, *thampala*, *gotukola*, *mugunuwenna* Other vegetables: young and mature jak fruit, jak seeds, bread fruit Relishes: ginger, lemon grass, turmeric, *karapincha* Medicinal plants: *pavetta*, arrow root
Purchased with cash	Crop based: vegetables, potatoes, sugar, tea, wheat flour, bread Animal based: dried fish, eggs and powdered dairy milk

Key: Species names are given in Appendix 2.

A. Lowland rice field

The valley bottoms were planted with lowland rice for two seasons between April -July and October-February (Figure 2.4). These cultivation seasons are referred to as major and minor, respectively. Major and minor seasons were planted with medium (4 to

4 1/2 month) and short (3 to 3 1/2 month) duration varieties respectively. All rice fields were planted during the major season and the fields which received water from small irrigation channels were also planted in the minor season[1]. These irrigation channels were due to natural stream flow of the Bolagala and Girihagama mountains as there were no major irrigation schemes in the area.

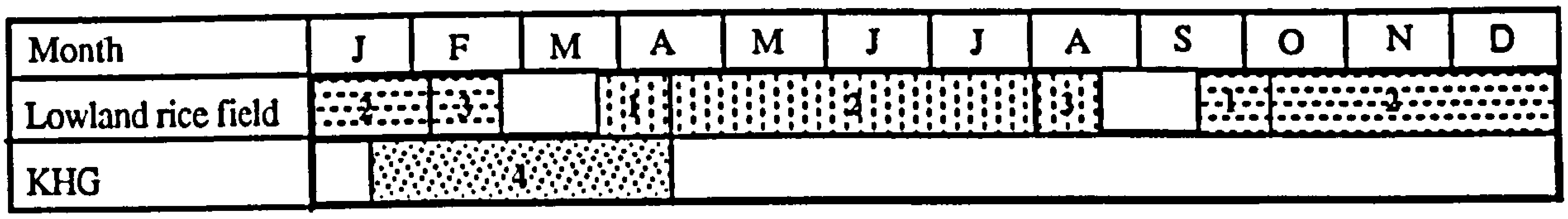

Figure 2.4 Calender of major farming activities in the lowland rice-KHG land use system.

Key:

Major season   Minor season

1. Land preparation and planting
2. Weeding
3. Harvesting and processing
4. Harvesting and drying of pepper, coffce, clove and nutmeg.

Note: Farmers said that before the decline of the price of cash crops, they undertook the following cultural practices in the KHGs: (i) weeded the homegarden and repaired the lateral drains during February or March which is the major dry season, and (ii) pruned the shade and other overstorey trees in May or June to provide sufficient light at the on set of flowering of understorey crops and also prior to the beginning of the monsoon when the cloud cover is high.

Each household aimed to produce all of its rice requirement and some surplus to sell. However, it was clear from the diagnostic survey that only 15 % of farmers managed to produce a surplus whilst 24 % of them did not even manage to meet their domestic requirement (Table 2.7).

Table 2.7 The farm supply of rice.

Farm supply of rice	Proportion of households
Meet over 75 % household requirement	24 %
Sufficient for home consumption	61 %
Surplus to sell (about 0.4 t a^{-1})	15 %

[1] A similar survey carried out earlier in the Galagedara RSD indicated that about 39 % of the area under paddy was rainfed; that is, there were no irrigation facilities and cultivation could only occur in the major season. The remaining 61 % received water from minor irrigation sources (IRDP, 1990).

Causal factors of low rice production

(i) Climate and soils

The inherent climate and soil types of the area are thought to be part of the reason why rice production is generally low compared with other areas (Table 2.8).

Table 2.8 A comparison of climatic and soil characteristics between Polonnaruwa (which is the best rice producing area of Sri Lanka) and wetter parts of Galagedara RSD.

Locality	Rainfall (mm)	Soil type and texture	Soil pH	Mean rice yield[1] (t/ha) during major season of 1992
Galagedara	2000-2500	RBL, IBL Sandy loam	5.0-6.0	2.36
Polonnaruwa	1250-1875	RBE, LHG Clay loam	6.0-7.5	4.26

Key: RBL-Reddish Brown Latosolic, IBL-Immature Brown Loam, RBE-Reddish Brown Earth, LHG-Low Humic Gley
Source: Department of Agriculture, 1988; GASC, 1992; Mahaweli Authority, 1992; Department of Agriculture, 1993

The rainfall at Galagedara is high and well distributed (Figure 2.2), thus there is high cloud cover throughout the year, which allows fewer sunshine hours per year than that found in better rice growing areas of Sri Lanka such as Polonnaruwa (Department of Agriculture, 1993). High sun light intensity (i.e. a clear sky) is vital for the production of high rice yields (Grist, 1983). As discussed earlier, the Reddish Brown Latasolic (RBL) and Immature Brown Loam (IBL) are the major soil types of the area. The proportion of low humic gley (LHG), which is the typical rice soil in Sri Lanka is low in the lowland rice fields of Galagedara region. The following characteristics of the RBL and IBL impose limitations on paddy cultivation:

[1] The national average in year 1992 was 3.43mt/ha

- The water holding capacity of RBL and IBL soils is relatively low (IRDP, 1990; Department of Agriculture, 1993). Retention of water is important to prevent water stress and control weeds.
- Soil acidity: Rice requires a soil pH of between 5.5 and 6.5 to produce high yields (Grist, 1983). The soils in the study area are slightly more acidic (pH range 5-6). The "bronzing effect" caused by excess of Fe^{++} under highly acidic conditions (Russell, 1988) was observed on 6 % of the farms.
- The cation exchange capacity of RBL and IBL soils is low (Department of Agriculture, 1993). The nutrient retention capacity of the soils, therefore, is probably low too.

The recent removal of a fertiliser subsidy caused a four fold increase in the price of fertilizer. A 50 kg bag of compound fertilizer was around Rs. 500 (75 Rupees = 1Sterling). Because of these very high prices about 86 % of farmers applied fertilisers below the recommended level. It was anticipated that this decrease in fertilizer application would result in a reduction in the nutrient status of the soil as a result of subsequent harvests.

(ii) Water stress due to inadequate water during the minor growing season

a. Delay of monsoonal rains

The records of the Galagedara Agrarian Services Centre (GASC, 1993), and experience of farmers in the area indicated that on average about one out of every five minor growing seasons is severely affected by inadequate water supply. As a result approximately 67 % of farmers fail to cultivate their fields during the minor season.

b. Water catchment problems

The diagnostic survey indicated that 56 % of the farmers had been able to cultivate rice in the ordinary minor seasons with water received from small irrigation channels. Among those, 32 % said grain yield was reduced significantly because of moisture stress caused as a result of low water levels in the irrigation channels. The farmers attributed the insufficient water supply to various factors including the destruction of vegetation in the watersheds, and the lowering of ground water levels due to the construction of tube wells, and other irrigation schemes including small dams and reservoirs built on the mountains to supply water for domestic purposes.

(iii) Impure seeds

Farmers commonly in the area plant new improved rice varieties (hybrids). Although they have the potential to produce high yields under high input levels and high management intensities when compared to traditional varieties, there are many factors which limit the use of hybrid paddy seed.

Farmers commonly use part of their harvest as seed for the following season if it is suitable, that is if the seed stock has not been used for more than three generations. If the seed is not suitable, it is exchanged for suitable seed produced by another farmer and this is used for planting. If both of these options fail seed has to be purchased. Use of the same seed stock over 3-4 generations causes a significant decrease in the purity of paddy seeds (Department of Agriculture, 1992). The seeds used by 39 % of the farmers are in this category and 71 % of the farmers attributed this to the scarcity of paddy seed whilst the remaining 29 % attributed it mainly to the high cost of the seed. Certified rice seed produced for planting is very expensive (about Rs. 20 kg^{-1}) where as uncertified seed costs around Rs. 7. Agrarian Services Centres received a small stock of seeds every season which only met about a third of the requirement from farmers (GASC, 1993). There are no subsidies for purchase of paddy seed. 7 % of farmers expressed dissatisfaction with certified seeds because they found them to have a low germination percentage .

(iv) A delay in planting caused a reduction in rice yield

The standard practice was to plant all blocks of a one rice tract simultaneously. This strategy is adopted to distribute the pest population among all fields thereby reducing severe damage on any single block as prevalent insect pests attack particular growth stages of the crop. The water was also received at the same time for all fields in a small area. Therefore, the cultivation of rice in any one village (i.e. VSO division) took place at the same time. Because of this pattern of planting there was a high peak demand for draft power and labour during the rice planting season. Short supply of draught power and labour, each of which is discussed below, delayed planting and, therefore, reduced the rice yield.

a. Scarcity of draft power for ploughing caused a delay in planting

Due to the presence of terraces, sloping terrain, and sandy soils it is difficult to use four wheeled tractors for land preparation. The common practice is to use buffaloes for land preparation and threshing the harvest. Only 7% of farmers kept buffaloes. Other farmers had to hire buffaloes specifically for land preparation. Because of the demand for buffalo at peak times 12 % of farmers experienced a delay in land preparation and, therefore, crop establishment. This was associated with lower yields both because the growing season was shortened and pest damages were severe.

Some farmers kept buffaloes primarily for hiring out. One pair of buffaloes can plough about 0.2 ha day^{-1} costing Rs. 300 inclusive of labour. The cost of buffalo husbandry was high and only 30 days of work was possible during a year. Although the planting season continues for about two months during one growing season, the animals have to be rested every other day. Farmers hiring out buffaloes also obtained some cash income during the harvesting season through threshing paddy. On average they earned about Rs. 500 a day for about 15 days a year. They experienced very little competition from tractors or portable threshing machines.

b. Labour scarcity for land preparation and transplanting caused a delay in planting and a decrease in the quality of land preparation

Farming has recently decreased in popularity, mainly because of the reduction of cash income caused by the recent fall in the price of cash crops. Other factors contributing to its unpopularity included the increasing cost of inputs for rice cultivation, the low social status of farmers, social security schemes available for the unemployed and people on low income, and the availability of more attractive off-farm employment. As a result most young people avoid farming unless they have no other option. Also their farming skills are not well developed because of the low status and interest accorded to farming activities. During the recent past many young people have joined the security forces (7% of total work force in the area), while some young women have found jobs in garment factories in the free trade zone and abroad (IRDP, 1990). There has been a labour migration from the area, and a loss of interest and commitment of young members of families towards farming. In fact some youths, both males and females, are supporting their parents and do not like to see them involved in farming activities because of the poor social status. Because of this social transformation that is taking place, there is a great reduction of both hired and family labour for agricultural activities.

About 58 % of the households covered in this study had a minimum of one male unit and 36 % had half a unit, while the other 6 % had no labour allocated for activities on their farms (Table 2.9). Adult men were employed off-farm in 94 % of households, and 47 % had allocated at least one unit for these jobs. 73% households had women engaged in farm activities while 21 % had women employed in off-farm jobs.

Table 2.9 Labour allocation of households for farm and off-farm activities.

Labour units	Percentage households			
	Men		Women	
	Farm	Off-farm	Farm	Off-farm
0	6	6	27	79
0.5	36	47	37	10
1.0	45	33	24	6
1.5	8	14	12	2
2.0	5	0	0	3
Total	100	100	100	100

Key: 1 unit= 1 full-time farmer= 2 part-time farmers

About 6 % of households gave their rice land to be managed by an *ande* labourer while 11 % of households gave part to *ande* labour and managed the rest by themselves with the assistance of *aththama.* The remaining 83 % managed all their rice land by themselves with the help of *aththama* for labour intensive activities (Table 2.10).

Transplanting and weeding were done by the hired skilled women labour teams that existed in the area. All VSO divisions investigated only had access to two to three teams each. A team of about 10 labourers planted 0.4 ha of rice land during a day and charged Rs. 1200 for doing so.

It was difficult to hire labour because of the low profit margins of farming. As a result, most paddy land was managed at a low intensity and productivity has decreased considerably in the recent past. About 71 % of farmers felt that the quality of cultivation practices, especially land preparation, had declined recently due to scarcity of labour. 53 % of the farmers said that planting was delayed in the last major season because of the lack of family labour for land preparation and 26 % of the farms suffered due to the lack of hired female labour for the transplanting of rice plants. As a result some farmers (3 %) have adopted broadcasting of seed as less labour intensive alternative to transplanting.

Table 2.10 Labour divisions and type of labour used under the two management systems of rice fields in the LUS-1.

Farming activity	Labour divisions by gender	*Aththama* system	*Ande* system
Land preparation a. Ploughing b. Levelling, making bunds and water management	 Men Men	 *Aththama* labour Family labour	 *Ande* labour *Ande* labour
Nursery management	Men	Family labour	*Ande* labour
Transplanting	Women	Hired labour	Hired labour
Application of fertilizers and pesticides, water management	Men	Family labour	*Ande* labour
Weeding (hand picking)	Women	Family and hired labour	Hired and *ande* labour
Harvesting	Men	*Aththama* labour	*Ande* labour
Collecting and carrying harvest to threshing floor	Both men and women	Family labour	*Ande* labour
Threshing and winnowing the harvest	Men	*Aththama* labour	*Ande* labour
Cleaning and drying the harvest	Women	Family labour	*Ande* labour

(v) Wild boar damage

Wild boar herds, have become a major problem for paddy cultivation in most parts of the region since the mandatory surrender of fire arms to the police for security reasons. About 13 % of the farmers have experienced considerable losses as a result of wild boar entering their fields, crushing plants, eating grains and damaging bunds.

B. Homegarden

The food produced from the homegarden is shown in Table 2.6. All households produced their requirement of coconut which is an essential item in the Sri Lankan diet. They also planted tuber crops and leafy vegetables in their homegardens for household consumption and sold any surplus fruits such as *durian* (*Durio zibethinus*), banana (*Musa balbisiana*), mango (*Mangifera indica*), avocado (*Persea americana*), jak and bread fruit.

Causal factors for lowering the production of coconut, fruit and tuber from the homegardens

Since the surrender of fire arms to the police in 1989 there have been no effective measures to control populations of large vertebrate pests. As a result damage, caused by wild boars, red monkeys and giant squirrels has become the major reason for reduced coconut, fruit and tuber production from the homegarden. The decrease in pruning activities has resulted in a dense overstorey in the homegardens which enables arboreal pests to move easily across the gardens and hide in the dense foliage. Wild boars damage young plants especially of coconut and banana and as a result establishment of those crops were reported to have become difficult for 11 % of the households. The root and tuber crops including yam and *kiri-ala* (*Colocasia esculenta*) had been attacked by wild boars in 25 % of households surveyed. Arboreal pests, especially, the red monkey and giant squirrel have caused significant losses of coconut and fruit production (especially, mango and *rambutan* (*Nephelium lappaceum*) in 43 % and 67 % of households respectively.

C. Purchased food

About 10 % of the farmers indicated that due to a reduction in cash income they had stopped buying certain non-essential items of food. The actual number of farmers that were affected might be much higher than this as it is extremely difficult to discuss food consumption for cultural reasons.

2.4.3.2 Food subsystem (animals)

A. Cattle production

There was very little potential for beef cattle production in the area as over 90 % of the population were Buddhist and considered rearing cattle for beef production unacceptable.

There were 20 farmers managing medium scale (5-15 cows) dairy farms (IRDP, 1990). On average 13 % of the households reared dairy cattle and 44 % of them produced a little surplus milk for sale (mean=2.45 l day^{-1}) earning them on average around Rs. 1200 per month.

Causes of low dairy cattle production

All farmers, whether or not they kept cattle, perceived that scarcity of grass was the most important limitation to dairy production in the area. Grass cannot grow in the homegardens because of the heavy shade from trees. Therefore, farmers who reared dairy cattle faced difficulties in feeding their animals especially in the rice growing season. They cut and fed grasses from bunds on rice fields, road sides, nearby hills and protected areas. They allow their animals to graze in the paddy fields during the dry season (February to March and August to September), which decreases the pressure on grass from other sources during this period.

Tree fodder is used by all farmers who keep cattle as a feed supplement. It typically constitutes approximately 20 % of the total diet. *Gliricidia sepium* and jak are the most popular tree fodder in the region, but high quality fodder such as these could not be obtained in large quantities. Hence there was a heavy dependence on grasses for feeding cattle. A large proportion of the rice straw produced in the area was available to feed cattle. Only 21 % of farmers recycled their straw to supplement potassium fertilizer and use of silage was not known to farmers. Rice bran was available in large quantities from the rice mills in the area free of charge and was considered to be a useful feed supplement.

The following facilities were available in the area for dairy cattle production, but only 10 % of farmers knew about the complete package.

- The price of dairy cattle is high and an average cow fetched about Rs. 8000-10000. Grants were available under the self employment scheme operated by the government to support low income families. Under these grants it was possible to obtain up to the total price of cattle purchase. The cattle must be of an approved breed and must satisfy certain health conditions when examined by the veterinary surgeon of the area.
- Insurance schemes were available for death or disability of any cows that satisfied medical conditions (approved by the Government Veterinary surgeon). The monthly instalment of insurance is paid only when the cow is producing milk and is less than Rs. 50 per month.
- A free insurance scheme and feed supplement is available for calves produced by artificial insemination.
- Artificial insemination of improved breeds (Ayrshire, Friesan and Jersey) is free of charge and is carried out by the Agricultural Instructor (Animal husbandry) Galagedara RSD when visiting farms.
- Advice on cattle management and husbandry can be obtained from the Agricultural Instructor (animal husbandry) for Galagedara RSD free of charge.
- A veterinary service is available from the Government Veterinary Surgeon for Galagedara RSD free of charge for examination and treatment of animals.
- There are five milk collecting points in the area. However, transporting milk is difficult because of poor transport facilities, a sparse road network and difficult terrain.

(B) Poultry production[1]

About, 29 % of the households kept poultry birds on a small scale (less than 50 birds) and 35 % of them produced a surplus of around 10 eggs per day. They earned on average Rs. 750 per month. There is a buoyant market for eggs in the area and prices normally range between Rs. 2.50-3.50 per egg. Higher prices prevailed during the Sinhalese and Hindu New Year (April) and Christmas (December) seasons.

Feeding materials were easily available for small scale poultry production from domestic activity, and formulated rations could be purchased in the market. There was a great potential for small scale (about 10 birds) poultry production under the free range system because over 75 % of their daily rations could be found on the floor of the homegarden, comprising worms, small insects and grasses. The rest could be supplemented from the materials thrown away from the house such as left over rice, broken rice and coconut pulp.

Causes of low poultry production

About 39 % of households showed an interest in rearing animals for meat and eggs. These included those who were already involved in poultry production. Most of them requested advice about poultry management. However, the majority (about 48 %) did not wish to rear animals for meat due to religious and cultural reasons and 13 % due to other reasons such as damage caused to herbaceous plants in the garden, depositing dung around the house and the strong smell of birds.

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[1] There are about 13 farmers managing medium scale (100-500 birds) poultry farms in the Galagedara RSD (IRDP, 1990). Large scale poultry production is mainly carried out by the Muslims in the area.

2.4.3.3 Cash subsystem

The cash subsystem in this land use system has become severely constrained since the fall of spice prices. About 62 % of the cash income was provided through the sale of cash crops and surplus food crops from the homegarden and lowland rice land. The remaining 38 % of cash income came from the members of the household who were involved in off-farm employment (Table 2.8). Cash was used to buy food items not supplied from farming activities, inputs for lowland rice cultivation and to meet other social expenditures. For most households (about 90%) the present cash income was sufficient to buy staple foods, but did not always meet other expenses, such as inputs for rice cultivation, clothing, maintaining houses and social costs. For example, contributions to social activities such as religious activities, weddings and funerals were not as large as they had been in the past, and savings for extraordinary expenses, health, education, travel, and entertainment costs were also reduced (Figure 2.5).

Before the recent fall of cash crop prices, (especially of clove, nutmeg, pepper and coffee) their cash income had been high. Therefore, people considered under the land use system I had been a rich and influential group in the area. Cash income has decreased on average by Rs. 26 000 per annum which was about one half of their cash income before the fall of spice prices. Because of this reduction, these, farmers are now struggling to remain in the same social strata. As a result they are seeking off-farm employment and are selling some of their timber trees from the homegardens to meet their day to day requirements. The timber trees were normally considered as household savings.

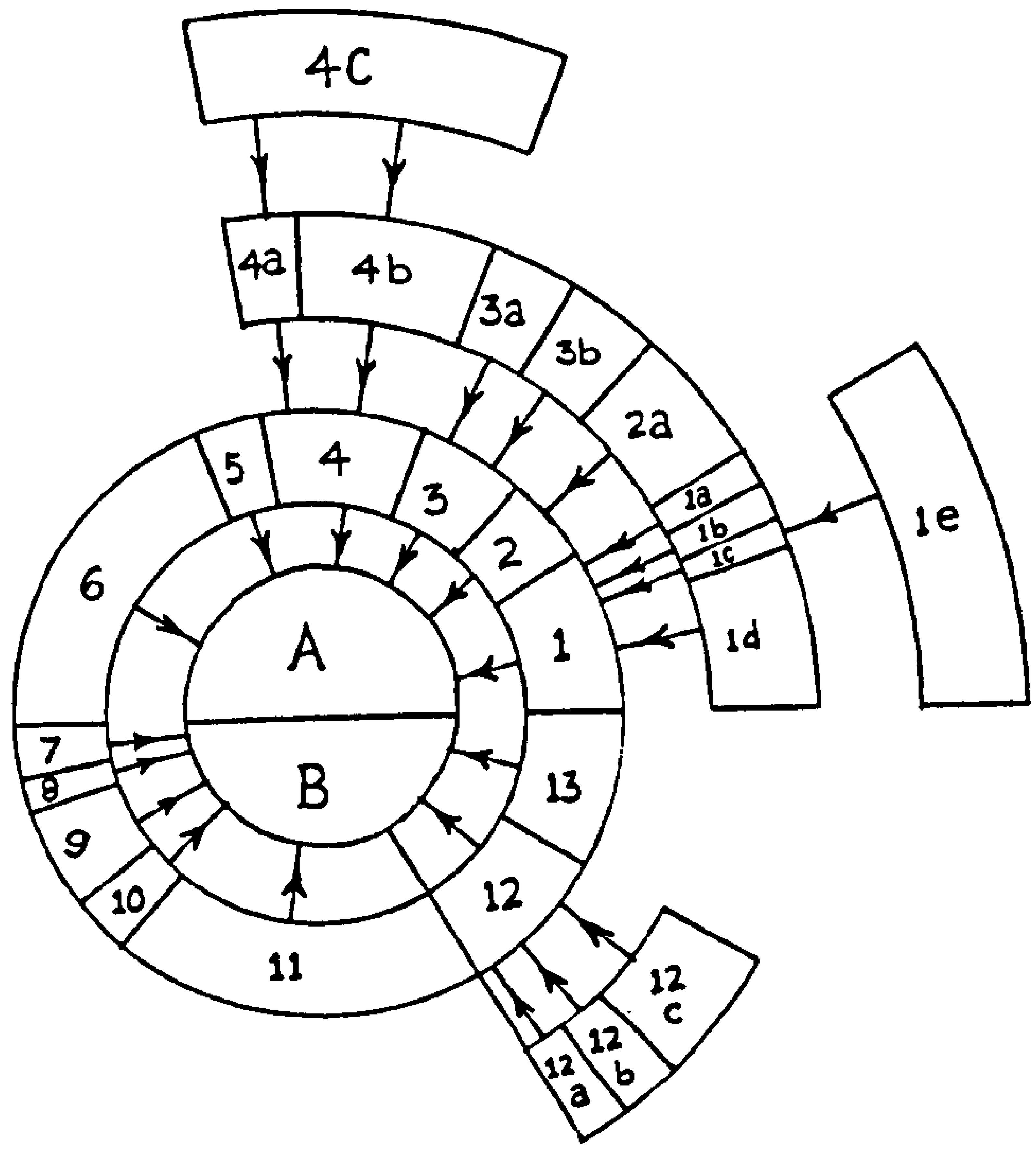

Figure 2.5 Circular diagram showing contributions to income and expenditure within the cash subsystem in the lowland rice-KHG land use system.

Key:

A	Income	B	Expenditure
1	Clove, nutmeg, pepper, coffee and cocoa	7	Social expenditure
1a	Monopolistic market	8	Health
1b	Pest damages	9	Clothing
1c	Low yields	10	Travelling
1d	Low prices	11	Food
1e	Lowering the management intensity of KHGs	12	Inputs for paddy
2	Coconut, arecanut and *kitul*	12a	Fertilizer cost
2a	Pest damages	12b	Draught power for land preparation and threshing the harvest
3	Banana and other fruits		
3a	Low prices	12c	Labour cost for transplanting and weeding
3b	Pest damages		
4	Timber	13	Education for children
4a	Low wood quality		
4b	Low timber volume		
4c	Pruning of timber trees		
5	Rice		
6	Off-farm employment		

(A) Factors causing a reduction in the cash obtained from the sale of farm produce

(i) Reduction in yields of rice, harvested fruits, and animal production

The factors causing the reduction in rice yields and animal production have been discussed in Sections 2.4.3.1 and 2.4.3.2, respectively.

Banana (1kg is about Rs.20), coconut (one coconut is about Rs. 2.50-4.00) and arecanut (1 kg is about Rs. 100-150) were enjoying high prices at the time of the survey. Although high prices were being paid, damage caused by vertebrate pests reduced yields as discussed in Section 2.4.3.1.

(ii) Low prices obtained for fruits harvested from homegardens

Another factor limiting cash income was the low price of surplus fruit such as *durian*, avocado, *rambutan* and jak in the local market. To obtain high prices for these products they had to be transported to the nearest city which was some 16-24 km away. Therefore, produce was normally sold to dealers who visited farms and paid low prices. Although it is a major fruit producing area there were no fruit processing factories in the region.

(iii) Low prices of clove, nutmeg, coffee and pepper

Again, the main problem with these crops was the low price obtained for them. These were once the major cash crops in the area and farmers earned large sums of money from them until a few years ago (Table 2.11). As mentioned previously the sudden fall in prices has reduced farmers' income by about 50%.

Table 2.11 Price changes in major cash crops produced in the KHGs.

Cash crop	Average price range (1985-90) Rs. per kg dry weight	Present price (1993) Rs. per kg dry weight	Price reduction
Clove	100-150	35	3.5 folds
Nutmeg	50-75	20	3.5 folds
Pepper	75-115	28	7 folds
Coffee	60-90	30	2.5 folds

Source: Tilakaratnebanda, 1993a

The Department of Export Agricultural Crops has introduced a security scheme for spices as a short term measure to keep farmers in spice production because the prices were expected to recover. Under this scheme farmers could receive an additional Rs. 10 for each kg (dry weight basis) of spice they produce. However, 75 % farmers complained that there were substantial delays (in many cases 3-6 months) in receiving these subsidies.

Private dealers have a monopoly over spice marketing. They commonly purchase at low prices by classifying produce as low grade regardless of its actual value. Because of the monopoly held by dealers the local farmers have little option but to accept the price offered.

(iv) Pest damage causing reduced cocoa yields

A high price pertained for cocoa (1kg of nuts fetched about Rs.40). Galagedara is considered one of the best cocoa growing areas in Sri Lanka. However, cocoa production is severely limited because of damage caused by giant squirrels, squirrels, parrots and red monkeys. All households who had cocoa grown in their homegardens (68 %) indicated high losses in yields because of pest damage.

(v) Reduction in management intensity of KHGs

The previously mentioned decrease in income from growing cash crops has had a negative effect with respect to the management of the KHGs. Management practises such as, maintaining lateral drains for soil and moisture conservation, weed management, management of litter and trees for green manure, pruning crop trees to maximise yield and to control competition had been neglected because of a loss of interest, the difficulty in paying wages for hired labour, and buying inputs such as fertilizers.

Only a small proportion of homegardens were eligible for subsidies allocated for growing and maintaining cash crops because the subsidies, provided by the Department of Export Agricultural Crops were only given for growing monocultures of cash crops such as banana, pepper, clove, nutmeg, coffee and cocoa. Most KHGs contained a mixture of woody species. In order to claim these subsidies farmers would have had to severely reduce the number of species in their gardens.

Reduction in management intensity has affected the light regime, tree pruning, soil moisture conservation and timber production each of which is discussed below.

a. Light control

Most cash crops grown in the homegardens require shade e.g. pepper, coffee, cocoa and tea. However, excessive shade (over 60%) may cause a significant decrease in their yields. This was found to be the case in most of the KHGs. Only about 4 % of farmers undertook pruning of the upper storey trees in order to control shade for the understorey crops. This can be attributed to the increasing loss of interest in understorey crops as the price for them has declined. As shade has increased, understorey yield has decreased and the cash income from these crops further diminished.

b. Pruning tree crops.

Tree crops such as coffee and cocoa need regular pruning to induce fruiting and to control height thus enabling easy harvest. The results of the survey found that only a very few households (less than 5 %) prune tree crops regularly for these purposes.

c. Soil and moisture conservation

Vegetation cover and density of the KHGs was highly variable. However, it is known from previous research that even when there was good vegetation cover and a litter layer, soil erosion may be significant on slopes > 55 % (Sivapalan *et al.*, 1986). This is because of the high and intensive rainfall during the monsoons and the presence of highly erodable soils. Because of this problem the construction and maintenance of soil and water conservation measures such as lateral drains and barrier hedges are of the utmost importance. Only a few farmers other than those who were receiving subsidies (less than 15 %) were maintaining soil and water conservation structures. Most farmers had experienced loss and damage to crops such as clove trees, pepper vines and young coconut fruits during drought periods which has further reduced production during years with low rainfall. This illustrates the importance of soil moisture conservation in KHGs.

(vi) Pruning timber trees

The number of timber trees that had reached the common rotation size of the area (above 30 cm diameter) found in the homegardens were from 5-12 and the mean was 7.2. Mahogany (*Swietenia macrophylla*), *gini-sapu* (*Michelia champaca*), *wana-sapu* (*Cananga odorata*), *lunu-midella* (*Melia dubia*) and *hawari-nuga* (*Alstonia macrophylla*) are the most common timber species in the KHGs. Average rotation, volume and value of those trees species are given in Table 2.12.

Table 2.12 Price and mean length of rotation[1] of major timber tree species.

Species	Age (years)	Price per tree (Rs.)
Gini-sapu	15	2500
Mahogany	15	3500
Wana-sapu	07	500
Lunumidella	10	2500
Hawari-nuga	12	2000

Key: Species names are given in Appendix 2.

The value of timber was dependent upon:

- the width of the planks that could be cut from the first (basal) log of the tree, which is determined by the diameter of the tree;
- the number of logs that could be cut from the tree which is determined by the length of the trunk;
- the length of the logs produced (normally varying from 2 to 3 m) and influenced by the straightness, the quantity of large branches, and any damage to the trunk.

Timber dealers also sell small wood such as branches (below 15 cm diameter) as fuel wood but this was not taken into account in the valuation of trees. Trees with a long, straight, trunk with few branches and little damage received the highest prices. Pruning was, therefore, an important practice to improve the value of trees for timber. Although, the timber trees provided approximately 17 % of the annual income, farmers showed little interest in managing them. Only 4 % of the households were found to be pruning timber trees in order to improve the returns from timber even when they had a large number of timber trees in their homegardens (Table 2.13). About 14 % attributed their lack of pruning to the scarcity of both skilled labour and the shortage of people to hire. 17 % said they were not adopting pruning (which reduces diameter growth) because their priority was to maintain high rates of diameter growth, thereby producing trees of saleable size as early as possible while 30 % said that pruning reduced the vigour of the

[1] At this stage on average the diameter at breast height (DBH) is about 30 cm and timber volume is 0.41 m^3 per tree.

tree. The farmers who were primarily interested in spices (35 %) were not interested in improving timber tree production. All farmers had managed timber trees as normal shade trees when they had crops in the understory, before the decline in spice prices.

Table 2.13 Reasons for not adopting branch pruning to increase volume and quality of wood.

Farmers interest	Pruning or not	Reasons for not pruning	Proportion of farmers
1. Spices, coffee, cocoa and timber	Yes	-	4 %
	No	Shortages of cash for hiring skilled labour	14 %
	No	Interested in producing a saleable tree as early as possible therefore interested in maintaining high diameter growth rate	17 %
	No	Keep the vigour and high rate of growth	30 %
2. Spices, coffee and cocoa	No	Not interested in timber trees	35 %

(B) Cash obtained from off-farm employment

Because of the low income from farming activities, household members, especially young men, looked for off-farm employment. However, people in this category were not willing to work as hired labour on other farms because of low social status of farm work. They were mainly self employed in small business enterprises such as the timber trade, small shops, rice mills or in the security forces or the rapidly growing private industrial sector in the free trade zones. All households in the survey received income through off farm employment and on average it constituted about 38 % of the total household cash income.

(C) Out flow of cash from the households

The main expenditure of the household was for purchasing food, education of children, inputs for lowland rice production, travelling costs and social expenditure (Figure 2.5).

2.4.3.4 Energy subsystem

A. Lighting

Most households were not supplied with electricity. Therefore, the lighting requirements of over 60 % households were met by using kerosene oil. A litre of kerosene oil is Rs. 11 and on average about 3 to 5l of kerosene oil were consumed by a household during a month.

B. Cooking

In all households heat for cooking was met by burning fuelwood. Farmers met their daily fuelwood requirements from their homegardens. Only under very special circumstances, such as for special ceremonies and festival seasons did they collect fuelwood from nearby rubber estates or protected areas[1] e.g. mountainous areas prohibited for cultivation to control erosion and protect the watersheds. In order to do this they had to walk from 0.4 to 0.8 km.

Fuelwood can be categorised under the following groups:

(i) Homegarden

- Branches lopped to control light: *Gliricidia sepium*, mango

[1] Although it was illegal, collection of wood by farmers from protected areas was common and there was little fear of prosecution. Farmers did not show reluctance to mention the fuelwood collection from protected areas as researcher was not a Governemnt official.

- Branches from commercial timber trees: *gini-sapu*, mahogany, *wana-sapu*, *lunu-midella*
- Live fences around the homegardens: *Gliricidia sepium*, *erabadu* (*Erythrina variegata*)
- Dead parts of trees: coconut, cocoa, jak, bread fruit
- Prunings: coffee, cocoa

(ii) Rubber plantations: the villagers can collect the dead branches of rubber trees from estates free of charge.

(iii) Protected areas: although it was illegal, villagers in the area did collect firewood from protected areas.

Fuelwood was mainly collected by women. However men also played a role in the lopping and pruning of branches.

2.4.3.5 Shelter subsystem

A. Housing

Most houses were constructed with brick walls and roofed with tiles, asbestos or galvanised sheets. About 67 % of the farmers indicated that their houses had been mainly built with cash received from the sale of spices. However, about 24 % of these houses were in need of renovation and improvement, which could only take place if the household had a sufficient amount of money from various sources of income (e.g. cash crops, timber trees, or from off-farm employment). It is culturally essential to have a decent house (i.e. tiled roof and brick and cement walls) before children get married because the condition of the house is considered an indicator of the wealth of the family. It is also considered important to provide adequate space and facilities for holding wedding ceremonies. Although skilled labour and materials were available, the major constraint in the renovation of houses was the lack of cash needed to hire labour and buy materials.

B. Fencing

Fencing was found only with 32% households because they were built only in the absence of land marks such as roads, ravines and leader drains to demarcate the boundaries. The live fences found were, commonly comprised of *Gliricidia sepium* and other trees tied with a few strands of barbed wire. *Gliricidia sepium* often produced little quantity of leaf material as they were highly shaded by the large trees. However, these live fences demarcated boundaries and offered some protection from theft for garden products and even to the house from theft. There were no stray cattle or goats in the area.

2.5 TECHNOLOGY DESIGN

It is clear form the previous discussion (Section 2.4) that the major constraints are in the food and cash subsystems. Basic needs, relating to both shelter and energy requirements were well met by the households despite some minor problems. Therefore, the following agroforestry and non agroforestry technological interventions were identified, based on the diagnostic information, for improving food and cash income of the lowland rice-KHG land use system.

2.5.1 Proposed technologies for improving the rice production

The problem of low paddy production and the contributing causal relationships are shown in the Figure 2.6. The following interventions were proposed to alleviate negative causal factors and improve rice production from lowland rice fields.

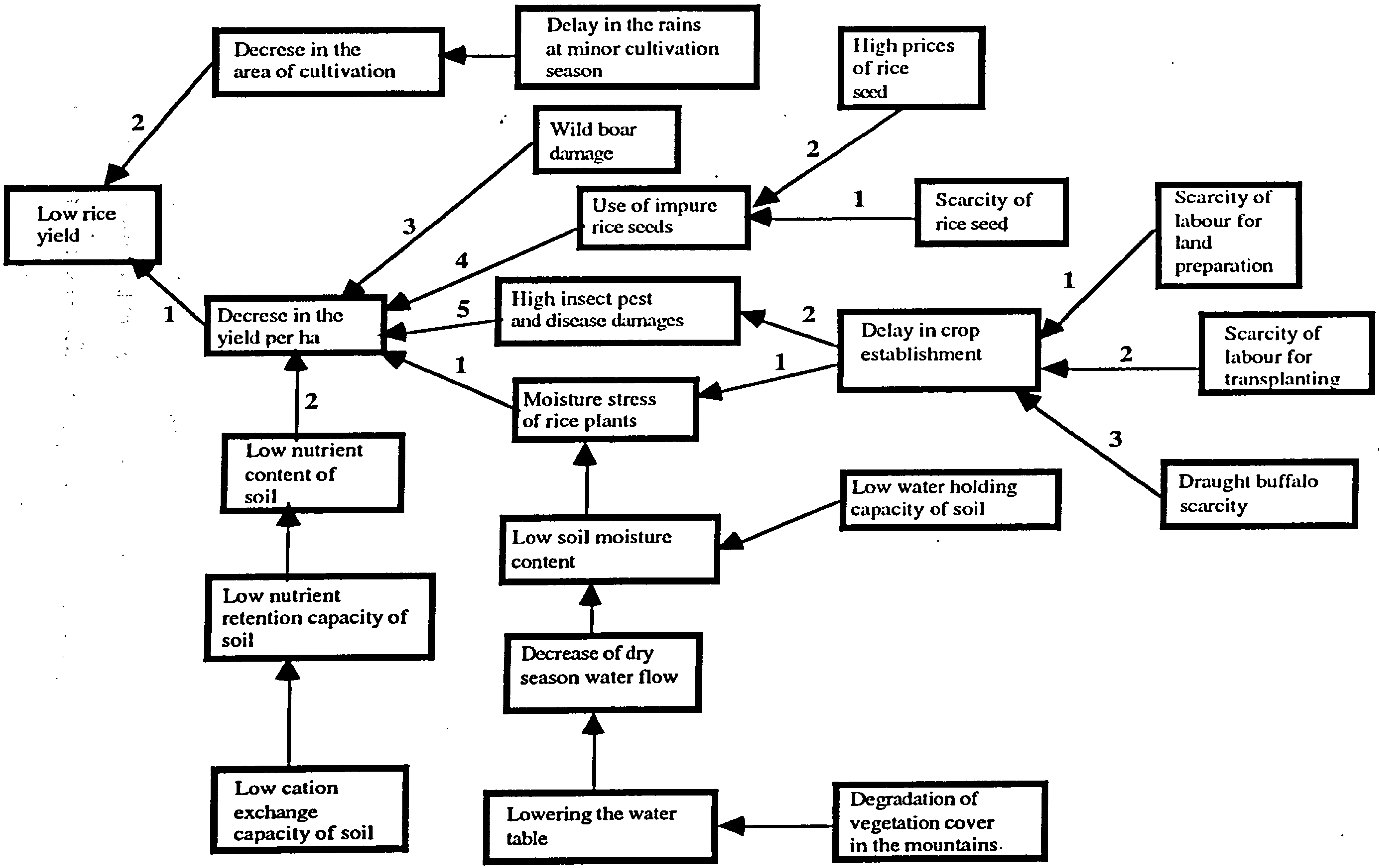

Figure 2.6 Partial causal diagram indicating causes of low rice production in the Rice-KHG land use system. Arrows on the diagram represent the word 'causes' and numbers rank the causal influences in terms of their importance (1-most important, 5-least).

1. Improvement of water flow in the streams during the dry season

Degradation of vegetation cover in the peaks of the hills and steep areas causes a decline in the water table (Salati *et al.*, 1983). This in turn results in a reduction of water flow in the streams, and of water levels in the bore holes especially during the dry season. Erosion of top soil further limits the capacity of the irrigation channels by causing siltation. Therefore, actions are necessary which will protect the existing vegetation cover on mountain peaks and steep areas to prevent them from being clear cut for extraction of timber and farming, and from fires, in order to facilitate natural regeneration. The following actions are recommended to halt the rapid degradation of the vegetation cover in protected areas.

- Launching a campaign to increase the awareness of people, especially those who live on the edges of those sensitive areas about the importance of vegetation cover.
- Providing farm land for the landless in the area and alternative land for people who have encroached into the protected areas.
- The police and Government should be encouraged to take legal action against the extraction of timber from the protected areas since it is a serious offence under Sri Lankan law.
- Many farmers believe there is a relationship between building of tube wells and the lowering of the water table. Therefore, research investigations need to be undertaken to examine the influence of tube well construction on the ground water table of the area.

2. Improving the draught power availability for land preparation

Two wheeled tractors can be used successfully for land preparation in the area because of its small size and low weight. Two wheeled tractors are faster and comparable in cost to the use of buffaloes. Therefore, providing loans to buy two wheeled tractors for the farmers, village co-operatives or to the Agrarian Services Centre to hire out to the local farmers could be a useful and feasible option.

3. Labour saving on land preparation

The use of herbicides in land preparation is not common in the area. Use of minimum tillage techniques in land preparation can reduce the ploughing costs by 50 %, minimise the labour requirement, and is superior in terms of soil fertility maintenance compared to methods used by farmers at the Galagedara RSD. Use of herbicides such as Parquet are common in the dry zone which is the main rice growing area of Sri Lanka. Therefore, the following actions are recommended to popularise the use of herbicides.

- The agricultural extension service could conduct programmes to increase the awareness of benefits from the use of herbicides to minimise tillage
- Ensuring that herbicides are available for sale at the village co-operative shops and Agrarian Services Centre sales outlets

3. Labour saving at rice transplanting

Transplanting rice fields has always been carried out by hired women. Mechanical rice planters have potential to save labour at the transplanting stage. Farm Machinery Research Centre (FMRC) of the Department of Agriculture have initiated designing such transplanters, however they have not yet been released for commercial use as they require further testing and modifications for various locations of the country.

4. Controlling wild boar attacks

Building fences around the rice fields is expensive and practically impossible. Efforts have been made in the FMRC to develop a mechanism to catch the wild boars as it could provide additional income to the farmers, (on average meat of a wild boar can be sold for Rs. 2000 in the open market) while controlling the population. Further, mechanisms (i.e. noise and lighting mechanisms) to scare wild boars which can be used by small farmers in the area are recommended.

5. Improving soil fertility

a. Rice straw as a potassium supplement

Decomposition of straw is very slow and it interferes with land preparation if it is incorporated as fresh material. Burning the straw in small heaps on different parts of the field is considered to be the most convenient method of applying straw to the rice fields. Also, controlled burning will not cause significant loss of potassium.

Recycling all of the straw produced from rice fields could supplement over 50 % of the potassium requirement. The Department of Agriculture have developed recommendations to supplement inorganic fertiliser by rice straw. However, still only 21 % of farmers recycle the straw in their rice fields.

Therefore, a programme is needed to increase awareness of the, benefits, and methods of applying straw to the rice fields. This could be launched in the area through the agricultural extension network.

b. Green manure

Applying nitrogen rich green manure is a useful option to supplement part of the N requirement of the crop, and may also improve soil structure and cation exchange capacity and thus its water and nutrient holding capacities (Russell, 1988). If green manure was used to substitute part of the recommended inorganic nitrogen input the cost of inorganic fertilisers would be reduced but obviously labour input is required to obtain and apply the mulch.

Planting trees on rice bunds as a hedge to produce N rich leaf mulch during the off season, and to act as a barrier to wild boars entering the paddy fields, is not feasible as the rice land is used as free grazing land for cattle and buffaloes during the off season.

The presence of large trees in homegardens, result in most parts of the gardens, including the edges where there were live fences being heavily shaded. The most popular green manure trees, such as *Gliricidia sepium* and *Leucaena leucocephala* require open conditions for producing high leaf yields. Therefore, the following measures are recommended for increasing green manure production from homegardens.

- Regular pruning of existing green manure trees to increase their leaf yield
- Planting open areas of homegardens (typically about 2.5% of total extent) with green manure trees such as *Gliricidia sepium* and *Leucaena leucocephala*
- Identifying green manure trees, shrubs and grasses such as *pavetta* (*Pavetta indica*) (UMWP, 1994) and *Pueraria phaseoloides* and *Centrocema pubescens* (Wijewardena and Waidyanatha, 1984) which could grow under low light levels prevailing in the homegardens

c. Compost manure

Large quantities of low quality plant material (including leaf fall and prunings) with low nutrient content and slow decomposition rates, are available from homegardens. This plant material could be used to produce compost with other materials available from the kitchen such as wood ash, rice, coconut husk, left over food, non consumed parts of vegetables, and coconut pulp. The methods of producing compost are well established and published elsewhere (Dalzell *et al.*, 1987). The barrel method is more suitable than the pit method because of the heavy and well distributed rainfall in the region.

During decomposition certain types of organic matter tends to produce chemical substances which are toxic to plants. Research is, therefore, necessary to discover and understand the occurrence and development of such toxins. It is also necessary to investigate the effectiveness and mineral content of the compost in order to calculate the proportion of inorganic fertilizer that can be substituted by compost manure for developing fertilizer recommendations with compost.

6. Rice seeds

Rice seed production is carried out by the farms of the Department of Agriculture and farmers registered under the seed production scheme of the above department. The diagnostic survey indicated that the supply and distribution of seed is not satisfactory in the area. Therefore, the following measures are recommended for improving availability and minimising the cost.

- Promotion of seed production among the farmers in the area, thereby registering more farmers in the rice seed production scheme undertaken by the Department of Agriculture. This will improve the seed supply and income of those farmers because rice seeds produced for planting receive a higher price than the grain produced for eating.
- Improving the distribution of rice seed across the area through the ASC and village co-operatives.
- Introducing a scheme to produce their own seed for planting rice as has been done successfully in the some parts of the country by the extension service of the Department of Agriculture.

2.5.2 Proposed technologies for improving dairy cattle production

Dairy cattle production in the land use system was constrained because of the shortage of grass mainly during the paddy seasons. The shortage of high quality fodder in large quantities close to the household limits large scale production, but, it is possible for each household to maintain 1-2 cows of an improved breed. This is because the farmer is available to carry out the required tasks in the early morning or later in the evening. In this way farmers can work in the cattle sheds without greatly disrupting their work in the paddy fields. Children above 12 years old and women also play a part in dairy cattle management by collecting feeding material, cleaning sheds, milking and providing drinking water.

Keeping dairy cattle provides the household requirement of milk. One litre is sufficient for a day for a family with five members. They can also earn some cash by selling the surplus. A cow producing about 5 l day^{-1} will give an additional income of Rs. 1800 per month by selling the surplus during the lactation period i.e 4 l day^{-1} at Rs. 15 l^{-1}. Cow dung is a valuable fertilizer. This can be used in the rice field or on the spice crops such as pepper to supplement the inorganic fertilizer.

(1) Increasing tree fodder availability

As discussed earlier (under the technologies proposed for improving rice production) opportunities are limited for high density planting of fast growing, protein rich trees (i.e. protein banks) to increase the production of high quality fodder for dairy cattle. The *Gliricidia sepium* found in the homegardens had been planted for providing shade and green manure for cocoa, coffee and pepper.

(2) Silage as a cattle feed

Although, there were large numbers of tree species and large quantities of leaf material available in the homegardens the fodder quality and palatability for cattle of most of those species were rather low. Producing silage with these species will improve digestibility and palatability. A method for making silage with suitable materials that can be used for silage production from the area would need to be identified. Therefore, the following actions are recommended:

- Research to identify a suitable method for producing silage with leaf material
- Extending the message to farmers about the advantages of using silage as a cattle feed

(3) Decreasing the high dependency on grasses in cattle diets

As discussed earlier grasses, tree fodder, dried rice straw, jak fruit and rice bran are available in the area. Furthermore, there is a high potential for the production of silage in the area. Thus, it is important to develop a dietary ration for dairy cows using these materials, so that the high dependency on grasses can be reduced. Such rations have to be further evaluated for growth, volume and quality of milk produced by dairy cattle.

(4) Increasing the awareness of support facilities available in the area

Increasing the awareness of the facilities available to small dairy farmers in the area (Section 2.4.3.2) should be extended and could make a significant impact in increasing the numbers of farmers managing dairy cattle.

(5) Motivation of farmers

The following actions may further motivate the farmers to keep dairy cattle in their households:

- It is important to increase the awareness of the dietary benefits of drinking fresh milk instead of powdered milk, which most Sri Lankans are used to. Lack of storage facilities (i.e. refrigerators) is a major constraint against using fresh milk for drinking. Farmers know the methods for producing curd and yoghurt, but they have no way of keeping fresh milk more than a day.
- Co-operatives are a well established concept in the country. Helping farmers to develop their own co-operatives gives them access to the advice and facilities available, enables an exchange of ideas and knowledge, and improves the marketing channels.

2.5.3 Proposed technologies for improving poultry production

About 39 % of households showed willingness to keep poultry but lacked management advice and had little knowledge of the support services available in the area. As with dairy cattle production there are many support facilities available in the area. The following suggestions are put forward to improve poultry production of the area:

Farmers should be made aware that;

- advice for management is available free of charge from the Agricultural Instructor.
- treatments for diseases and vaccinations are available free of charge from Government Veterinary Surgeon.
- there are loan schemes from Government banks for buying poultry birds and making sheds under the self employment schemes.
- circulate leaflets on poultry management among the farmers as they are only normally available at the sales outlets of head offices of the Department of Animal Production and Health.

2.5.4 Proposed technologies for improving cash income

The arrangement of components and factors influencing the household cash flow were illustrated in the Figure 2.3. The following technological interventions have been identified to remove constraints and improve the cash supply of households:

1. Fruits

Farmers in Galagedara receive low prices for the fruit they produce. The Marketing Department buy fruits for processing as fruit drinks, jam, chutney and slices. They have no buying centres in the Galagedara RSD. Therefore, establishing such centres in the area could greatly benefit the farmers as the Marketing Department offer standard prices for the items they buy.

2. Spices

There is much potential to improve the cash income from spices which are discussed below.

(i) Security scheme

The price security scheme for spices was found to be very unpopular as many farmers complained about delays in payment of the subsidies. This was mainly because of the bureaucratic process involved in the scheme. Therefore, measures have to be taken by the Export Agricultural Crops Department to expedite the process and prevent the delays.

(ii) Techniques of extracting oils

As a long term measure it is important to develop methods of extracting spice oils. Pure oil obtains a higher price than unprocessed produce and the market is much more stable. Therefore, research investigations can be undertaken by the Department of Export Agricultural Crops to develop methods of extracting spice oils.

(iii) Co-operatives to improve marketing

As mentioned earlier private dealers have a monopoly over spice marketing in the area. Therefore, establishing farmer co-operatives to market spices could improve the prices they obtain.

(iv) Government depot to purchase produce

There are depots of Department of Export Agricultural Crops involved in buying spices in some areas. Establishing such spice buying centres can remove the monopoly that private traders have on the spice trade and provide a reasonable price for the farmers.

3. Timber

The following actions are recommended to improve the volume and quality of wood produced from the KHGs:

- As a large proportion (35 %) of farmers are not interested in managing timber trees, gains might be made if farmers were made aware of the benefits of pruning and the potential for improving the quality and volume of timber.
- As many as 30 % of the farmers expressed a relationship between pruning and the reduction in vigour of trees. It is important to evaluate the pruning regime carried out by the local farmers in order to discover why vigour was reduced. It may then be possible to develop and recommend a more suitable pruning regime, particularly for the more common trees e.g. *gini-sapu* which could be extended to the farmers.

4. Wild boar damage

Improving the existing live fences by planting *Gliricidia sepium* so that there are no gaps more than 15-20 cm wide could prevent wild boars entering the homegardens.

5. Planting vegetables in the rice fields which are not planted in the minor season

Only 4 % farmers in the area were found growing vegetables in the rainfed rice fields during the minor season. Although, it is a very common practice in many parts of

Sri lanka, there is no tradition in Galagedara of growing vegetables and annual cash crops in the rice fields. Such efforts could improve farmers' income substantially.

It would, therefore, be relevant to carry out feasibility studies for planting vegetables and other cash crops such as tobacco (*Nicotiana tabacum*), onion (*Allium cepa*) and chilli (*Capsicum annuum*) in the rice fields during the minor season in the rainfed rice fields. Soil drainage and acidity can be especially problematic hence measures have to taken during land preparation and with the selection of varieties of suitable crops to overcome these problems.

2.6 SUSTAINABILITY PROBLEMS, CAUSES AND SOLUTIONS

1. Density of vegetation and microclimate

Timber trees (starting from 15 cm DBH) were being cut and sold at a very rapid rate from the homegardens in the area. This was done to meet the farmers day to day expenses because of the low prices for major cash crops, the high demand for timber, and the establishment of saw mills in the area which are able to process small trees (i.e. 15 cm DBH) whereas the traditional methods (i.e. hand sawing) could only accommodate large trees (i.e. over 30 cm DBH). In the long run this trend could lead to a decrease in the density of vegetation, an alteration of the micro climate of the homegardens, and a decrease in the potential for natural regeneration of popular tree species. The following actions are, therefore, recommended to understand and check the rate of timber extraction from the homegardens:

- A research investigation to quantify the rate of timber extraction by examining number and sizes of trees removed, the decrease of canopy cover, and the estimation of the residual stand and its regeneration potential.
- It is important to impose some limits in the size of trees cut and rate of timber extracted at the regional level by limiting the issue of licences for timber harvesting

and transport. This has to be planned carefully as it could lead to lowering the demand and hence the price of timber, and to a further reduction in income for the farmers.

2. Soil fertility

The reduction in management intensity could cause a decrease in the sustainablity of the homegardens because of the following reasons:

- As mentioned earlier (Section 2.4.3.3) farmers have almost stopped actively managing their gardens. Therefore, management practices (such as soil conservation) have been neglected because of the low returns from the gardens. The parts of gardens with a more sloping terrain and non vegetated cover could further degrade. Although nutrient deficiencies have not yet been reported such a situation could arise in the near future if this trend continues.
- Some farmers believed that the soil fertility of homegardens was declining because of the cultivation of clove due to its allelopathic effects. They also attributed low yields of coconut partly to the cultivation of clove.

Therefore it could be relevant to undertake research into the effect of clove trees on the soil and other plants in the homegardens.

2.7. CONCLUSIONS

The interventions identified through the diagnostic procedure and proposed means of implementing them are summarised in Table 2.14. It can be seen that some of these may conflict. For example, green manure could either be used to supplement inorganic fertiliser or as fodder for feeding cattle but given the limited options for increasing supply, could not provide sufficient green leaf material for both uses. It is also apparent

Table 2.14 Summary of interventions identified and proposed institutions / officials for implementing those to improve lowland rice-KHG land use system.

Leverage points	Interventions	Implementation
A. Rice production		
1. Improvement of water flow in the streams during the dry season	Halting the rapid degradation of vegetation cover	
	• campaign to increase the awareness of the importance of vegetation cover in the sensitive areas	ACF, AO, AI, EO(EAC), CDO, TI, RI
	• providing farm land for the landless who have settled in those sensitive areas	RS and ACF
	• legal actions against the extraction of timber from protected areas	ACF, RS, VSO, police
	• research to establish the relationships between tube well construction and the depth of the ground water table	WSDB of DI or LWUD of DA
2. Improving the draught power availability for land preparation	Introducing two wheeled tractors for the farmers in the area	
	• providing loans for farmers to buy tractors	AO, government banks
	• hiring them through the government agencies supporting the agricultural development in the area	ASO, village co-operatives
3. Labour saving on land preparation	Introducing herbicides	
	• campaign to increase the awareness of use of herbicides to minimise the tillage	AO, AI
	• ensuring the availability of herbicides at the local agricultural sales outlets	ASO, village co-operatives, private dealers
4. Labour saving at the rice planting	Introducing mechanical rice planters	
	• research to develop and test the mechanical rice planter	FMRC of DA

5. Controlling wild boar attack	Mechanisms to catch and scare wild boars • research and testing to develop mechanisms to catch and scare wild boars	 FMRC of DA
6. Improving soil fertility	Recycling straw to supplement potassium • program to increase the awareness of farmers about the benefits and methods of recycling straw Increasing the green manure production • pruning of existing green manure trees to improve their leaf production • planting green manure trees in the open areas in the homegardens • research to identify shade tolerant trees and shrubs which produce high quality green manure Use of compost manure • research and testing the compost manure to be used as a supplement to inorganic fertiliser	 AO, AI AO, AI AO, AI DC and DCF of DA DCF and DC of DA
7. Improving the supply of rice seed	• encouraging more farmers to register under the seed production scheme • improving the distribution of rice seed across the area • encouraging farmers to produce their own seed for planting	AI, ASO ASO, village co-operatives, private dealers AI
B. Dairy cattle production		
1. Increasing the availability of feeding material	Increasing the tree fodder production in homegardens • planting fodder trees in open areas of homegardens • pruning of existing fodder trees to increase their leaf production • research to identify shade tolerant trees and shrubs producing high quality fodder	 LO LO LO, DCF of DA, VRI

	<u>Silage as a cattle feed</u>	
	• research to identify a suitable method for producing silage with leaf material	LO, VRI
	• extending the message to farmers about the advantages of using silage as a cattle feed	LO
	<u>Decreasing dependency on grasses in the cattle diets</u>	
	• developing dietary rations for dairy cows using plant material available in the area	VRI
2. Increasing the awareness of support facilities available in the area	• increasing the awareness of the facilities available to small dairy farmers	LO
3. Motivation of farmers	• increasing the awareness of benefits of drinking fresh milk	LO, RS
	• helping farmers to develop their own co-operatives and thus provide: more easy access to advice, exchange of knowledge and improving marketing channels	LO, ASO, RS and village co-operatives
C. Cash supply		
1. Improving marketing of fruits	• establishing buying centres of fruits in the area	AO, MD
2. Increasing income from spices	• increasing the efficiency of the price security scheme launched by the Department of Export Agriculture	DM of DEA, EO(EAC)
	• research to develop methods to extract oils from the spices	DR of DEA
	• helping farmers to develop own co-operatives to improve marketing of spices	DM of DEA, EO(EAC)
	• establishing government depots to purchase spices	DM of DEA
3. Increasing income from the timber	<u>Improving the yield and quality of timber</u>	
	• increasing the awareness of farmers about benefits of pruning timber trees	ACF[1]
	• research to develop a pruning regime for common timber species grown in the homegardens	DR of FD[1]

4. Controlling wild boar damage	• improving the existing live fences by planting gliricidia	AI, EO(EAC)
5. Planting vegetables in the lowland rice fields which are not planted with rice in the minor season	• carrying out feasibility studies to examine the potential of planting vegetables and also identifying suitable varieties	Division of Agronomy of DA
D. Sustainability of homegardens		
1. Maintaining the density of vegetation and micro climate	• research investigations to examine the quantity of timber extracted, associated decrease of canopy cover and the regeneration potential of the residual stand	DR of FD[1], RS
	• minimising timber extraction from Kandyan homegardens through limiting licences issued to timber dealers by the RS for felling and transporting timber	ACF, RS
2. Maintaining the fertility of soil	• research to monitor the soil fertility of homegardens as they were not actively managed	DCF of DA
	• research to examine any allelopathic effects due to the cultivation of clove	DCF and DC of DA

Key: ACF-Assistant Conservator of Forests (Kandy), AO-Agricultural Officer (Kandy), AI-Agricultural Instructor (Galagedara), EO(EAC)-Extension Officer (Export Agricultural Crops-Galagedara), CDO-Coconut Development Officer (Galagedara), TI-Tea Instructor (Galagedara), RI-Rubber Instructor (Galagedara), RS-Regional Secretary (Galagedara), VSO-Village Services Officer, WSDB-Water Supply and Drainage Board, DI-Department of Irrigation, LWUD-Land and water Use Division, DA-Department of Agriculture, ASO-Agrarian Services Officer (Galagedara), FMRC-Farm Machinery Research Centre, DC-Division of Chemistry, DCF-Division of Conservation Farming, LO-Livestock Officer (Galagedara), VRI-Veterinary Research Institute, MD-Marketing Department, DM-Division of Marketing, DEA-Department of Export Agricultural crops, DR-Division of Research, FD-Forest department

[1]The Forest Department has recently extended their mandate to develop timber resources outside forest areas managed by them. However, they have still not appointed officials or created a division which would involve developing timber resources in the homegardens.

that most of the interventions require implementation at an institutional level mainly by government sector institutions.

This poses a particular problem in view of the prevailing situation in Sri Lanaka. Village-level agricultural extension staff were subsumed in to general administrative duties in a government reform in 1993, which has resulted in weakening the link between farmers and the agriculture extension service and as a result there is widespread disillusionment and lack of motivation among staff (IRDP, 1990; MALF, 1995). Furthermore, the extension effort at a village level in the country is fragmented amongst a large number of line agencies with differing structures and mandates that are difficult to co-ordinate (Table 2.15). At its most extreme competing and conflicting advice and technical packages are proposed to farmers by staff working for different agencies some even in different ministries. Furthermore, the high bureaucracy involved in the Government sector institutions make the implementation of these interventions difficult and slow. While these shortcomings have been nationally recognised, it is clear that structural reform at a much higher level than the focus of the present diagnosis would be required to create an environment in which infrastructural development at village level would be expected to proceed.

Table 2.15 Institutions involved in the agriculture and forestry development in the Galagedara RSD.

Regional officers / office location	Main duties	Department / Ministry
1. Agrarian Services Officer[1], Agrarian Services Centre	Agricultural records, supplying agricultural inputs, making plans for solving farmer problems, agricultural insurance	Agrarian Services department, Ministry of Agriculture, Lands and Forestry
2. Agricultural Instructor[1], Agrarian Services Centre	Agricultural Extension, training programmes, demonstrations	Department of Agriculture, Ministry of Agriculture, Lands and forestry

3. Veterinary Surgeon, Veterinary Office, Galagedara	Animal health and welfare	Department of Animal Health and Welfare, Ministry of Livestock Development and Rural Industries
4. Extension Officer-Export Agricultural Crops, Agrarian Services Centre, Galagedara	Export Agricultural crops development	Department of Export Agricultural Crops, Ministry of Agriculture, Lands and Forestry
5. Coconut Development Officer, Agrarian Services Centre, Galagedara	Advice on coconut cultivation	Coconut Development Board, Ministry of Plantation Industries
6. Rubber Instructor, Agrarian Services Centre, Galagedara	Advice on rubber cultivation	Rubber Controllers Department, Ministry of Plantation Industries
7. Tea Inspector, Agrarian Services Centre, Galagedara	Advice on tea cultivation	Sri Lanka Tea Board, Ministry of Plantation Industries
8. Livestock Officer, Agrarian Services Centre, Galagedara	Advice on management of livestock	Department of Animal Health and Production, Ministry of Livestock Development and Rural Industries
9. Assistant Conservator of Forests, Divisional Forest Office, Kandy	Protection of forests and issuing of permits for felling and transporting timber	Forest department, Ministry of Agriculture, Lands and Forestry
10. Regional Secretary, Regional Secretary's Office, Galagedara	In-charge of the public administration of the region and of co-ordinating the development activities of the region	Ministry of Home Affairs, Public Administration and Local Government
11. Colonisation Officer, Regional Secretary's Office, Galagedara	Land management of the colonisation schemes	Ministry of Home Affairs, Public Administration and Local Government
12. Village Services Officers[2] (*Grama Niladari*)	Public administration of a village: they assist the Regional Secretary to administer the region	Ministry of Home Affairs, Public Administration and Local Government
13. Village co-operatives (there are 32 village co-operatives in the area)	Sale of essential food items and agricultural inputs and buying agricultural produce such as paddy rice.	Ministry of Co-operatives
14. Water Supply and Drainage Board, Kandy	Water management	Irrigation Department, Ministry of Irrigation, Power and Energy

15. Bank of Ceylon, Galagedara	Credit and banking	Ministry of Finance
16. Peoples bank, Galagedara	Credit and banking	Ministry of Finance

Key:
[1]There were four officers employed for the region: they were based at the four Agrarian Services Centres at Galagedara, Weliwita, Hataraliyadda and Aludeniya in the Galagedara RSD.
[2]There were 124 Village Officers employed for the Galagedara RSD

The main problems in the land use system lie in the cash sub system. Low income has constrained the purchase of food for household consumption. Therefore, interventions for improving the cash supply were identified in this study (Section 2.5.4). Further, there were opportunities for increasing the supply of rice from lowland fields, food produce from homegardens and also dairy cattle production through the implementation of interventions. In contrast, poultry production had little potential to expand in the area. Energy and housing requirements were adequately met in the majority of households.

The results of the diagnostic survey also indicate that the cultivation of lowland rice had become the dominant practice within the land use system as KHGs have become less important because of the low income received for main products from them. Family members were employed off-farm to supplement cash income. As a result the management of homegardens has been neglected and timber trees have been cut and sold at a very rapid rate.

The homegardens in the Galagedara area, however, performed very important environmental roles, including maintaining the regional climate and landscape. Further, these KHGs existed in an area which has a small proportion of natural forest cover (about 10% in the Galagedara RSD) (Table 2.3). The area receives medium intensity rain fall, has highly erodable soil and moderately sloping terrain and thus has a high erosion potential. Soil erosion was extremely low however, in well managed homegardens. Also the Galagedara area is part of an important catchment comprising four small streams that start from the two main mountains in the area: Bolagala and Girihagama. These streams serve the rice fields in the area and also feed the main rivers that supply water to the intermediate and dry zones of Sri Lanka. The benefits of homegardens could be summarised as follows:

- Increase the rate of water infiltration leading to less surface run-off, higher water tables and increased water flow in streams in the dry season
- Reduce soil erosion that causes diminution of soil fertility and siltation of irrigation structures.
- Reduce understory air temperatures as the vegetation cover provides shade.
- Provide habitat for many wild animals and plants

Therefore, it could be seen as important at the landscape and regional level to encourage farmers to manage homegardens since these fulfil a vital environmental role. Among the interventions identified earlier, improving the efficiency of the price security scheme for spices and their marketing are of crucial importance as short term measures to keep farmers managing homegardens, until the price of spices recovers. The prices of spice crops that prevailed were depressed because of the political situation. The lucrative Indian market has declined in recent years but is expected to open up again as international relations between India and Sri Lanka improve[1] (Tilakaratnebanda, 1993b). Furthermore, the cash income received from the sale of timber produced from KHGs could be increased in the longer term through encouraging improved tree management by farmers (Section 2.5.4). Pruning would be expected to increase the volume and quality of wood sold and thus cash income per tree. This may also reduce the number of trees felled and so assist in the maintenance of tree cover.

[1] The cause of the low prices of cash crops is a politically very sensitive issue, therefore, it is hidden from the public.

CHAPTER 3

LAND USE SYSTEM CLASSIFICATION FOR AGROFORESTRY

3.1 INTRODUCTION

This Chapter describes research carried out to evaluate the classification of Land Use Systems as a means of identifying sufficiently homogenous groups of agroforestry practices for research and extension purposes. Categorising farms into discrete groups, where farmers within a category operate under similar circumstances, is an important step in the application of farming systems research and extension (FSR/E) methods but it is unclear whether its application at a household level or above is effective in grouping farmers with similar agroforestry practices, where these practices are ecologically complex and have a supplementary role within the farming system.

As stated in Chapter 2, FSR/E approaches were developed to try and improve the targeting of research and extension activity to farmers' needs, circumstances and priorities, especially in systems involving low resource levels. Farmers in an area are classified into discrete groups on the basis of their land use system (i.e. farming systems). Farm resources, the bio-physical conditions of the farm and the socio-economic status of the land user are indicators by which the land use system is classified (Raintree, 1987b). Secondary data of the targeted area are used as the primary source of this information. Each group is carefully examined using diagnostic surveys in order to comprehend the strategies which they adopt, and the major constraints under which they operate. Thus, an appropriate set of recommendations is developed, aimed at alleviating the constraints that limit the potential of each land use system.

However, agroforestry practices, such as the Kandyan home gardens, have a discrete and supplementary role within the farming system. This may be partly related to the complexity and diversity of the gardens which is far greater than for the agronomic situations that FSR/E methods were developed for (McCracken *et al.*, 1988; Hildebrand, 1981), and allows farmers flexibility in garden management.

When agroforestry practices are highly complex, it may be possible to classify them for improvement purposes at the level of the practice rather than the farming system. Agroecosystem Analysis and Development (AAD) views the world as a hierarchy of systems so that what may be a single component of a system at a higher level (for example a tree within a farming system) may also be viewed, at a lower level, as a whole system in itself (i.e. with leaves, roots, stem etc) (Conway, 1987). The appropriate level of hierarchy to work at depends on the purpose of the analysis. FSR/E methodologies, including the D & D methodology, are applied at various levels in the hierarchy but commonly at the household level (i.e. the farming system or micro D & D level) or at landscape and regional scales (Raintree, 1990). The effectiveness of diagnosis at practice level will depend upon how discrete the practices are and the extent to which there are similarities in the ecological structure and function of individual gardens.

Because of their extreme complexity, it may not be possible to successfully classify multi-layered homegardens through examination of their characteristics even at the practice level. If so, then FSR/E methods, in terms of defining a recommendation domain may be ineffective in improving such systems and a different approach may need to be adopted.

It can be argued that the ecological structure of farming practices provides some insight in to the conditions and circumstances of those practices. Thus if land use system classification is effective, then it could be expected that the ecological structure of farming practices in any land use system will be similar, while gardens from different land use systems may be significantly different. Therefore, examining the ecological structure of agroforestry practices within land use systems may provide some evidence as to the effectiveness of the land use system classification in the present context.

3.2 METHODOLOGY

Ten Kandyan homegardens from each of the five land use systems previously identified (Section 2.3.5) were selected randomly for the investigation. The following parameters were used to examine the ecological structure of homegardens in relation to the land use systems:

3.2.1 Land types

3.2.1.1 Characteristics of land types

Kandyan homegardens are not a homogenous area where plants are evenly mixed throughout, there are, in fact, parts of each garden which can be distinguished as having particular functionality and species assemblages such as, live fences, vegetable plots and flower gardens (Southern, 1994). These areas, called land types for convenience here, represent reasonably discrete units of land utilisation within gardens and are important in describing the ecological structure of gardens. The different land types occurring in the sampled gardens were identified.

3.2.1.2 Frequency of different land types

Chi-square tests were done with respect to all land types to examine whether their frequency of presence was the same or whether it differed between homegardens within different land use systems. The null hypothesis (Ho) was, therefore, that the frequency of presence of different land types was the same for homegardens in different land use systems.

Chi-square tests were also done to examine whether differences between the mean number of land types per homegarden differed significantly across the land use systems.

The null hypothesis in this case was, therefore, that, the mean number of land types present was similar in the homegardens of different land use systems.

3.2.2 Characteristics of forestgarden types

The most prominent land types in the gardens, in terms of both land area and activity, was the forestgarden area where mixtures of productive trees and shrubs were grown. Many different types of forestgarden could be identified on the basis of the species grown. The structure of forestgarden areas within the homegardens were, therefore, further, examined.

3.2.2.1 Number of forestgarden types

The various forestgarden types in the homegardens were identified on the basis of differences in the assemblage of dominant species using direct observations. The dominant species present within each type were identified and used to name those areas. The classification of forestgarden types was confirmed by dividing each forestgarden type into four equal portions, one of which was randomly selected and an inventory plot, 15m x 5m, laid out in the middle. Layers within each such quadrat were identified based on the IUFRO classification scheme (Lamprect, 1989). The mean height of the tallest tree from each of the 40 plots was used as the top height. A few trees of approximately 2/3 and 1/3 the top height were identified and used as standards by which to categorise individuals into different layers. Trees taller than 2/3 of top height were classified as the upper story, trees within 2/3 and 1/3 of top height as the middle story and trees less than 1/3 of top height as the lower story. This gives a ratio of average tree height within the different layers of:

Lower : Middle : Upper = 1: 3: 5.

An individual in the lower story is, therefore, given a rating of one, an individual in the middle story a rating of three and in the upper story a rating of five. Thus in terms of ecological dominance three individuals in the lower story are equal to one individual in middle story, and five individuals in lower story are equal to one individual in the upper story. Only individuals taller than 1m were considered.

An importance value (i) for each species within a forestgarden type was calculated using these ratings in the following formula (adapted from, Lamprect, 1989):

$$i_{(A)1} = R_A / R_T \times 100 \text{..........................Equation 3.1}$$

$i_{(A)1}$= Importance value of species A within forestgarden type '1'
R_A= The sum of ratings for all individuals of species A in the 15m x 15m plot
R_T = The sum of ratings for all the individuals in the 15m x 15m plot

The species with the importance value (i) above 10 were identified as dominants. Dominant species were then used to classify the different forestgarden types within the homegardens.

Analysis of variance was undertaken to examine whether the mean number of forestgarden types identified per homegarden differed between land use systems and the means were compared using Least Significant Difference (LSD) at significance level 0.05 (Sokal and Rohlf, 1995). Absolute values were used in the analysis since the results were similar to that achieved when using data that had been subjected to angular transformation.

3.2.2.2 Importance value of species for forestgardens

Since there were many forestgarden types within a single homegarden it was useful to calculate a single importance value for each of the dominant species across all of the forestgarden areas of the homegarden (i.e. a single value for each species in one homegarden or a total importance value). This was calculated using the following formula (adapted from, Lamprect, 1989):

$$I_{(A)} = (i_{(A)1} / (E_1/E_t)) + (i_{(A)2} / (E_2/E_t)) + \ldots$$ ....Equation 3.2

$I_{(A)}$= Importance value of species A for all forestgarden types in a homegarden

$i_{(A)1}$= Importance value of species A within forestgarden type '1'

$i_{(A)2}$ = Importance value of species A within forestgarden type '2'

E_1= Extent of forestgarden type 1

E_2= Extent of forestgarden type 2

E_t= Sum of extents of all forestgarden types within the homegarden

Analysis of variance was used to examine whether the total importance value (I) for each dominant species in a homegarden varied with land use system. Absolute values were used in the analysis since the results were similar to those achieved when using data that had been angularly transformed. The total importance values of each species in different land use system were compared using Least significant difference (LSD) at significance level 0.05 (Sokal and Rohlf, 1995).

3.2.2.3 Classification of homegardens based on the dominant species of forestgarden areas

An attempt was made to classify the forty homegardens investigated in LUSs 1, 2, 3 and 4 based on the dominant species of the forestgarden areas. Gardens surveyed in LUS-5 did not possess forestgarden areas and, therefore, were not included in this analysis. The species with total importance values above 10 were identified as dominant species.

3.2.2.4 Physical characteristics of forestgarden types

Soil texture and slope are considered to be the key physical factors influencing the growth of woody crops in the Galagedara RSD. With tea, for example, it has been found that soil with either a high gravel content (over 30%) or a slope greater than 50% causes severe limitations to the tea crop in the area (Sivapalan *et al.*, 1986) and a similar relationship could also be expected for woody plants in the homegardens.

(i) Soil texture: the soil texture of the forestgarden area of each homegarden (i.e. considering all forestgarden types in one homegarden together) was examined using visual observation and hand feeling of the soil. The forestgarden area of each homegarden was divided in to four quarters and a point in each quarter was randomly selected. Soil was collected from this location to a depth of 1m using a soil auger and from this sample the percentage of gravely soil in the forestgarden area of homegarden was estimated. This estimate was used to characterise the distribution of gravel in forestgarden areas. Analysis of variance was used to examine whether differences between the mean area of forestgarden covered with gravel soil varied significantly with homegardens from different land use systems (P=0.05) (Sokal and Rohlf, 1995). Absolute values were used in the analysis since the results were similar to those achieved when using data that had been angularly transformed.

(ii) Slope: the slope of the land over the forestgarden area of each homegarden (i.e. considering all forestgarden types in one homegarden as a single area) was measured, using a trigonometric method, with a tape and a rectangular square. The forestgarden area of each homegarden was divided in to four quarters and a point in each quarter was randomly selected. The mean slope of the forestgarden area for each homegarden was computed from the average of the slope measurements at these points. Analysis of variance was used to examine whether the mean slope of forestgardens differed significantly between land use systems (P=0.05). Absolute values were used in the analysis since the results were similar to that achieved when using data that had been transformed by an angular transformation (Sokal and Rohlf, 1995).

3.2.3 Homegarden structures within LUS-1

The sample of 10 homegardens in LUS-1 were selected for further examination of the variation of gardens with a single land use system. LUS-1 was chosen for this, because the homegardens in this system were: (a) the largest and (b) the farming practice that generated the largest proportion of cash in the land use system. Homegardens found in the other four land use systems did not have such a dominant role in the household economy.

3.2.3.1 Extent of land types

The extent of different land types identified in the ten homegardens sampled from LUS-1 were calculated by multiplying length by width. Lengths and widths were measured using a meter tape.

3.2.3.2 Characteristics of forestgarden types

Forestgarden types in the ten homegardens of LUS-1 were examined further. The largest forestgarden type in each garden was selected and divided into four equal portions. One of these portions was randomly selected and a plot, 15m x 5m, laid out in the middle. Within this plot all individuals above 50 cm in height were recorded. Top height, crown height, trunk diameter at breast height (1.3m above ground level) (DBH) and crown diameter were measured and the location of each individual in the plot (i.e. X, Y co-ordinates) was recorded. The location of individuals within the plot were estimated by placing two tapes along the long and short sides of the plot. DBH was measured using a diameter tape, heights by a clinometer and crown diameter by the length of the shadow cast when the sun was directly above the trees. Sketches of all individual crown shapes were made.

The data were used to draw profile diagrams (Hamilton and Bensted-Smith, 1989; Reitsma, 1988) from which the vertical distribution of species could be examined (Appendix 3).

(i) Dominant species

The importance values of all species in each plot (I_S) were calculated using the following formula (Lamprect, 1989):

$$I_S(A) = 1/4 \times (N_A / N_T) \times (B_A / B_T) \times (H_A / H_T) \times (C_A / C_T) \times 100 \quad \text{.........Equation 3.3}$$

where:

$I_S(A)$=Importance value of species A

N_A = Number of individuals of species A

N_T = Total number of individuals in the plot

B_A = Sum of basal areas of all individuals of species A

B_T = Sum of basal areas of all individuals in the plot

H_A = Sum of heights of all individuals of species A

H_T = Sum of heights of all individuals in the plot

C_A = Sum of crown diameters of all individuals of species A

C_T = Sum of crown diameters of all individuals in the plot

(ii) Vertical structure of forestgarden areas

The characteristics of the different layers (stories) within forestgarden types were also examined. The ratio of stems to species in each layer and total stems and species per plot were calculated. The layers of the forestgardens were identified as per Section 3.2.2.1. For this analysis however, a standard top height was calculated as the objective here was to compare the vegetation profiles across the different forestgarden types

(Appendix 3). Therefore, the mean height of the tallest tree from each of the 10 plots was used as the top height.

3.3 RESULTS AND DISCUSSIONS

3.3.1 Land types

3.3.1.1 Characteristics of the land types

Discrete units of land utilisation (management) were identified in the selected homegardens and termed 'land types'. These different land types provide a wide range of products and services to the household, and are composed of a diverse range of species and vertical structures. This diversity may be due to differences in management objectives or intensities of management as well as variations in the micro climate.

i. Forestgardens

Complex tree crop gardens were the most prominent land type in the homegardens. These complex tree crop gardens, termed forestgardens, were mainly managed for cash crops such as spices, coffee (*Coffea arabica*), cocoa (*Theobroma cacao*), coconut (*Cocos nucifera*), arecanut (*Areca catechu*), banana (*Musa balbisiana*), timber and tea (*Camellia sinensis*).

ii. *Midula*

'*Midula*' is the term used for the open area around the house which provides a space for drying the harvests, for children to play and relaxation during leisure times.

iii. Flowergarden

Ornamental plants such as flowers and foliage were commonly grown in front of the houses for amenity purposes. Thus flowergardens are present in the majority of homegardens in all land use systems. Ornamental plants and fruits were found growing in mixtures in some homegardens. In these mixtures, upper stories were made up of fruits whilst ornamental plants were found in the under storey.

iv. Fruit band

Farmers usually planted fruit trees as close to the house as possible but outside the '*midula*' area. Therefore, fruit trees can be seen as a narrow band between the *midula* and the forestgarden area especially to the front and sides of the houses.

v. Kitchengarden

Kitchengardens were commonly found in the backyard of the house, close to kitchen. They were dominated by herbaceous plants of vegetables and relishes. Other plants found growing in the kitchengardens were trees providing leafy vegetables, papaw, banana and plantain as well as medicinal and ornamental plants. Kitchengardens have a close interaction with the kitchen itself. Residual materials from the kitchen, such as water used for washing, unused parts of vegetables, spoiled food and wood ash from stoves are deposited in the kitchengarden. Hence, soils in these areas are likely to be richer in organic matter, plant nutrients and moisture than other areas of the gardens. In some gardens the kitchengarden area formed an under storey of a forestgarden area.

vi. Vegetable plots

Vegetable plots were found in some homegardens, these were distinguishable from kitchengardens because they had much less interaction with the kitchen and were not located close to the house.

vii. Live fence

The main function of 'live fences' in gardens was the demarcation of boundaries rather than the protection of homegardens from herbivores or the production of tree products. Here, fences were only built in the absence of other land marks such as roads, ravines or leader drains which could be used to demarcate boundaries.

viii. *Kamatha*

A '*kamatha*' is the area where the rice harvest is threshed. The common practise is to reserve a permanent place at the upper part of the lowland rice field for threshing and so minimise transport costs. However, some farmers had allocated land from the homegarden to serve as a '*kamatha*' where the homegarden was bordering the paddy field.

ix. Other areas

Wells (bore holes), unplanted areas, rocky outcrops and houses of farmers were also found in the gardens.

3.3.1.2 Frequency of different land types

Table 3.1 shows the occurrence of different land types within the 10 homegardens investigated from each of the five land use systems. Chi-square tests were carried out to examine whether the presence of other land types was the same or different in homegardens across different land use systems. The chi-square value calculated was found significant only for the forestgarden and vegetable plot land types. This is because forestgardens were found frequently in the homegardens of LUSs 1, 2, 3 and 4 while none were present in the homegardens sampled from LUS-5. The absence of forestgardens in LUS-5 can be attributed to the smaller extent of the homegardens in this land use system and the ability of farmers to obtain a high income from other sources, and hence to have less interest in generating cash from their homegardens.

Vegetable plots were found more frequently in the homegardens of LUS-1. This could be a strategy adopted by these farmers to minimise the outflow of cash (through producing vegetables for home consumption) which is becoming increasingly necessary as their cash inflow is constrained by the lowering of cash crop prices.

The presence of other types was found to be similar across the five land use systems. Differences in their presence across the different five land use systems were, therefore, random with no distinguishable pattern evident (Table 3.1).

3.3.1.3 Total number of land types per homegarden

The total number of land types present in the homegardens of different five land use systems (Table 3.1) were also compared using the chi-square test. The chi-square values calculated were found to be significant (P=0.05). This was attributed to the larger number of land types present in the homegardens of LUS-1. The single most important factor contributing to this was the greater presence of vegetable plots. Although the occurance of land types in the homegardens of LUS-5 was less than in LUSs 2, 3 and 4, the difference was only small. This was mainly due to the higher frequency of occurrence of forestgardens in the homegardens of LUSs 2, 3 and 4. Despite their small size a large number of land types were still to be found in the homegardens of LUS-5. This can be explained by the fact that, despite the variation in size of homegardens, land users must allocate areas, however small, to enable them to meet their diverse and essential subsistence needs.

Table 3.1 Presence of different land types in the 10 homegardens investigated from each of the five different five land use systems.

Land type	Land Use System					Chi-square test
	1	2	3	4	5	
Forestgarden	10	10	10	10	0	S
Midula	10[1]	10	10	10	10	NS
Flower garden	09	08	08	07	06	NS
Flower and fruit	04	03	04	05	02	NS
Fruit band	03	04	01	01	01	NS
Kitchen garden	10	05	06	06	08	NS
Vegetable plots	07	0	02	02	02	S
Live fence	02	03	04	05	09	NS
Kamatha	03	01	03	0	0	NS
Well (bore hole)	05	01	01	0	03	NS
Unplanted	04	02	01	02	0	NS
Rocky	03	0	01	01	0	NS
House	10	10	10	10	10	NS
Total	80	57	63	59	51	
Mean land types per homegarden	8.0	5.7	6.3	5.9	5.1	S

Key: S-Significant at 0.05 level of significance, NS- Non significant at 0.05 level of significance
[1] grass lawns were found on the '*midula*' of two homegardens

3.3.2 Characteristics of forestgarden types

3.3.2.1 Number of forestgarden types

The forestgarden areas of homegardens were further examined since they were the dominant land type and form the main agroforestry activity within the land use systems. Distinct forestgarden types were identified on the basis of species dominance (Appendix 4). The mean number of forestgarden types identified are presented in Table 3.2. The results indicate that the mean number of forestgarden types per homegarden within the different land use systems were significantly different. The number of forestgarden types per homegarden in LUS-1 was significantly higher than in all the other systems. LUS-2, LUS-3 and LUS-4 did not differ significantly in this respect, while none of the ten homegardens surveyed from LUS-5 had a forestgarden area. This difference can be attributed to the variation in size of the homegardens across the five land use systems as shown in Table 2.3. Thus, in general, the greater the extent of the homegarden the higher the number of forestgarden types occurring.

Table 3.2 The mean number of forestgarden types identified in homegardens from the five land use systems, based on differences in dominant species combinations.

Land use system	Mean number of forestgarden types per homegarden	Standard error
1	2.70^{a}	0.30
2	1.80^{b}	0.20
3	1.70^{b}	0.15
4	1.50^{b}	0.22
5	-	-
Mean	1.93	-
LSD (P=0.05)	0.75	-

Key: 1. Differences between means identified by different letters are significant while differences between means identified by the same letters are not significant.
2. P= Significance level
3. LSD = Least Significant Difference

3.3.2.2 Importance value of dominant species

Coffee, coconut, arecanut, banana, *Gliricidia sepium*, cocoa, clove(*Syzygium aromaticum*), jak (*Artocarpus heterophyllus*), pepper (*Piper nigrum*), nutmeg (*Myristica fragrans*), tea, *gini-sapu* (*Michelia champaca*), mahogany (*Swietenia macrophylla*) and *halmilla* (*Berrya cordifolia*) were identified as dominant species. They form the common cash crops of the area. Not all were present as a dominant species in every homegarden. The ten species which obtained the highest importance values (*I*) (for 40 homegardens of LUSs 1,2,3 and 4) are shown in Table 3.3. Having subjected the data to analysis of variance, the mean importance values across the five land use systems were only found to vary significantly (P=0.05) for pepper. For pepper, the differences in mean importance values between LUS-3 and LUS-2; and, LUS-3 and LUS-4 were significant. Differences between all other pairs of means for pepper were not significant. It is clear, therefore, that the ecological role of the dominant species varies more between homegardens of a single land use system than in homegardens of different land use systems. From this it is reasonable to conclude that the present classification of land use systems was ineffective in grouping homegardens with similar ecological structures.

3.3.2.3 Classification of homegardens based on the dominant species of forestgarden areas

The 14 dominant species identified in forestgarden areas of homegardens are shown in Table 3.4. Thirty five different dominant species combinations were found in the 40 homegardens investigated. Hence, no clear categories or patterns emerge when they are examined with relation to dominant species. This suggests that homegardens cannot be classified effectively on the basis of species assemblage due to their extreme species diversity and structural complexity.

Table 3.3 Importance value (*I*) of dominant species in forestgarden areas of the KHGs from LUSs 1,2,3 and 4.

LUS	Coffee		Coconut		Arecanut		Banana		*Gliricidia*		Cocoa		Clove		Jak		Pepper		Nutmeg	
	Mean	S.E	Mean	S.E	Mean	S.E	Mean	S.E	Mean	S.E	Mean	S.E	Mean	S.E	Mean	S.E	Mean[1]	S.E	Mean	S.E
1	13.09	2.08	10.19	1.76	15.58	2.45	10.24	3.59	6.60	1.92	5.66	1.88	4.22	1.50	4.11	1.03	4.29^{ab}	1.13	1.41	0.95
2	21.14	4.08	13.98	1.50	8.02	2.72	1.47	1.47	5.21	1.98	4.98	1.85	7.20	3.07	4.76	1.33	1.46^{a}	0.87	2.58	2.08
3	7.94	2.12	13.44	2.69	5.24	1.46	17.35	6.02	11.07	4.13	5.30	3.83	6.90	4.06	4.33	1.32	8.29^{b}	3.38	1.10	1.10
4	16.69	4.71	14.84	1.84	9.83	3.47	5.91	3.94	4.24	1.87	5.66	3.53	2.93	2.02	7.31	2.39	0.92^{a}	0.68	2.93	2.02
Mean	14.71	NS	13.11	NS	9.67	NS	8.74	NS	6.78	NS	5.40	NS	5.31	NS	5.13	NS	3.74^{a}	S	2.01	NS
LSD (P=0.05)	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	4.49		-	-

Key: S-Significant, NS-Non-significant, LSD-Least significant difference, P- Significance level
[1] In a column, differences between means identified by different letters are significant while differences between means identified by the same letters are not significant.
Species names are given in Appendix 2.

Table 3.4 Dominant species identified in forestgarden areas from homegardens of LUSs 1, 2, 3 and 4.

Homegarden	Land use system			
	1	2	3	4
1	1, 2, 11	1, 3	1, 3, 8 [e]	1, 2, 5, 10
2	2, 5, 14 [a]	1, 3, 6, 14	1, 4, 14	2, 3, 6, 7, 14
3	2, 3, 8	1, 3, 11 [c]	1, 2, 3, 6	2, 3, 14
4	1, 2, 3, 6, 8	1, 3, 9	1, 4, 14	6, 7, 13
5	1, 3, 14 [b]	1, 8, 10, 14	1, 8	1, 3, 8 [e]
6	1, 3, 14 [b]	2, 5, 14 [a]	1, 8, 14	1, 2, 3, 10
7	2, 3, 8, 14	1, 3, 7, 10	1, 6, 7	1, 8, 13
8	1, 2, 5	1, 2, 6, 9	1, 3, 5	1, 2, 5, 14
9	1, 2, 5, 6	3, 6	4, 8, 14 [d]	1, 3, 11 [c]
10	8, 12, 14	1, 2, 3	4, 8, 14 [d]	1, 3, 10, 11

Key: 1-Coconut, 2-arecanut, 3-coffee, 4-pepper, 5-cocoa, 6-clove, 7-nutmeg, 8-banana, 9-tea, 10-jak, 11-*gini-sapu*, 12-*halmilla*, 13-mahogany, 14-*Gliricidia sepium*
Species combinations identified by same letters are similar, while all others are different from each other
Species names are given in Appendix 2.

The dominant species identified in forestgarden areas from homegardens of LUSs 1, 2, 3 and 4 (Table 3.4) can be classified using both ecological and economic criteria:

Group F: upperstorey trees that primarily produce fruit- 1-coconut, 2-arecanut, 10-jak

Group T: upperstorey trees that primarily produce timber-10-jak, 11-*gini-sapu*, 12-*halmilla*, 13-mahogany

Group B: shade tolerant beverage shrubs that are in understorey-3-coffee, 5-cocoa, 9-tea

Group S: mid-layer, high value, spice crops-not necessarily shade tolerant and may cast heavy shade themselves-6-clove, 7-nutmeg

Group M: a miscellany of mid-layer plants that are difficult to classify-4-pepper, 8-banana, 14-*Gliricidia sepium*

Applying this classification to Table 3.4 indicates following general patterns of species grouping in relation to land use systems:

- timber trees do not feature as dominants except in LUS-4
- fruit trees and beverage shrubs occur together except in LUS-3 where miscellany of mid-layer plants (pepper, *Gliricidia sepium* and banana) appears to largely replace beverage shrubs
- LUS-1 typically has fruit trees, beverage shrubs and miscellany of mid-layer plants (pepper, *Gliricidia sepium* and banana)

Combining species in this way (with economic and ecological elements used as criteria) indicates some pattern with respect to garden structure in relation to land use system type. However, there is still species diversity within each group and, given such complexity, it is hard to see how recommendation in an FSR context could be made across a domain classified in this way. Thus, it appears as though there are structural differences between the homegardens amongst land use systems, indicative of having split farmers up sensibly with respect to their whole system, but these are not particularly functional with respect to homegardens because of the species diversity involved.

3.3.2.4 Physical characteristics of forestgarden types

(i) Soil texture (graveliness)

Graveliness is a critical factor influencing tree growth through its effect on root growth and the moisture content of the soil, especially during the dry season (Sivapalan *et al.*, 1986). The extent of gravely soil in homegardens in the different land use systems is shown in Table 3.5. Differences in the mean extent of forestgarden area covered with gravely soil across land use systems were not significant. Thus, variation in soil texture in homegardens within a single land use system was higher than between land use systems. Hence the land use system classification used in the present research did not group homegardens of similar soil textures.

Table 3.5 Mean extent of forestgarden area covered with gravel soil in homegardens of different land use systems.

LUS	Extent covered with gravel soil (%)	Standard error
1	7.50	3.82
2	30.00	13.33
3	30.00	13.33
4	45.00	13.84
Mean	28.13	NS

Key: NS- The differences in the mean percentage extent of gravel soil in forestgardens of different land use systems are non significant (P=0.05)

(ii) Slope

Slope is a critical factor influencing the ecology of production systems in the Galagedara RSD through its effect on the rate of soil erosion and moisture content (Sivapalan *et al.*, 1986). The mean percentage slope found in the homegardens of different land use systems are shown in Table 3.6. Differences in mean percentage slope between land use systems were not significant (P=0.05) when the data were analysed using the analysis of variance. Thus variation in slope within a land use system is higher than between land use systems and so the land use system classification does not group homegardens of similar gradients.

Table 3.6 Mean percentage slope of forestgarden areas in the homegardens of different land use systems.

LUS	Slope (%)	Standard error
1	22.60	4.58
2	23.41	4.43
3	24.63	7.11
4	12.25	2.87
Mean	1.58	NS

Key: NS- The differences of mean percentage slope in forestgardens of different land use system are non significant (P=0.05).

3.3.3 Homegarden structures within LUS-1

3.3.3.1 Extent of land types

The extent of different land types found in the homegardens of LUS-1 are shown in Table 3.7. It is clear from the results that forestgarden areas occupy the largest proportion of these homegardens (88.3%). As stated earlier, these areas are commonly planted with cash crops, thus there is a great emphasis placed on cash production by farmers in LUS-1 in their management of homegardens. The co-efficient of variation indicates that the area allocated to different land types varies greatly across the homegardens.

Table 3.7 Mean extent of different land types identified in the homegardens of LUS-1

Land type	Mean extent (m^2)	CV (%)
Forestgarden	6987.10^a (88.3%)	66%
Midula	180.00^b (2.3%)	90%
Flowergarden	33.80^b (0.4%)	84%
Flower and fruit	46.10^b (0.6%)	152%
Kitchengarden	92.60^b (1.2%)	73%
Vegetable plot	71.70^b (0.9%)	172%
Kamatha	63.30^b (0.8%)	185%
Bore hole	17.00^b (0.2%)	127%
Unplanted	177.60^b (2.3%)	145%
Rocky	63.60^b (0.8%)	193%
House	176.90^b (2.2%)	54%
LSD (P=0.05)	998.47	

Key: The figures in parenthesis are percentages of absolute values.
CV- Co-efficient of variation
LSD-Least Significant Differences
P-Significance level

3.3.3.2 Characteristics of forestgarden types

(i) Dominant species

Importance values (I_S) were calculated for each species following the detailed investigation of forestgarden areas in LUS-1 (Appendix 3). The ten species which obtained the highest importance values are shown in Table 3.8. Nine of the ten species were identified earlier (Section 3.3.2.2) as dominants across all the land use systems. Nutmeg was not identified here, while *Kahata* (*Careya arborea*) was because of one very large tree in the sample which contributed over 50% to the total importance value for all ten homegardens. The co-efficient of variation (CV) indicates a high variation in the ecological role played by any given species within different homegardens. This reinforces the findings from Section 3.3.2.2 and further highlights the variation in ecological structure of forestgarden areas within homegardens of LUS-1.

Table 3.8 Importance values (I_S) of plant species occurring in the horizontal layers of forestgardens of 10 KHGs investigated from LUS-1.

Species	KHG										Mean I_S of species	CV (%)
	1	2	3	4	5	6	7	8	9	10		
Arecanut	27.90	47.59	19.04	18.65	0.00	3.57	30.55	6.64	10.57	5.53	17.00	88%
Coffee	0.00	5.07	38.10	19.43	17.33	9.26	16.66	13.44	15.63	3.33	13.83	78%
Coconut	25.05	0.00	0.00	0.00	28.49	38.43	2.78	4.29	0.00	11.10	11.01	130%
Jak	0.00	1.85	0.00	5.80	0.00	9.60	4.17	33.80	7.54	1.11	6.39	160%
Clove	7.60	0.00	0.00	30.06	0.00	9.60	0.00	0.59	2.81	4.18	5.48	170%
Gliricidia	4.84	0.00	0.00	0.00	18.52	15.26	4.17	5.14	1.04	4.44	5.34	121%
Banana	0.00	0.00	38.10	0.00	0.00	0.00	12.49	0.00	0.00	0.00	5.06	242%
Kahata	1.61	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	35.34	3.70	301%
Pepper	1.61	0.00	0.00	0.00	5.88	10.71	9.72	2.35	1.04	4.44	3.58	112%
Cocoa	0.00	25.98	0.00	0.72	0.00	0.00	0.00	5.18	3.02	0.00	3.49	232%
Total	68.61	80.49	95.24	74.66	70.22	96.43	80.54	71.39	41.65	69.47	-	

Key:
1. I_S- Importance value
2. CV- Co-efficient of variation
3. Species names are given in Appendix 2.

(ii) Vertical structure of forestgarden areas

The characteristics of the different layers of forestgarden in the 10 homegardens of LUS-1 are shown in Table 3.9. On average 84% of individuals were found in the lower layer (0-7m), 10% in the middle layer (7-14m) and 6% in the top layer (>14m). The number of species present within different layers follows a similar pattern. The co-efficient of variation indicates that the number of individuals and species at different layers varied highly between homegardens of LUS-1, especially in the top layer. In addition, stem number per plot(*T*), species number (i.e. species richness) per plot (*S*) and the ratio of individuals to species varied greatly. This, again, provides further evidence that the structure of forestgardens in homegardens from a single land use system varies greatly.

Table 3.9 Characteristics of the different layers identified in forestgarden areas in 15m x 5m plots from KHGs of LUS-1.

KHG	Lower (0-7m)		Middle (7-14m)		Upper (>14m)		Stem number (*T*)	Species number (*S*)	Ratio *T/S*	Top height (m)
	Stem number	Species number	Stem number	Species number	Stem number	Species number				
1	24 (77)	14 (93)	4 (13)	3 (20)	3 (10)	2 (13)	31	15	2.07	18.60
2	42 (78)	12 (92)	6 (11)	3 (23)	6 (11)	3 (23)	54	13	4.15	25.00
3	40 (95)	4 (100)	1 (2.5)	1 (25)	1 (2.5)	1 (25)	42	04	10.5	16.20
4	64 (93)	17 (100)	5 (7)	2 (12)	-	-	69	17	4.06	13.57
5	26 (81)	12 (86)	6 (19)	3 (21)	-	-	32	14	2.29	21.20
6	8 (57)	4 (50)	4 (29)	4 (50)	2 (14)	2 (25)	14	08	1.75	17.40
7	63 (88)	15 (100)	6 (4)	2 (13)	3 (8)	2 (13)	72	15	4.80	19.41
8	73 (86)	22 (88)	7 (8)	3 (12)	5 (6)	5 (20)	85	25	3.40	30.30
9	38 (79)	13 (76)	5 (10.5)	4 (24)	5 (10.5)	4 (24)	48	17	2.82	28.00
10	38 (84)	20 (83)	6 (13)	5 (21)	1 (3)	1 (4)	45	24	1.88	14.40
Mean	41.6 (84%)	13.3	4.9 (10%)	3.0	3.2 (6%)	2.2	49.2	15.3	3.22	20.41
CV (%)	49%	44%	34%	39%	83%	82%	44%	42%	69%	28%

Key: 1. The numbers in parenthesis indicate percentages of absolute values.
CV-Co-efficient of variation

3.4 CONCLUSIONS

The results relating to presence or absence of different land types, total number of land types present per homegarden, characteristics of forestgarden types such as dominant species, number of forestgarden types per homegarden, slope and soil texture (graveliness) provides sufficient evidence to suggest that structural differences between homegardens within a single land use system are greater than the variation between homegardens of different land use systems. The number of different land types per homegarden and the number of forestgarden types per homegarden were found to increase with the extent of homegardens.

Further investigations in to homegardens from LUS-1 examined the extent of land types, dominant species and the vertical structure of forestgarden areas. These results provide further confirmation that the structure of forestgarden areas within a single land use system varies greatly.

The attempts made to classify homegardens based on the dominant species were found ineffective due to extreme species diversity and complexity in their arrangement.

This Chapter has shown that complex agroforestry practices such as the Kandyan homegardens are not necessarily classified effectively through classification of the land use system of which they form a part. Hence, the grouping of Kandyan homegardens based on land use systems may not be appropriate for the diagnosis of land use problems and the design of solutions and explains why imprecise diagnoses result from the application of FSR/E methods in this context. Also, it was shown that Kandyan homegardens cannot be classified effectively at the land use practice level suggesting that the recommendation domain may not be useful for such complex practices and alternative methodology needs to be developed. An incremental knowledge-based systems approach that may be more effective in deriving research and extension recommendations is explored in subsequent chapters and the implications for methodological developments in agroforestry reserach and extension discussed in the final conclusions (Chapter 7).

CHAPTER 4

APPLICATION OF KNOWLEDGE-BASED SYSTEMS APPROACH

4.1 INTRODUCTION

As stated previously (Section 1.5), the overall objective of this study was to explore the role of a knowledge-based systems approach (Walker *et al.*, 1995a) in agroforestry research and extension and to compare it with that of conventional farming system research and extension methods (FSR/E). The purpose being to identify the strengths, limitations and complementarity of the two approaches with the overall aim of improving agroforestry practices. To achieve these objectives FSR/E methods and the knowledge-based systems approach were applied sequentially at the same site and the resulting outputs were compared. This made it possible to examine the extent to which the application of a knowledge-based systems approach resulted in new information in comparison to results from the application of conventional FSR/E methods and, whether this led to different recommendations for research and extension. It was then possible to consider whether it was worthwhile adopting the knowledge-based systems approach given the effort involved.

The results of applying FSR/E methods at the selected field site were described in Chapter 2, the present chapter describes the subsequent application of a knowledge-based systems approach at the same site. The knowledge-based systems approach is applied for the collection and representation of indigenous ecological knowledge concerning specific aspects of agroforestry practices. Analysis of this knowledge enables identification of the ecological basis underlying management of agroforestry practices and gaps in farmers knowledge that constrain development of the system. This chapter, therefore, describes the methods and tools used for collecting, representing and analysing indigenous ecological knowledge and also the output resulting from adopting this form of analysis. The methodology is still in a developmental stage and alternative approaches have been taken to evaluate the representativeness of knowledge collected from a small, non-random sample of key informants prior to generalising conclusions from knowledge bases (Preechapanya, *in preparation*; Thapa, 1994). Two methods of testing representativeness were, therefore, implemented and compared in the present research enabling conclusions, to be drawn regarding strategies for knowledge elicitation and sampling of informants.

4.2 MATERIALS AND METHODS

The knowledge-based systems methodology and proprietary computer software developed by the ODA Forestry and Agroforestry research strategy project "Formal representation and use of indigenous ecological knowledge about agroforestry" undertaken at the School of Agricultural and Forest Sciences, University of Wales, Bangor in collaboration with the Institute of Ecology and Resource Management, University of Edinburgh was adopted for collecting and representing knowledge (Walker *et al.*, 1994). Detailed descriptions of the software and methodology are presented elsewhere (Thapa, 1994; Walker, 1994; Walker *et al.*, 1994; Kendon *et al.*, 1995; Walker *et al.*, 1995a), thus the methodological discussion here is limited to the identification of methods and tools that were adopted in the present study.

4.2.1 Specification

The aim of the specification stage was to define the boundaries of the study including topic, study site and informants for the study. The researcher was already familiar with the site from the rural appraisal presented in Chapter 2 and it was, therefore, possible to select key informants and a topic for knowledge acquisition using information from this appraisal.

4.2.1.1 Specification of the subject domain

The KHGs became the focus in this study, being a long established agroforestry practice in the land use system with a critical environmental role and potential for income-generation through intensification. A narrow domain was required to investigate the role of farmers' knowledge about agroforestry in some depth and the central role of tree pruning, which dominates the productivity of the garden system, was selected.

The diagnostic survey had indicated that the trees were not regularly pruned (Section 2.4.3.3) and crops were heavily shaded due to the dense canopy formed by the uncontrolled growth of upper storey trees. Also, tree trunks which were heavily branched, short, tapered or bent with many knots in the timber were common across the KHGs in the area. Trees with such poor form and wood quality fetched low prices and farmers were, therefore, not receiving as much income as they might if timber trees were pruned. Cash income was a high priority in garden management and was heavily constrained (Section 2.4.3.3).

Farmers who were particularly interested in understorey crops indicated that tree pruning was essential to minimise competition with crops. They also indicated that pruning was often not practised due to decreasing interest in understorey crops because of low prices of spice crops. The farmers who were more interested in producing timber responded variably when they were asked about the reasons for not pruning trees. They indicated that pruning was not practised because of the shortage of skilled labour. Some said pruning was not required while others said it was harmful to the growth of the tree. These varied responses indicated that there was difference of opinion amongst the farmers in the community about pruning timber trees in order to increase the volume and quality of wood. Such variation could reflect constraints in the local knowledge system held by the community.

There was a widespread interest amongst farmers in the area in growing timber trees. This was mainly due to a change of priority resulting from the fall in prices of cash crops, frequent and extensive pest damage to annual food crops and cocoa (*Theobroma cacao*), high demand and prices received for timber, and labour shortages. Timber trees were not subject to serious pest attack and required less care and management than annual crops or plantation crops such as tea (*Camellia sinensis*), coffee (*Coffea arabica*) and cocoa. Timber could be readily sold in local markets and there was also a large national demand for timber because of the decline of wood supplies from forest land (MALF, 1995).

Branch pruning was also one of the few management interventions that appeared feasible from a scientific perspective. Tree leaf area clearly has a dominant role in mediating interactions in agroforestry systems, affecting the light intercepted by the trees and the microclimate of the understorey (Monteith *et al.*, 1991). Shoot pruning reduces tree leaf area, and may also have an impact on root growth of trees and hence resource capture and competition below-ground (Cannell, 1985).

Although there was an interest in growing timber trees outside natural forests in the district there was no extension or support service to encourage this. Furthermore, there was no scientific information available on the effect of pruning the timber tree species grown in KHGs. This was because the Forest Department which has the mandate for developing timber resources in the country has been primarily concerned with protecting the natural forests owned by the state, and tree species grown for enrichment of degraded forests or monocultural plantations (Weerawardena, 1993; Weragoda, 1993). This contrasts with the situation for other crops grown in the KHGs (e.g. tea , coconut (*Cocos nucifera*), spices, coffee and cocoa) for which there were well organised research and extension services to provide knowledge and support. New knowledge was regularly extended to the community about these crops.

The, knowledge-based systems approach was, therefore, applied to collect and represent explanatory ecological knowledge, underlying the branch pruning of trees in

Kandyan homegardens in relation to the volume and quality of wood produced, and the management of tree-crop interactions.

4.2.1.2 Specification of the geographic domain

The purpose of the present study was to explore in principle, what could be learnt from adopting a knowledge-based systems approach to a well-focused domain identified from the broader diagnostic procedure. This could be achieved more efficiently by restricting the geographic scope to a single ASD during the knowledge elicitation phase (Section 4.2.2). It would be reasonable to expect that the knowledge elicited from a single ASD would broadly reflect what might be found more generally. This was confirmed when representativeness of the knowledge was evaluated across the three ASDs in the wetter part of Galagedara RSD (Section 4.2.3). The Galagedara ASD was selected for the knowledge elicitation phase because it had the highest concentration of KHGs and was the most extensive of the three ASDs considered. The population of the Galagedara ASD was about 24 300 and covered an area of about 32 km^2 (IRDP, 1990; GASC, 1993).

4.2.1.3 Selection of key informants

The requirement for a purposive sample of key informants chosen for their ability to inform has been well established (Knight, 1980). The application of the D & D methodology helped to identify 12 farmers whom the researcher considered were knowledgeable and articulate and were, therefore, potentially suitable as key informants. Members of the Agrarian Services Committee, which consisted of farmers from various parts of the division who represented the farming community, suggested another 88 farmers whom they also felt satisfied the same criteria.

Short, informal, semi-structured interviews with these one hundred people were used to evaluate, and identify categories of farmers who could provide various types of information related to the topic. This round of interviews also helped the development of rapport amongst the researcher and farmers. The criteria used to select key informants from the hundred initial informants were as follows.

(i) Informants were male: male farmers were involved and were, therefore, experienced in timber tree management (Section 2.3.5 and Section 2.4.3.4). This was earlier reported by Southern (1994) with respect to the Kandyan homegardens at Senarathwela and Wewegama villages. Women's involvement was limited to the collection, storage and subsequent use of pruned or dead branches as fuelwood in household cooking. Interviews with a 100 farmers, (including 10 women) revealed that selection of female farmers as a category was not of crucial importance in the present study as the utilisation of tree prunings had no significant influence on the decisions related to tree pruning. Because of the high interest of cash from the homegardens the dominant influencing factors affecting decision making about tree pruning were, the minimisation of competition with understorey crops in order to increase their yield, and the maximisation of the volume and quality of wood produced. Even though cash crop prices were low, farmers had not changed their strategies for collecting fuelwood as they were optimistic that the price of cash crops would recover.

Furthermore, it became evident that the availability of wood materials (other than tree prunings) for use as fuelwood had given them the opportunity to make their tree pruning decisions independently of fuelwood utilisation of the woody material gathered from pruning. The farmers collected wood from dead branches of large trees, various parts of coconut trees and mango (*Mangifera indica*) trees (often pruned to supplement household fuel wood requirements as they were commonly grown close to the house). The farmers who had smaller homegardens largely supplemented their fuelwood requirements from nearby rubber estates or protected areas. Although it was illegal, collection of wood by farmers from protected areas was common and there was little fear of prosecution. The dead wood and the material left over from the uprooting of rubber trees and tea plants, were allowed to be collected free of charge by villagers.

Furthermore, it was common practice to collect large quantities of fuelwood and store them in small huts in the back yard of houses, when ever possible.

(ii) Informants were more than 35 years old: older men were more experienced than younger men because of the lack of interest and involvement shown by young people in farming activities (Section 2.4.3.1).

(iii) Informants were experienced in managing their multi-layered homegardens: that is, they were full-time or part-time farmers, who were actively managing homegardens or had managed such gardens in the recent past.

(iv) Informants were those who were willing to participate in the study, were interested in so doing and had the time available to be repeatedly interviewed.

Farmers in the area were categorised into three groups on the basis of their interests and activities relating to pruning (Table 4.1). This was done to facilitate selection of a stratified sample of farmers covering the range of experience apparent in the community, in order to elicit comprehensive knowledge in relation to the topic. Eight farmers from each of the three groups, fulfilling the previously stated criteria were selected as key informants. A total of 24 farmers were, therefore, selected for detailed knowledge acquisition. It has been suggested that 25-40 farmers is an effective number for knowledge elicitation on any single subject domain (Walker, 1992) . The subject domain selected here was well defined and, therefore, the lower part of the range was considered appropriate. Since there were three groups, eight farmers from each category was a convenient number to arrive at the desired total sample size.

The farming population of the area mainly consisted of people of Sinhala ethnicity while Tamils were found in the estates working as hired labourers. Muslims were concentrated in the small townships and involved mainly in trade-related occupations. The Sinhaleese farmers belonged to different casts but they were all found to be fully engaged in farming regardless of whether or not they belonged to the main farming cast '*goyigama*'. Traditionally, however, non-*goyigama* people would have had cast-related occupations in addition to farming. No differences were observed in farming practices of farmers of different casts. It was not, therefore, considered necessary to stratify sampling of key informants with respect to cast.

Table 4.1 Main characteristics of three categories of farmers selected as key informants.

Main characteristics	Categories of key informants		
	1	2	3
Main activities	Farming	Farming	Farming and timber sawing or trading
Main interests	Crops	Crops and trees	Timber sawing and / or trading
Targeted knowledge	Pruning to minimise competition with crops	Pruning to improve tree form	Relationships of tree form, wood quality and price

4.2.2 Collection and representation of knowledge

4.2.2.1 Field work strategy

The field work to collect indigenous ecological knowledge was conducted in three rounds. The main knowledge elicitation phase involved an informal round of individual semi-structured interviews. Based on the impressions gained during the specification stage of field work (Section 4.2.1) and from the rural appraisal presented in Chapter 2, a checklist of topics was initially devised in order to guide the interviews (Table 4.2). The questions raised were non-leading and each interview varied from 45 to 90 minutes. The second round of interviews was conducted to clarify statements made by informants during the first set of interviews. The length of these interviews varied from 15 to 45 minutes. The final round of interviews was conducted to resolve conflicting statements in the knowledge base. Both individual and group interviews were undertaken for this purpose (two to four informants per interview). The length of these interviews varied from 15 to 60 minutes. One of these interviews was held at a saw mill to interpret and resolve conflicts related to wood quality in relation to pruning.

Most of the interviews were prearranged. They took place at the informant's house or in their Kandyan homegarden or both. The choice of place and time for interviews was based on the informant's convenience. This was to provide a comfortable and relaxed atmosphere for the informant during the interview.

Table 4.2 List of research topics identified to guide the interviews with key informants.

(i) Branch pruning to increase volume and quality of wood
(i.i) Effects of microclimatic and soil fertility on different attributes of tree form including trunk length, trunk diameter and trunk taper.
(i.ii) Effect of tree form and microclimatic conditions on attributes of wood quality including knotty wood, stem rots and spiral grain.
(i.iii) Species-specificity in terms of effects in i.i and i.ii above
(i.iv) Attributes of tree form that could be manipulated by branch pruning.
(i.v) Different aspects of tree pruning technique used to increase volume and quality of wood including place of pruning cut and the timing, frequency and intensity of pruning.
(ii) Branch pruning for managing tree crop interactions
(ii.i) The nature of ecological processes including light interception, leaf drip and soil fertility of overstorey trees on understorey crops
(ii.ii) The intensity of effects in ii.i caused by different tree species
(ii.iii) The attributes of tree species which accounted for the effects in ii.i
(ii.iv) Variable intensity of the effects of trees on different understorey crops (including coffee, cocoa and pepper)
(ii.v) Different aspects of tree pruning techniques used to manage tree-crop interactions including place of pruning cut, timing, frequency and intensity.

4.2.2.2. Recording and processing knowledge

The interviews were recorded using a voice activated portable cassette recorder. This allowed the researcher to concentrate on listening to what the informant was saying and, therefore, to encourage the informant to expand upon points of interest that arose.

The ecological knowledge relating to branch pruning of tree species was abstracted from the taped interviews. The clarity and any contradictions in the knowledge recorded in each interview were identified and noted to be resolved in the clarification stage. This was achieved through an informal analysis of knowledge which took place during the processing of each interview.

The knowledge base was created and managed using the proprietary computer software toolkit AKT-1 (Agroforestry Knowledge Toolkit) (Walker *et al.*, 1994; Walker *et al.*, 1995a). Knowledge abstracted from interviews was represented as unitary statements entered on computer using AKT-1, which together constituted a knowledge base. Unitary statements are the smallest useful units of knowledge in that they contain knowledge that is useful without reference to other statements but they cannot be broken down into two or more statements. Associated conditions (i.e. conditions under which each unitary statement was valid) were also recorded. Multiple conditions could be recorded by use of as many 'AND' and 'OR' clauses as required. Each statement was tagged with its source to facilitate any subsequent clarification, and to ensure that people contributing knowledge could be credited with the knowledge they had supplied.

These unitary statements recorded in natural language were subsequently converted to a formal representation using a restricted syntax (Table 4.3) of a declarative clause grammar (Appendix 5) designed to capture description of the components in an agroforestry practice and interactions between those components. This formalisation enabled the development of an unambiguous statement of knowledge, and also facilitated automated reasoning on computer with the knowledge. A statement is useful if it can be used in a reasoning process to answer a question about the topic. The unitary statements may be combined in different ways for different purposes by the informant or subsequently by a knowledge base user. This method of recording provides flexibility so that statements can be used as individual building blocks that, in combination with other unitary statements, create new arguments. In contrast, higher level statements and whole arguments may only be valid in the context in which they were articulated.

Table 4.3 Some illustrative examples of natural language statements and their formal equivalents. The formal syntax is given in Appendix 5.

Natural language statement	Formal statements
Jak is a tall tree	att_value(jak, 'tree height', tall)
Nutmeg leaves are thick	att_value(part(nutmeg, leaf), thickness, thick)
Trees self prune if they are growing under closed canopy conditions	att_value(process(tree, 'self pruning'), rate, high) if att_value(tree, location, 'closed canopy')
Pruning reduces the number of branches	action(pruning) causes 1 way att_value(tree, 'branch number', decrease)
A reduction in the number of branches causes an increase in the rate of height growth	att_value(tree, 'branch number', decrease) causes 2 way att_value(process('height growth', rate, increase)
An increase in tree crown density causes an increase in the amount of light intercepted	att_value(tree, crown density, increase) causes 2way att_value(process(crown, 'light interception'), rate, increase)
Gini-sapu fruits attract birds	link(attracts, part('gini sapu', fruits), birds)
Clove trees are taller than coffee bushes	comparison(tree height, clove, 'greater than', coffee)

The formal statements, which may be conditional, include five fundamental elements: (i) objects, which are physical items e.g. trees; (ii) processes (or events), that are changes or fluxes, e.g. germination or soil erosion; (iii) actions, that are a special type of process involving human interference e.g. pruning; (iv) attributes, which are properties of objects, processes or actions e.g. tree height, rate of soil erosion or pruning frequency; and (v) values, which are the measurable state of an attribute e.g. 5 m, tall, or 5 t ha^{-1} a^{-1}. The elements may be combined in four ways that involve (i) associating attributes and values to objects, processes or actions; (ii) representing causal linkages; (iii) representing other user-specified linkages; and (iv) making comparisons. A part construct is available to identify component parts of an object, and causation may be two-way, in which case an increase in x causing an increase in y is automatically equivalent to a decrease in x causing a decrease in y; or one way, in which case this equivalence does not necessarily hold.

In addition the textual interface AKT-1 also provided facilities for entering unitary statements diagramatically so that pairs of nodes and their connecting link corresponded to a unitary statement. This diagram interface had the advantages of:

i. facilitating visual appraisal of a connected set of statements, and

ii. enabling automatic translation of natural language statements into the formal syntax.

Unitary statements that were linked could, therefore, be presented more effectively as diagrams (see Figures 4.3 and 4.6).

Object, attribute, process, action and link keywords in the formal statements were identified by a parser. These were added to glossaries of terms (Figure 4.1). Hierarchical relationships between objects were represented allowing statements to be made about groups of objects (Figure 4.2). The hierarchical structure facilitated exploration of the knowledge base (for example, what is known about fruit trees) as well as a concise statement of knowledge (for example, Mango is a type of fruit tree; rather than five statements for each fruit tree species). All terms were defined and synonyms identified and recorded within the knowledge base.

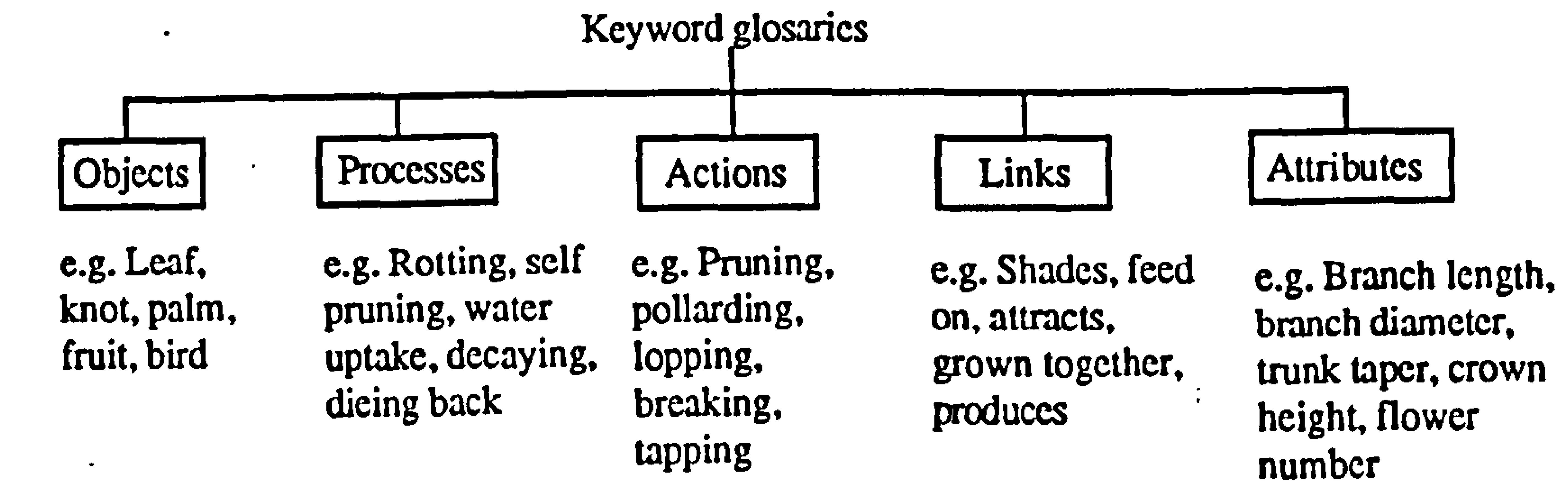

Figure 4.1 Key word glossaries (some examples of key words ocurring in different glossaries).

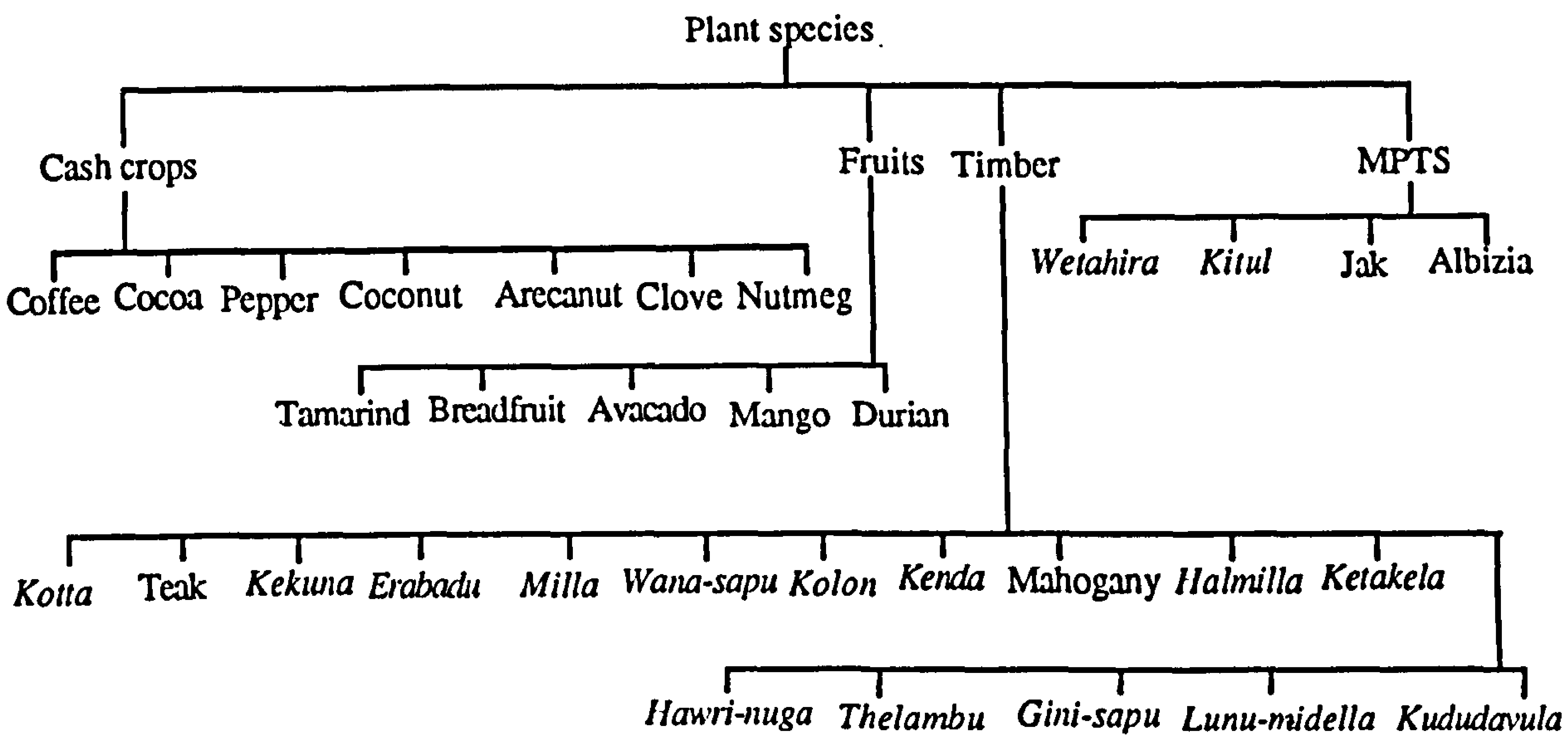

Figure 4.2 Plant species hierarchy (an example of an object keyword hierarchy). Species names are given in Appendix 2.

4.2.2.3. Editing and analysis of the knowledge

The AKT-1 software provided facilities to abstract sub sets of knowledge from the knowledge base using the framework provided by the glossaries and object hierarchies. Keywords were selected from the object hierarchies or the process, action, attribute and link glossaries and the relationship between the keywords specified by selecting ANDs or ORs. The facilities available in AKT-1 including abstracting subsets of knowledge through keyword searches and development of node-and-link diagrams were used to edit and analyse the knowledge base.

(i) Node and link diagrams. Causal knowledge was captured in the diagrams and provided a very useful way of analysing the content of knowledge (e.g. detailed ecological explanations of the causal mechanisms involved). The diagrams required the user to organise information relevant to a particular area of knowledge and assisted in ensuring a comprehensive set of knowledge about the topic was collected and represented.

(ii) Subsets of knowledge. Statements including particular terms were selected and printed and were evaluated manually (e.g. species specific information such as tree or crop attributes which influenced ecological processes).

4.2.3 Generalisation of the knowledge base

4.2.3.1 Representativeness of knowledge

Only a small purposive sample of farmers were consulted during knowledge elicitation. It was, therefore, important to evaluate the representativeness of the knowledge base derived from this sample in terms of the population of farmers in the study area as a whole. Such evaluation also provides the opportunity to assess the distribution of the knowledge across the community which has implications for the development of future sampling strategies. Furthermore, the degree to which existing knowledge could be confirmed and new knowledge uncovered provides a measure of the success of the approach used for knowledge elicitation and may have implications for future knowledge elicitation strategies.

Key informants' local knowledge relating to branch pruning of tree species in KHGs was evaluated for consistency with knowledge held by the general farming population in the study area using two contrasting approaches used previously by Preechapanya (*in preparation*) and Thapa (1994). Both approaches use a formal questionnaire on a random sample of farmers. Thapa (1994) used non-leading questions to test what proportion of farmers articulated similar knowledge to that held in the knowledge base. Preechapanya (*in preparation*) adopted a more direct questioning strategy where farmers reactions to previously articulated knowledge were assessed.

4.2.3.2 Methodology

(i) Selection of informants

Twenty villages (ten for each approach) were selected randomly from the 114 villages in the three selected ASDs (Section 4.2.1.2). Townships and villages visited during the knowledge elicitation were excluded and other villages which were predominately inhabited by farming families were selected. Ten farmers managing multilayered gardens were randomly selected from each of the 20 villages. Thus a total of two hundred farmers were selected for the study.

(ii) Questionnaires and questioning strategy

A questionnaire was used to guide the interview. The questionnaires developed were translated to Sinhaleese, the language used by the community, and were tested with five farmers before the actual survey. The results and experiences of the trial run were used to make some changes to the structure of questions in order to improve their clarity and, therefore, enable the farmers to understand the questionnaire more easily. The duration of the interviews was 30-45 minutes and they were recorded using a portable tape recorder and by completion of proforma questionnaire sheets.

(a) Non-leading questioning approach

The following step-by-step procedure was adopted to develop the questionnaire and the questioning strategy (Appendix 6):

- Four subsets of knowledge that contained both species specific information (such as tree or crop attributes which influence ecological processes) and detailed ecological explanations of the causal mechanisms involved were selected from the knowledge base and are outlined below.
    i. Attributes of trees affecting whether or not timber volume and quality could be improved by pruning
    ii. Attributes of trees affecting shade
    iii. Attributes of understorey crops affected by shade
    iv. Attributes of trees affecting soil nutrient content (i.e. *pohora-gathiya*)
- Two non-leading questions were designed to elicit knowledge from farmers relating to each topic.
- These consisted of an initial question requiring the informant to classify from three to seven tree or crop species that had distinct attributes relevant to the topic in question, and then to provide explanations for why each species had been so classified.

(b) Direct questioning approach

The questionnaire was developed in two sections (Appendix 7):

Section I

Twenty statements were selected randomly from the knowledge base. Half of the statements were inverted from how they appeared in the knowledge base. This was to establish whether farmers were simply agreeing to the statements presented by the researcher without giving them much thought. Farmers were asked to express their opinions on these statements using one of the four following possibilities:

- Agree
- Agree with conditions
- Disagree
- Don't know

The proportion of farmers in agreement with each statement, averaged over all twenty statements, was used as an estimate to identify the representativeness of the knowledge.

Section II

Three sub sets of knowledge, where the statements in each set were linked and related to the following three topics, were selected from the knowledge base:

- Effect of micro climate and pruning on tree form
- Effect of trees on micro climate
- Effect of micro climate on crop yield

Farmers were asked to comment about these three sets of causal type statements. Their responses were evaluated and the following conclusions relating to representativeness were drawn:

- If a farmer agrees with a statement then it can be said that he confirms the conclusions drawn from the chain.
- If a farmer agrees with all the statements in a set then it can be said that he confirms the chain of reasoning in the statement set.

4.3 RESULTS

4.3.1 Local knowledge relating to branch pruning of timber trees

The farmers in the Galagedara ASC Division articulated ecological knowledge relating to the pruning of tree species grown in the KHGs. The knowledge base developed contained 915 statements. The local terms related to pruning of trees commonly used by farmers are shown in the Appendix 8. As stated earlier (Section 4.2.1.1), the primary purposes of pruning were to:

- improve the quality and volume of wood, and
- manage tree-crop interactions.

The knowledge base, therefore, included knowledge relating to these purposes and knowledge on each area is summarised below.

4.3.1.1 Pruning for improvement of quality and volume of timber

(i) Size and form of trees and wood quality

An explanation of how, firstly different attributes of the tree trunk and wood quality were influenced by the number of branches retained in the crown and, secondly, how the number of branches in the tree crown was influenced by light intensity, soil conditions, pollarding and branch pruning is shown in Figure 4.3.

(ii) Bole dimensions and price relationships

The interface between timber market demands and the size and quality of wood are well understood as is the relationship between log size and wood quality with price.

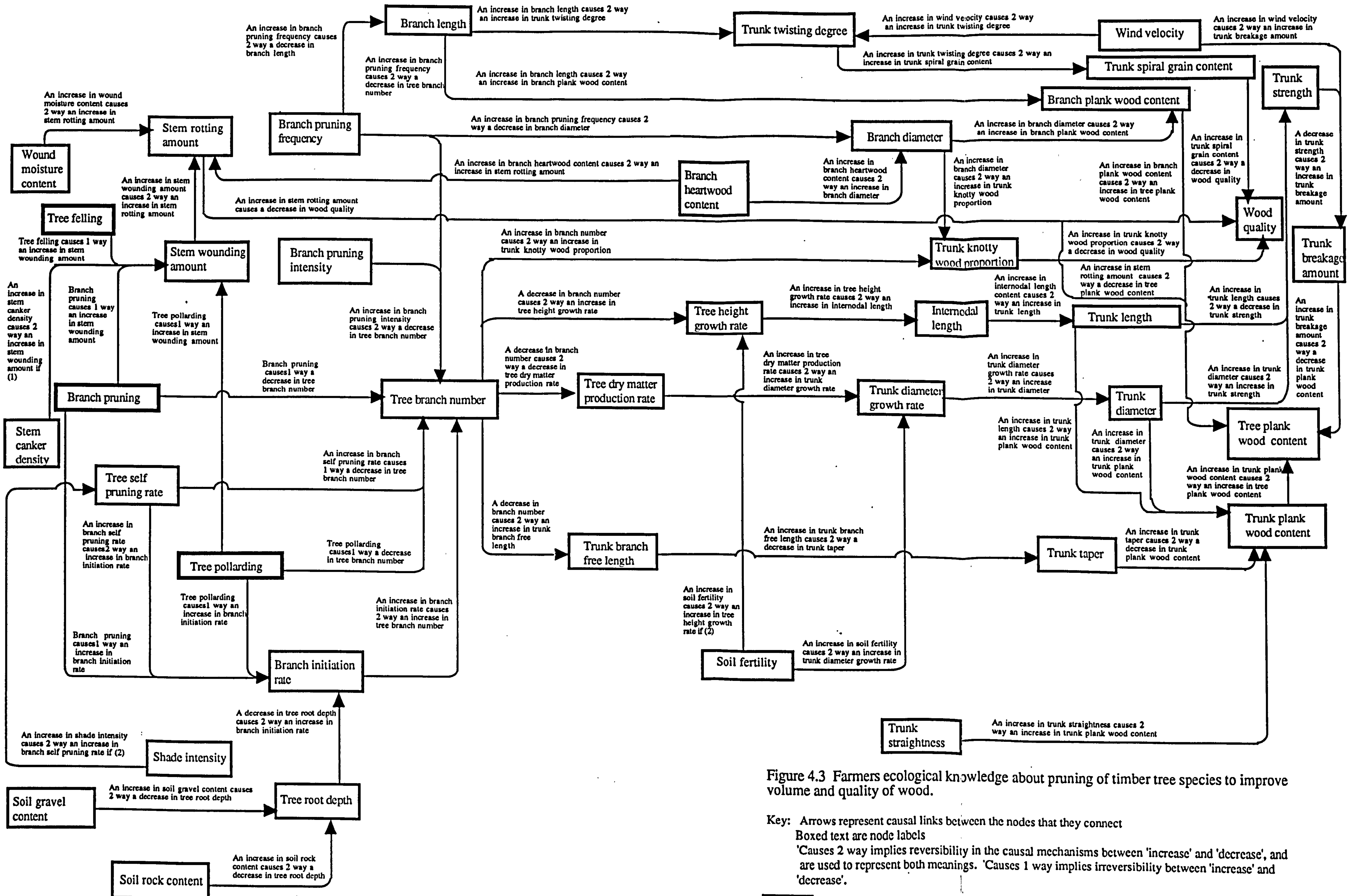

Figure 4.3 Farmers ecological knowledge about pruning of timber tree species to improve volume and quality of wood.

Key: Arrows represent causal links between the nodes that they connect
Boxed text are node labels
'Causes 2 way implies reversibility in the causal mechanisms between 'increase' and 'decrease', and are used to represent both meanings. 'Causes 1 way implies irreversibility between 'increase' and 'decrease'.

Attribute node   Action node

Conditions: (1) stem is *gini-sapu;* (2) stem is *gini-sapu* or mahogani

(iii) Wood quality

The farmers in the area classified trees according to the quality of wood (i.e. strength properties) such as density, hardness, permeability and cleavage (Table 4.4). Timber value is directly related to wood quality at the local market. Species are classified as hard, soft and very soft and valued in descending order of price at the local market.

Table 4.4 Classification of common trees species based on the strength properties of wood.

Characteristic	Categories of timber species		
	Hard	Soft	Very soft
Wood density	High	Medium	Low
Hardness	High	Medium	Low
Permeability	Low	Medium	High
Cleavage	High	Low	Low
Growth rate	Low	Medium	High
Species	Jak, *halmilla*, teak, *milla*, *kolon*, *ketakela*, *thelambu*	*Gini-sapu*, mahogany, *lunu-midella*, *hawari-nuga*, *kududavula*	*Wana-sapu*, *kekuna*, *erabadu*, *kenda*, *kotta*

Key: Species names are given in Appendix 2.

(iv) Decision making about pruning

Analysis of information stored in the knowledge base also provided an opportunity to identify the basis of decision making relating to pruning of timber trees. The farmers in the study area could be categorised into two groups based on their perceptions of pruning. The first category considered several tree attributes before deciding whether a species should be pruned or not. The second category of farmers believed that branches were essential for tree growth in all species and circumstances (including length of rotation) and hence pruning of branches decreased vigour. Further, they considered diameter growth rate, form and strength of trunk, tree height growth rate and tree dry matter production rate as tree attributes (irrespective of species) that were affected as a result of pruning. Such farmers, always avoided pruning.

The tree attributes that were considered by the first category of farmers in the decision making process and the resulting classification of trees and pruning processes can be represented as a decision tree models (Figure 4.4 and 4.5). The values of these tree attributes in Figure 4.4 and 4.5 for different species are presented in the Table 4.5.

Table 4.5 Timber tree attributes which influence tree classification for pruning in relation to timber quality and yield.

Species	Wood quality	Growth rate	Self pruning rate	Rate of branch initiation	Trunk straightness	Response of tree form to site factors	
						Light intensity	Soil fertility
Kenda	Low	High	Medium	Low	Medium	Low	Low
Kotta	Low	High	Medium	Low	High	Low	Low
Erabadu	Low	High	Medium	Low	Medium	Low	Low
Wana-sapu	Low	High	High	Low	High	Low	Low
Kekuna	Low	High	High	Low	High	Low	Low
Hawari-nuga	Medium	High	Medium	Low	High	Low	Low
Lunu-midella	Medium	High	Medium	Low	Medium	Low	Low
Gini-sapu	Medium	Medium	[1]High / Medium	[1]High / Medium	[1]High / Medium	Medium	High
Mahogany	Medium	Medium	[1]High / Medium	[1]High / Medium	[1]High / Medium	Medium	High
Thelambu	High	Low	High	Low	High	Low	Low
Kolon	High	Low	High	Low	High	Low	Low
Teak	High	Low	Low	Low	High	Low	Low
Halmilla	High	Low	Low	Low	High	Low	Low
Kududavula	Medium	Low	Low	Low	High	Low	Low
Milla	High	Low	Low	High	Low	Low	Low
Ketakela	High	Low	Low	High	Low	Low	Low

Key: [1] Varied with the site conditions
Species names are given in Appendix 2.

Timber species: form not affected by site factors

Farmers made a judgement relating to the actual tree attributes that pertained in a particular case in deciding whether a tree should be pruned or not (Figure 4.4). In summary:

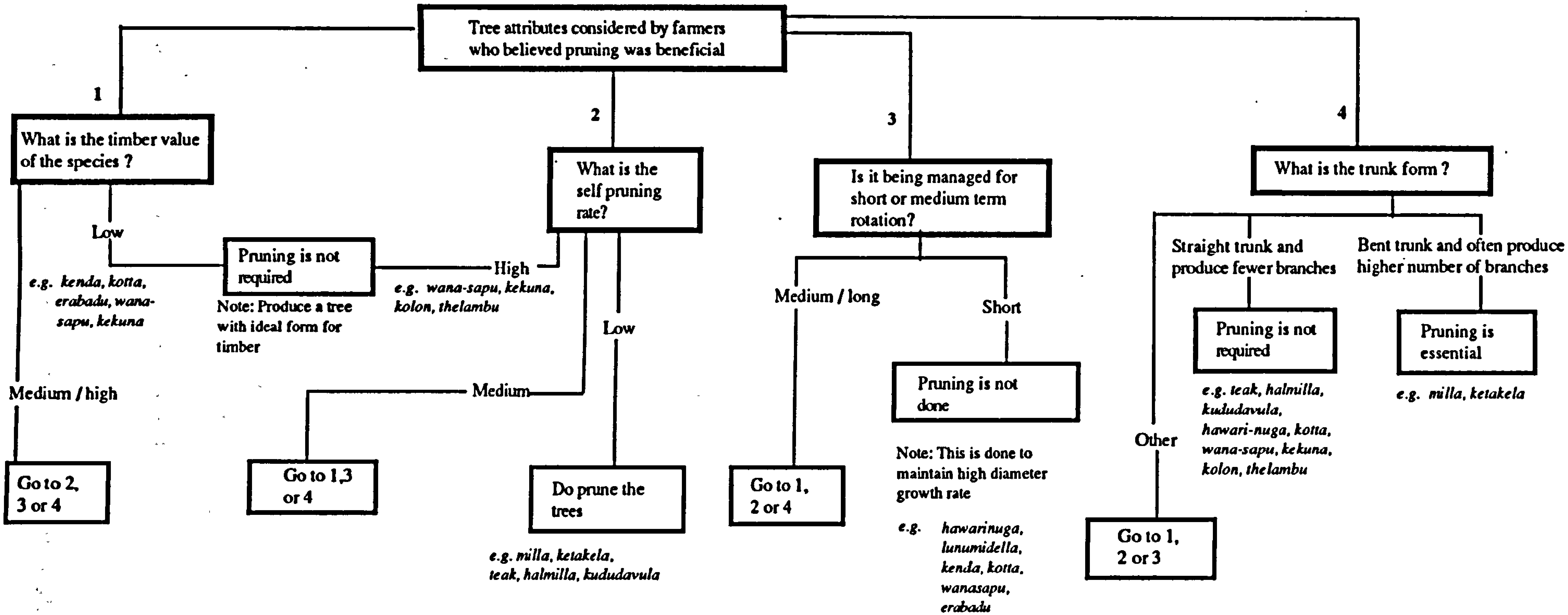

Figure 4.4 Tree attributes considered by farmers in their decision making about pruning timber species for which form was not considered to be affected by site conditions.

Key: Species names are given in Appendix 2.

- farmers showed very little interest in pruning trees of low value (Table 4.4).
- species with a high self pruning rate were not pruned.
- species which produced straight trunks were not pruned.
- species with a high rate of branch initiation were pruned.
- intended rotation length of species influenced the pruning decision.

Farmers knew that the saleable size and price of the tree was dependent upon the width of the plank that could be cut from the basal log; and that was directly related to the diameter of the trunk which in turn depended upon the diameter growth rate. Pruning was thought to decrease this rate of growth. Pruning, therefore, was thought to delay achievement of trees of saleable size, although it may contribute to developing a long, branch free trunk. Tree species of high and low growth rates were usually managed for short and long rotations respectively, where as species with medium growth rates were managed for both short and medium rotations. Therefore, fast growing species were not pruned and slow growing species were pruned. The species with medium growth rates were not pruned when they were managed for short rotations, but were pruned when managed for longer rotations.

Timber species: form affected by site factors

In addition to the attributes considered above, the level of response to such site factors as light and soil fertility also influenced the decision as to whether some species were pruned or not. *Kenda* (*Macaranga peltata*), *kotta* (*Ceiba pentandra*), *erabadu* (*Erythrina variegata*), *wana-sapu* (*Cananga odorata*), *kekuna* (*Canarium zeylanicum*), *hawari-nuga* (*Alstonia macrophylla*) and *lunu-midella* (*Melia dubia*) were thought to be intolerant of low light intensities hence farmers said they occur only in open corners of KHGs. Thus form of those tree species were less affected by light intensity (Table 4.5). Farmers indicated that those species showed little response to soil fertility and were considered as species which were capable of growing in low fertility conditions. Slow-growing species, such as *halmilla* (*Berrya cordifolia*) and *ketakela* (*Bridelia retusa*), were thought to have little or no response to light intensity or soil fertility .

Gini-sapu (*Michelia champaca*) and *mahogany* (*Swietenia macrophylla*), which were considered by farmers as intermediate in terms of their response to light and soil fertility, were known to survive under low light (i.e. responded moderately to light intensity) but also had a high self pruning rate. The diameter and the height growth rate of these species were thought to be high when they were grown in highly fertile soil. Indeed, farmers, assess the level of soil fertility by the internodal length and diameter increment rate of such trees. Light intensity and soil fertility were also thought to influence tree form and, therefore, the pruning requirements of *gini-sapu* and mahogany (Table 4.6). Farmers' decision making about pruning was, in this respect, for these species, influenced by the site conditions under which they were found (Figure 4.5).

As stated earlier the value of timber trees also depended upon the length of planks (i.e. logs) that could be cut. As logs were normally cut at the point where main branches were attached to the stem to minimise knots in the timber. Farmers indicated that if the internodal length of species (i.e. the distance between main branches) was high, then income was also high, and they could, therefore, avoid pruning. Farmers were aware that large internodal lengths occurred under conditions of high soil fertility (Figure 4.3), however, they also know that the height, straigthness and taper of the trunk was lower when trees were not pruned and hence there was some loss of income in such circumstances due to a reduction in the volume and quality of timber.

Table 4.6 The influence of light intensity and the resulting pruning action taken by farmers for *gini-sapu* and mahogany species.

Light intensity	Soil fertility (i.e. nutrients and moisture)	Expected tree form	Farmers response to pruning
1. Low	High	Long and clean trunk with reasonable diameter: ideal form for a timber tree	Not required
2. Low	Low	Produces a slender tree of medium height: diameter growth is slow but height will increase in response to the shedding of branches due to low light	Pollarding may be required, otherwise tree may break with winds. Pruning can worsen the situation.
3. High	High	Medium height, thick tree with large number of branches but they are not as close together as in 4: diameter increases rapidly but height growth rate is low compared to 1. Trunk taper is high	Pruning is not essential since the internodal lengths are reasonably large. However pruning can improve timber quality and volume.
4. High	Low	Grows slow both in height and diameter. Produces close branch layers hence a dense crown	Pruning is essential otherwise trees can become dormant and be of no timber value

Some key informants in the first category were not experienced in managing certain trees species for timber production, and here the outcome of pruning was uncertain. Hence they responded 'don't know' when asked whether pruning was useful or not for improving volume and quality of wood of certain species.

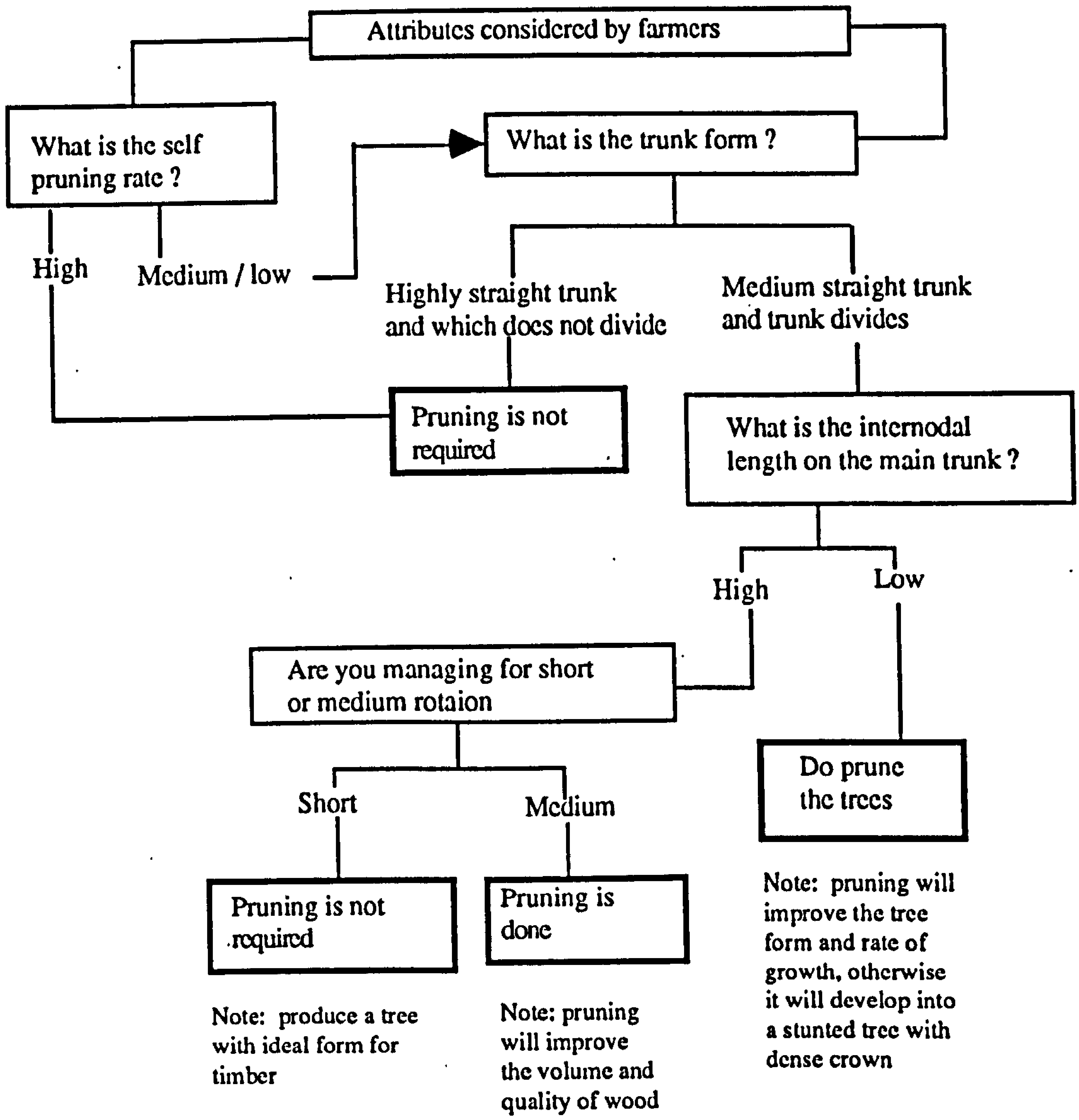

Figure 4.5 Decision making process about pruning of tree species for which tree form was significantly affected by site conditions.
Note: local knowledge holds that self pruning rate is directly related to light level and also internodal length and diameter growth rate to the level of soil fertility (Figure 4.3).

(v) Timing of pruning

Farmers referred to certain attributes of the trees to identify whether an individual was due for pruning. These attributes and how they influence the time of pruning are shown in the Table 4.7.

Table 4.7 The influence of tree attributes on the time of pruning.

Tree attribute	Effect on next pruning time	
	When attribute high	**When attribute low**
Branch number	Prune imminently	Delay pruning
Trunk straightness	Delay pruning	Prune imminently
Tree height growth rate	Delay pruning	Prune imminently
Tree diameter growth rate	Prune imminently	Delay pruning
Taper of branch free length of the trunk	Delay pruning	Prune imminently

(vi) Frequency and intensity

The frequency and intensity of pruning by farmers for improvements in the volume and quality of *gini-sapu*, which is the most common timber species, are summarised in Table 4.8. This regime had been adopted primarily for promoting timber quality through aiming to produce long, thick, clean, cylindrical trunks. Such trunks produce long and wide panels with few knots, which meet the requirements of the local timber market.

Table 4.8 Pruning regime[1] followed by farmers managing *gini-sapu* under a 15 year rotation.

Age	DBH	Tree height	Branch free length after pruning	Pruning intensity (proportion of branches removed from the live crown)
2-3 years	10 cm	6m	3 m	50 %
5-6 years	15 cm	9 m	6m	50 %
9-10 years	20 cm	12 m	9 m	50 %

[1] The trees are also pruned at sapling stage if they produce extraodinary number of branches or start to lean.

(vii) Pruning technique

A heavy, sharp knife (typically about 500g with blade of 7.5 cm wide and 25 cm long) was used to chop the branches.

Pruning was carried out in two cuts:

- the first cut was on the underside of the branch, its main purpose being to stop the branch breaking from the base taking a piece of bark from the trunk with it,
- the second cut was made on the upper side of the branch to remove it from the tree

The cuts were made about 15-30 cm away from the base of the branch (i.e. node). This minimises the damage to the trunk. The farmers said that if the cut was made closer to the base of the branch then there was not enough time for the wound to heal before the stump died back to the trunk and rotting would, therefore, start from the wound and spread into the trunk.

4.3.1.2 Pruning in relation to tree-crop interactions

Branch pruning was also practised by farmers managing KHGs for the manipulation of ecological processes, thereby achieving favourable ecological interactions between trees and crops by manipulation of shade, soil fertility, leaf drip, stem flow and branch and fruit fall. The local knowledge underlying management of these interactions, i.e. tree and crop attributes influencing them, and detailed ecological explanations of the causal mechanisms involved are presented in Figure 4.6. The following discussion, therefore, focuses primarily on species-specific information (i.e. tree and crop attributes) which were considered by farmers to influence each of the following intermediate effects.

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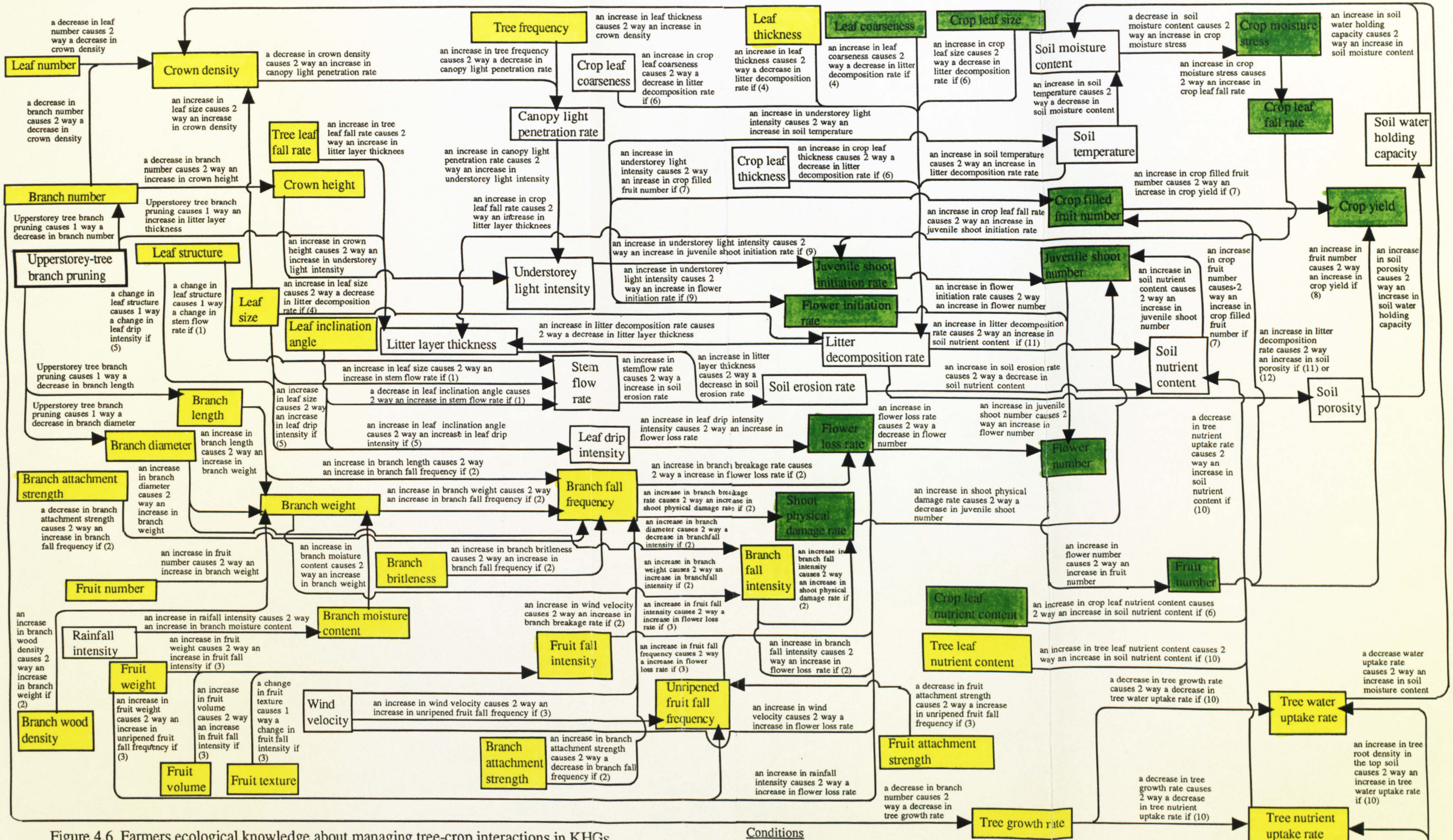

Figure 4.6 Farmers ecological knowledge about managing tree-crop interactions in KHGs.

Key: Arrows represent causal links between the nodes that they connect
Boxed text are node labels
'Causes 2 way implies reversibility in the causal mechanisms between 'increase' and 'decrease', and are used to represent both meanings. 'Causes 1 way implies irreversibility between 'increase' and 'decrease'.

Attribute node
Action node
Tree attributes
Crop attributes
Other attributes

Conditions
(1) leaf is of palm (coconut, arecanut or *kitul*) type
(2) branch is *lunu-midella* or jak or mango or bread fruit or *durian* or palm (coconut, arecanut or *kitul*) leaf
(3) fruit is jak or mango or *durian* or coconut
(4) leaf is *erabadu* or albizzia or gliricidia or *lunu-midella* or tamarind or jak or *halmilla*
(5) leaf is palm (coconut, arecanut or *kitul*) leaflet
(6) crop is pepper or coffee or cocoa or clove or nutmeg
(7) crop is pepper
(8) crop is coffee or cocoa
(9) crop is pepper or coffee
(10) tree is *erabadu* or albizzia or gliricidia or *lunu-midella* or tamarind or jak or *halmilla*
(11) litter is of leaf from *erabadu* or albizzia or gliricidia or *lunu-midella* or tamarind or jak or *halmilla*
(12) litter is of leaf from pepper or coffee or cocoa or clove or nutmeg
Note: crop refers to pepper, coffee or cocoa, unless specified.

(i) Shade effect

a. Tree attributes influencing shade intensity

The attributes of upper storey trees which were considered by farmers to cause a shade effect on crops are shown in the Table 4.9. Farmers considered two attributes, namely, crown density and crown height (Figure 4.6) to be the key factors influencing shade intensity. Crown density was considered to be determined by leaf thickness, leaf size, leaf number and the number of branches on the tree. Pruning of basal branches was thought to increase the crown height and decrease the number of branches and leaves, and so decrease crown density. Thus, pruning of upper storey trees was said to decrease the intensity of the shade effect on crops.

The shade effect of mahogany, *kududavula* (*Neolitsea cassia*), *kenda* and nutmeg (*Myristica fragrans*) were high, whereas *gini-sapu*, *erabadu*, *milla* (*Vitex altissima*)and *ketakela* had a moderate effect, and other species that were considered here had a low effect. Species giving a high shade effect were more likely to be pruned more often and intensively than others. Nutmeg trees have all the attributes which were identified by farmers as causing high intensity shade effect. Nutmeg was not, however, pruned, as it is a crop tree and the value of the nutmeg outweighed the negative effects on lower value groundlayer plants.

Table 4.9 The attributes of the upper storey tree species recognised by farmers as causing a shade effect of different magnitude on crops.

Species	Tree attributes						Effect
	Leaf thickness	Leaf size	Number of leaves	Number of branches	Crown density	Crown height	Intensity of shade effect
Wana-sapu	High	High	Low	Low	High	High	Low
Halmilla[1]	High	High	Low	Low	Low	High	Low
Hawari-nuga	High	High	Low	Low	Low	High	Low
Teak[1]	High	High	Low	Low	Low	High	Low
Lunu-midella	Low	Low	High	High	Low	High	Low
Kotta	Medium	Medium	Low	Low	Low	High	Low
Kolon	High	High	Low	Low	High	High	Low
Thelambu	High	High	Low	Low	High	High	Low
Kekuna	High	High	Low	Low	High	High	Low
Gini-sapu	High	High	Medium	Medium	Medium	Medium	Medium
Erabadu	High	High	High	Low	Low	Medium	Medium
Milla	Medium	Medium	Low	Medium	Low	Low	Medium
Ketakela	Medium	Medium	Low	Low	Low	Low	Medium
Mahogany	High	High	High	Low	High	Medium	High
Kududavula	Medium	Medium	High	Low	High	Low	High
Kenda	High	High	Low	Low	Medium	Low	High
Nutmeg[2]	High	High	High	High	High	Low	High

Key:
Species names are given in Appendix 2.
[1]Farmers considered that the crown lengths of teak and *halmilla* are high although the self pruning rate is low due to retention of dead branches for a longer period.
[2]Nutmeg was considered here although it is managed as a crop tree in KHGs, because farmers identified it as a tree which had attributes causing a high intensity shade effect.

b. Light requirement of crops

The light requirements of understorey crops and the implications of this for pruning the upper storey trees in order to manage tree-crop interactions were articulated by farmers. They said that they pruned upper storey trees when they had a pepper crop below because the pepper preferred high light intensities, where as they did not prune when cocoa was below, as their perception was that cocoa preferred low light intensities.

They considered that coffee was suited to moderate light intensity and, therefore, the decision about whether to prune the upper storey above it depended very much on the density of the upper storey. Farmers, also stated that the light intensity of the understorey influenced crop attributes such as the number of juvenile shoots, the number of flowers, the number of fruits and the number fruits which are filled, which ultimately determine crop yield (Figure 4.6).

(ii) Leaf drip effect

The knowledge base also included knowledge on leaf drip effects; that is, where water droplets fall from tree leaves. Size, structure and angle of inclination of the leaflets were identified as the attributes which influenced the intensity of the leaf drip effect on crops from upper storey trees (Table 4.10). Farmers expressed the view that crops were not affected significantly by the leaf drip caused by upper storey trees, other than that of palms. However, the three palm species found in the KHGs are managed as crop trees for the harvest of nuts and flower sap and hence are not usually pruned in order to manage tree-crop interactions. Knowledge was not in this case, related to practice.

Table 4.10 The attributes of the upper storey tree species recognised by farmers as causing leaf drip effects on crops.

Species	Tree attributes			Effect
	Leaflet size	Leaflet structure	Leaflet inclination angle	Intensity of effect of leaf drip
Palms: coconut, arecanut and *kitul*	Very large	Palm type	Droopy	High
Other species	Varied	Other types	Varied	Low

Key: Species names are given in Appendix 2.

(iii) Stem flow effect

Knowledge was also elicited from farmers about effects of stem flow on soil caused by upper storey trees. They expressed the view that soil erosion rates as a result of stem flow of upper storey trees, other than palms, was not significant. Size, structure and inclination angle of leaves were identified as attributes which influenced the intensity of stem flow effects on soil (Table 4.11). However, as stated earlier palm trees are not often pruned, although farmers often take extra care in conserving the soil around them.

Table 4.11 The attributes of the upper storey tree species recognised by farmers as causing stem flow effects of different magnitude on top soil.

Species	Tree attributes			Effects
	Leaf size	Leaf structure	Leaf inclination angle	Intensity of stem flow
Palms: coconut, arecanut and *kitul*	Very large	Palm type	Vertical	High
Other species	Varied	Other types	Varied	Low

Key: Species names are given in Appendix 2.

(iv) Branch fall effect

Both live and dead branches of upper storey trees can break and fall causing physical damage to understorey plants (i.e. a branch fall effect). The attributes of upper storey tree species recognised by farmers as causing physical damage to understorey crops by branch fall are shown in the Table 4.12. Intensity of the branch fall effect was determined by the weight and diameter of the branches. Branch brittleness, the strength of branch attachment and branch length were identified as tree attributes influencing the frequency of live branches falling. Farmers would, therefore, prune live and dead branches of the tree species which cause intensive live and dead branch effects, respectively (except palms which are not often pruned) (Table 4.12). Other common upper storey tree species in KHGs do not cause significant branch fall effect by either live or dead branches.

Table 4.12 The attributes of the upper storey tree species recognised by farmers as causing branch fall effect due to live and dead branches on crops of different magnitude.

Species	Tree attributes					Effects		
	Branch weight	Branch diameter	Branch brittleness	Strength of branch attachment	Branch length	Frequency of live branch fall effect	Intensity of live branch fall effect	Intensity of dead branch fall effect
Lunu-midella	Low	Medium	High	High	Medium	High	Medium	Low
Jak	High	High	High	Low	High	High	High	High
Mango	Medium	Medium	High	Medium	High	High	Medium	Medium
Bread fruit	High	High	Low	High	High	Low	-	High
Durian	High	High	Low	High	High	Low	-	High
Palms: coconut, arecanut and *kitul*	Low	Low	Low	Low	Low	Low	-	Medium

Key: Species names are given in Appendix 2.

(v) Effects of fruit fall on crops

Farmers articulated knowledge relating to the effects of fruit fall on crops from upper storey fruit trees (Table 4.13). Fruit weight and fruit attachment strength were identified as attributes influencing the frequency of unripened fruit fall. Farmers also identified attributes other than fruit attachment strength as influencing intensity of fruit fall. The attributes recognised by farmers as causing fruit fall are shown in the Table 4.13. These species are rarely pruned to control fruit fall, however, as they are grown for harvesting fruits which are of a high value. Other common upper storey tree species were not identified by farmers as causing significant fruit fall effects on crops.

Table 4.13 The attributes of upper storey tree species recognised by farmers as causing fruit fall effect on crops of different magnitude.

Species	Tree attributes				Effects	
	Fruit weight	Fruit volume	Fruit texture	Strength of fruit attachment	Frequency of unripened fruit fall effect	Intensity of fruit fall effect
Jak	High	High	Spiny	Medium	Medium	High
Mango	Medium	Small	Smooth	Low	High	Medium
Durian	High	Medium	Spiny	High	Low	High
Coconut	High	Medium	Smooth	High	Low	High

Key: Species names are given in Appendix 2.

(vi) Soil fertility effect

a. Recycling of nutrients

Tree species with leaves of a high manure quality; that is, leaves with high nutrient content and decomposition rates, are regularly pruned and added to the soil to increase soil nutrients (Figure 4.6). The attributes recognised by farmers as influencing the manure quality of leaves are shown in Table 4.14. Although, tamarind (*Tamarindus indica*) and *lunu-midella* leaves are considered to be of high manure quality, they are often managed for fruits and timber rather than their leaf manure properties.

Table 4.14 The attributes considered by farmers as influencing the manure quality of tree leaves.

Species	Tree attributes					Effects
	Leaf coarseness	Leaf size	Leaf thickness	Leaf decomposition rate	Nutrient content of leaf	Manure quality of leaf
Erabadu	Medium	Medium	Low	High	High	High
Albizia	Low	Small	Low	High	High	High
Gliricidia	Low	Small	Low	High	High	High
Lunu-midella	Low	Small	Low	High	High	High
Tamarind	Low	Small	Low	High	High	High
Jak	High	Medium	High	Low	Low	Low
Hawari-nuga	Medium	Large	Medium	Medium	Low	Low

Key: Species names are given in Appendix 2.

b. Effects of trees on the porosity, nutrient and moisture content of soil

Farmers articulated knowledge relating to the effects of upper storey trees on crops through their influence on soil porosity, and soil nutrient and moisture content. The attributes of upper storey tree species recognised by farmers as causing these effects are shown in Table 4.15.

Only leaf nutrient content was seen to cause only a soil nutrient enrichment effect, whilst all other attributes led to both soil nutrient enrichment and conservation of soil moisture. An increase in leaf fall and decomposition rate was said to cause an increase in the soil nutrient content. High density of roots in the top soil and a high rate of tree growth were said to cause high removal of nutrients and moisture from the top layer of soil whereas pruning reduced tree growth rate and hence their uptake of nutrients and water. Farmers often, therefore, pruned upper storey trees that had low soil nutrient enrichment or moisture conservation effects to reduce the extent to which they removed moisture and nutrients from the soil. Soil porosity was affected by leaf decomposition and fall rates only. Other common tree species of KHGs not in Table 4.15 were not considered by farmers to have a significant effect on crops through their influence on soil porosity, or soil nutrient and moisture contents.

Table 4.15 The attributes of the tree species recognised by farmers as influencing soil porosity, nutrient and moisture for crop plants.

Species	Tree attributes					Effects		
	Density of roots in the top soil	Tree growth rate	Leaf nutrient content	Leaf decomp-osition rate	Leaf fall rate	Soil porosity effect	Soil nutrient enrichment effect	Soil moisture conservation effect
Jak	Low	Low	Low	Low	High	High	Low	High
Erabadu	Low	High	High	High	High	High	High	High
Albizia	Low	High	High	High	High	High	High	High
Gliricidia	Low	High	High	High	High	High	High	High
Lunu-midella	High	Medium	High	High	High	Low	Low	Low
Hawari-nuga	Medium	Medium	Low	Medium	Medium	Low	Low	Low
Tamarind	High	Low	High	High	High	Low	Low	Low

Key: Species names are given in Appendix 2.

(vii) Pruning regimes

The key components of the pruning regime followed by farmers with KHGs for managing tree-crop interactions are presented in the Table 4.16.

Table 4.16 The key components of the pruning regime followed by farmers with KHGs for managing the tree-crop interactions.

Pruning characteristic	Description	Farmers justification
1. Pruning frequency	Ideally one or two prunings of high intensity during the year.	There are two fruiting seasons during a year.
2. Pruning intensity	Intensity varies with understorey crop.	The light requirement of the understorey varies with different crops
3. Pruning time	At the onset of crop flowering, to increase light intensity to the understorey and provide green manure for crops.	Pepper and coffee require high light intensity for flowering, also the manure increases soil fertility and so influences the crop yield.
	At the onset of the rainy season to:	Dense cloud cover present in the rainy season means light received by the understorey is low.
	• increase light intensity, therefore soil and air temperature	Low air and soil temperatures can lead to: • low soil fertility due to low leaf decomposition rates • increased disease incidence due to high atmospheric humidity
	• reduce the weight of certain heavy branches	Heavy branches of certain species can break due to increased weight and high wind velocity in the rainy season
4. Size of branches removed	Branches of various sizes are removed for managing tree-crop interactions.	Small branches are removed for managing all interactions discussed above except for controlling: (i) branch fall effect (where large branches are removed), (ii) shade effect (where branches of any sizes are removed).
5. Pruning cut	Same as method used when trees are managed for improving volume and quality of wood (Section 4.3.1.1).	-
6. Pruning tool	-ditto-	-

4.3.2 Representativeness of knowledge base

4.3.2.1 Introduction

As stated earlier, the knowledge collected from the small purposive sample of farmers was evaluated for consistency with similar knowledge held by the wider community in the study area. The objectives of this evaluation and the methods used are described in Section 4.2.3. This section summarises the results obtained and their implications for knowledge elicitation and sampling strategies.

4.3.2.2 Non-leading approach

Four non-leading questions were designed to collect similar knowledge to that of four knowledge subsets in the knowledge base. These related to four key topics, typical of the type of knowledge captured in the knowledge base (Section 4.2.3.2). The following discussion describes the knowledge resulting from responses to these questions and compares it with similar knowledge captured in the knowledge base in order to evaluate the representativeness of knowledge base.

(i) Volume and quality of wood

The first question from the non-leading questionnaire (Appendix 6) elicited knowledge from the wider community regarding pruning of tree species to improve the volume and quality of the wood. From the 100 farmers investigated 69% said pruning was beneficial in improving volume and quality of wood and they looked at several attributes of the tree species before deciding whether or not they should be pruned (Table 4.17). The others (31%) said that branch pruning reduces the vigour of the tree species and they, therefore, regarded pruning as undesirable in the management of timber trees.

Hence, the two categories of farmers articulated knowledge similar to that differentiated earlier (Section 4.3.1.1) after the analysis of the original knowledge base.

Table 4.17 Percentage of farmers with respect to different categories of pruning.

Species	Category I: pruning is beneficial			Category II:
	Prune	Do not prune	Don't know	pruning is harmful
Kenda	-	63 (± 4.8)	6 (± 2.4)	
Wana-sapu	-	61 (± 4.9)	8 (± 2.7)	
Hawari-nuga	3 (± 1.7)	62 (± 4.9)	4 (± 2.0)	31 (± 4.6)
Gini-sapu	38 (± 4.9)	31 (± 4.6)	0	
Halmilla	52 (± 5.0)	12 (± 3.3)	5 (± 2.2)	
Ketakela	54 (± 5.0)	0	15 (± 3.6)	

Key: Figures in the parentheses are standard errors
Species names are given in Appendix 2.

First category of farmers

The tree attributes cited for classification of tree species for pruning by the farmers of the first category are presented in the Table 4.18. The inconsistency in results can be explained, at least to some extent, as follows.

(i) Some farmers (2% and 6%, respectively) said *kenda* and *wana-sapu* were not pruned as they were managed for short-rotations. Until very recently *wana-sapu* and *kenda* were not considered as commercial species but due to increasing demand for timber some farmers now classified them as such.

(ii) Timber quality of *hawari-nuga* was little realised until very recently and hence was not managed or used as a timber species. Some farmers (12 %) still, therefore, categorised it as a low valued species.

(iii) 3% of farmers said pruning of *hawari-nuga* was useful in minimising the density of knotty wood since its self pruning rate was not high. Conversely, 4% said that the self pruning rate was high enough to avoid pruning. The knowledge base indicated that the self pruning rate was not a significant attribute in determining pruning of *hawari-nuga*.

Table 4.18 Percentage[1] of farmers quoting tree attributes affecting whether or not timber volume and quality could be improved by pruning for different tree species.

Attributes quoted	Species					
	Kenda	*Wana-sapu*	*Hawari-nuga*	*Gini-sapu*	*Halmilla*	*Ketakela*
A. <u>Prune</u>						
a. Increase trunk height	0	0	0	34 (±4.7)	45 (±5.0)	14 (±3.5)
b. Increase trunk straightness	0	0	0	7 (±2.6)	0	46 (±5.0)
c. Decrease knotty wood proportion	0	0	3 (±1.7)	0	16 (±3.7)	0
d. Increase trunk diameter	0	0	0	1 (±1.0)	0	0
B. <u>Do not prune</u>						
a. Maintain high diameter growth rate	2 (±2.7)	6 (±2.4)	11 (±3.1)	24 (±4.3)	0	0
b. High self pruning rate	0	22 (±4.1)	4 (±2.0)	7 (±2.6)	0	0
c. High trunk straightness	0	0	32 (±4.7)	0	10 (±3.0)	0
d. Low rate of branch initiation	0	0	5 (±2.2)	0	7 (±2.6)	0
e. Low timber value	61 (±4.9)	33 (±4.7)	12 (±3.3)	0	0	0

Key: Bold type indicates inconsistency with the original knowledge base
Figures in the parentheses are standard errors
[1]as a percentage from 100 farmers used in the representative evaluation
Species names are given in Appendix 2.

Tree attributes considered by farmers (irrespective of species) as affecting whether or not timber volume and quality could be improved by pruning are presented in the Table 4.19. A total of six attributes: trunk height; trunk straightness; knotty wood density; rate of branch initiation; trunk diameter; and self pruning rate were quoted. All six attributes were contained in the knowledge base suggesting that it was reasonably representative of the knowledge held by the farmers in the study area.

There was no consensus in quoting tree attributes affecting whether or not timber volume and quality could be improved by pruning amongst 69% farmers who were in favour of pruning to improve volume and quality of wood (Table 4.19). Most farmers quoted the tree attributes timber value, trunk height and trunk straightness and half of them trunk diameter and self pruning rate. Less than a quarter of farmers cited knotty wood proportion and rate of branch initiation. These differences could be attributed to the fact that some tree attributes are known to more people in the community than other attributes.

Table 4.19 Tree attributes considered by farmers as affecting whether or not timber volume and quality could be improved by pruning irrespective of species.

Tree attribute	Percentage of farmers[1]
Timber value	63 (± 4.8)
Trunk height	56 (± 5.0)
Trunk straightness	55 (± 5.0)
Trunk diameter	31 (± 4.6)
Self pruning rate	27 (± 4.4)
Knotty wood proportion	17 (± 3.8)
Rate of branch initiation	11 (± 3.1)

Key: [1]as a percentage from 100 farmers used in the representative evaluation
Figures in the parentheses are standard errors

Second category of farmers

As said earlier 31% of farmers considered pruning is not beneficial irrespective of species. The tree attributes cited as affected by pruning by the farmers of the second category are presented in the Table 4.20. Of the second category of farmers about two third quoted trunk diameter growth rate, one third tree height growth rate and one quarter of them quoted trunk strength, trunk form and rate of dry matter production as tree attributes that were affected by pruning. These differences could be because the knowledge about tree attributes varied between the farmers in the Galagedara RSD.

Table 4.20 Percentage of farmers citing tree attributes[1] which are affected by pruning.

Tree attribute	Percentage of farmers[2]
Decrease trunk diameter growth rate	22 (±4.1)
Increase tree height growth rate	11 (±3.1)
Decrease trunk strength	8 (±2.7)
Change (slender) trunk form	7 (±2.6)
Tree dry matter production rate	7 (±2.6)

Key: [1]they articulated the attributes irrespective of species
[2]as a percentage from 100 farmers used in the representative evaluation
Figures in the parentheses are standard errors.

2. Shade

The second question from the non-leading questionnaire (Appendix 6) elicited knowledge from the wider community regarding ecological knowledge relating to the management of shade (Table 4.21). Although, knowledge articulated by farmers was highly consistent with the tree pruning knowledge base, there were some diverging results observed with mahogany, *kenda* and *wana-sapu*:

(i) About 5% of farmers categorised mahogany as a tree which causes low shade. Of these 2% explained this was because mahogany is often defoliated by caterpillar damage, whilst the other 3% cited its deciduous nature as being responsible for the low shade effect. This suggests that susceptibility to defoliating pests and the deciduous nature of trees may also be considered by farmers as attributes which influence crown density and, therefore, the shade cast by upper storey trees. It may be that recent experience of such effects (essentially the context of the interview) affects whether or not farmers mention these attributes.

(ii) Seven percent of farmers classified *kenda* as a species which caused only a low shade on the basis that leaf number and size, and therefore the crown density and crown height, decreases with age. These farmers clearly considered the tree age as an attribute which causing variation of shade effects within species.

(iii) The two percent of farmers who categorised *wana-sapu* as a species which cast a high shade on understorey crops did so because they said that it had a low crown height and high crown density. Most farmers considered the tree to have high crown height and high crown density. It is clear that the disagreement relates, therefore, to the value of attributes for the species rather than the causal mechanism relating attributes to shade.

Table 4.21 The percentage of farmers citing the intensity of shade effect of different trees species.

Species	High shade	Low shade	Don't know
Mahogany	86 (± 3.5)	5 (± 2.2)	9 (± 2.9)
Nutmeg	100 (± 0)	0	0
Kenda	85 (± 3.6)	7 (± 2.6)	8 (± 2.7)
Lunu-midella	0	100 (± 0)	0
Hawari-nuga	0	97 (± 1.7)	3 (± 1.7)
Wana-sapu	2 (± 1.4)	88 (± 3.3)	10 (± 3.0)

Key: Figures in the parentheses are standard errors.
Species names are given in Appendix 2.

The attributes articulated by the wider community of farmers as causing high shade intensity are presented in the Table 4.22. Farmers identified another five attributes of upper storey trees as causing shade on the understorey crops in addition to the five attributes identified in the knowledge elicitation phase. However, only a small proportion of farmers identified these additional attributes. They included petiole length with respect to mahogany (identified by 4% of farmers); fan like branching pattern with respect to nutmeg and *kenda* (by 14% and 5% of farmers respectively); low internodal length with respect to nutmeg (by 8%); high leaf longevity with respect to nutmeg (by 3%) and horizontal leaf inclination angle with respect to *kenda* (by 4%).

Table 4.22 The percentage of farmers citing different tree attributes for three species causing high shade.

Attribute	Species		
	Mahogany	Nutmeg	*Kenda*
High number of branches	74 (± 4.4)	47 (± 5.0)	31 (± 4.6)
High number of leaves	45 (± 5.0)	53 (± 5.0)	25 (± 4.3)
Large leaf size	5 (± 2.2)	3 (± 1.7)	68 (± 4.7)
High leaf thickness	0	20 (± 4.0)	4 (± 2.0)
Fan like branching pattern	0	14 (± 3.5)	5 (± 2.2)
Low internodal length	0	8 (± 2.7)	0
Low petiole length	4 (± 2.0)	0	0
Horizontal leaf inclination angle	0	0	4 (± 2.0)
High leaf longevity	0	3 (± 1.7)	0
Low crown height	0	28 (± 4.5)	0

Key: Bold letters indicate attributes quoted during representative evaluation that were not contained in the original knowledge base
Figures in the parentheses are standard errors
Species names are given in Appendix 2.

The attributes identified by farmers as causing low shade intensity are presented in the Table 4.23. Farmers identified a further three attributes in addition to the five identified in the knowledge elicitation phase. These included; high internodal length with respect to *hawari-nuga* (identified by 28% of farmers); leaf longevity with respect to *lunu-midella*, *hawari-nuga* and *wana-sapu* (by 7%, 3% and 2%, respectively); drooping leaf inclination angle with respect to *hawari-nuga* and *wana-sapu* (by 8% and 3%, respectively).

Table 4.23 Percentage of farmers cited different tree attributes for three species causing low shade intensity.

Attribute	Species		
	Lunu-midella	*Hawari-nuga*	*Wana-sapu*
Low number of branches	27 (± 4.4)	48 (± 5.0)	80 (± 4.0)
High crown height	29 (± 4.5)	20 (± 4.0)	40 (± 4.9)
Small leaf size	72 (± 4.5)	4 (± 2.0)	4 (± 2.0)
Low number of leaves	0	44 (± 5.4)	24 (± 4.3)
Leaf thickness	34 (± 4.7)	0	4 (± 2.0)
High internodal length	0	28 (± 4.5)	0
Low leaf longevity	7 (± 2.6)	3 (±1.7)	2 (± 2.7)
Drooping leaf inclination angle	0	8 (± 2.7)	3 (± 1.7)

Key: Bold letters indicate attributes quoted during representative evaluation that were not contained in the original knowledge base
Figures in the parentheses are standard errors
Species names are given in Appendix 2.

Ten tree attributes were considered by farmers (irrespective of species) as affecting shade (Table 4.24). Only five of these attributes were contained in the original knowledge base. This may be attributed to the fact that farmers may have cited crown density as an attribute influencing shade instead of specifying all tree attributes that were influencing crown density. About three quarters of the farmers cited number of branches, leaf size and number of leaves, one half of them crown height and leaf thickness, one third of them internodal length whilst the other four attributes branching pattern, leaf inclination angle, leaf longevity and petiole length were mentioned by less than one fifth of farmers. These differences could be attributed to the fact that some tree attributes are known to more people in the community than other attributes.

Table 4.24 Tree attributes considered by farmers as influencing shade irrespective of species.

Tree attribute	Percentage of farmers
Number of branch	88 (± 3.2)
Leaf size	82 (± 3.8)
Number of leaves	68 (± 4.7)
Crown height	48 (± 5.0)
Leaf thickness	40 (± 4.9)
Internodal length	30 (± 4.6)
Branching pattern	16 (± 3.7)
Leaf inclination angle	11 (± 3.1)
Leaf longevity	10 (± 3.0)
Petiole length	4 (± 2.0)

Key: Figures in the parentheses are standard errors

3. Growth and yield of understorey crop species

The knowledge relating to effects of shade on growth and yield of understorey crops are represented in the Table 4.25. Nearly all farmers perceived that crop yields could be increased by pruning upper storey trees underplanted with pepper (*Piper nigrum*) to provide direct sunlight rather than not pruning to provide the darker conditions preferred by cocoa. However, their responses were varied when they were asked the same question in relation to coffee. About a third said that pruning of the upper storey was beneficial for coffee while roughly two thirds said that it was harmful. This is not surprising because the decision as to whether to prune the canopy or not to provide optimum light intensity for the understory largely depends on the canopy cover. The sort of explanations farmers gave for their responses included the following:

- to provide moderate shade for coffee
- to provide a light level between that required by pepper and cocoa
- neither high shade nor direct sun light are suitable for coffee

It is clear from these responses that their ultimate objective was to provide moderate shade for coffee, confirming the light requirement of coffee represented in the knowledge base. A few farmers responded 'dont' know' with respect to certain crops for which they had no direct experience.

Table 4.25 The percentage of farmers pruning upper storey trees to create the light intensity suitable for common understorey crops.

Species	Prune	Do not prune	Don't know
Pepper	97 (± 1.7)	0	3 (± 1.7)
Coffee	35 (± 4.8)	61 (± 4.9)	4 (± 2.0)
Cocoa	0	93 (± 2.6)	7 (± 2.6)

Key: Figures in the parentheses are standard errors

Farmers, unsurprisingly related that crop yield was reduced when optimum light intensity was not received. Farmers also more specifically identified the attributes of the crop that were affected by shade (Table 4.26). These results confirm that the knowledge held by the wider community of farmers regarding the effects of shade on growth and yield of understorey crops are consistent with the knowledge base.

Table 4.26 Percentage of farmers citing crop attributes of three species that are affected by shade.

Attribute	Species		
	Pepper	Coffee	Cocoa
Number of fruit	16 (± 3.7)	96 (± 2.0)	93 (± 2.6)
Number of filled fruit	90 (± 3.0)	4 (± 2.0)	0
Number of flowers	17 (± 3.8)	5 (± 2.2)	6 (± 2.4)
Number of juvenile shoots	6 (± 2.4)	19 (± 3.9)	0

Key: Figures in the parentheses are standard errors

Attributes of understorey crops (irrespective of species) considered by farmers to be affected by shade are presented in Table 4.27. All four attributes were contained in the knowledge base suggesting that it was reasonably representative of the knowledge held by the farmers in the study area. Nearly all farmers considered number of fruit and filled fruit and roughly about one fifth of them cited number of juvenile shoot and flowers as attributes of understory crops that were affected by shade. These differences could be attributed to the fact that some crop attributes are known to more people in the community than other attributes.

Table 4.27 Attributes of understorey crops irrespective of species considered by farmers as affected by shade.

Tree attribute	Percentage of farmers
Number of fruit	96 (± 2.0)
Number of filled fruit	91 (± 2.9)
Number of juvenile shoot	22 (± 4.1)
Number of flower	21 (± 4.1)

Key: Figures in the parentheses are standard errors

4. Soil nutrients

Knowledge relating to the attributes of trees affecting soil nutrient enrichment was elicited using the fourth question of the non-leading questionnaire (Appendix 6). They are presented in the Table 4.28. As with previous topics the knowledge elicited from a large number of farmers was highly consistent with the knowledge already stored in the knowledge base derived from key informants. There were some inconsistent results however. About 22% of farmers indicated that unless managed, the nutrient content of soil in which *Gliricidia sepium* was grown was low because of its fast growth rate and the high density of roots in the top soil. 7% of farmers said the nutrient content of soil in which *erabadu* was grown was low due to its fast growth rate. 6% and 8% of farmers said the nutrient content was considered high in soil where jak (*Artocarpus* *heterophyllus*) and *hawari-nuga* were grown due to high leaf fall, but they did not mention the nutrient content of those leaves as did other farmers.

A small proportion of farmers (2-7%) were not exact with their opinions in relation to some of the species hence they replied "don't know". This was generally because they had no experience of growing those particular crops. All other results were consistent with the knowledge base.

Table 4.28 Percentage of farmers recognising soil nutrient enrichment effects of varied magnitude caused by different tree species.

Species	High nutrient content	Low nutrient content	Don't know
Gliricidia	98[1] (± 1.4)	0	2 (± 1.4)
Erabadu	89 (± 3.1)	7 (± 2.6)	4 (± 2.0)
Tamarind	0	93 (± 2.6)	7 (± 2.6)
Jak	6 (± 2.4)	88 (± 3.2)	6 (± 2.4)
Hawari-nuga	8 (± 2.7)	87 (± 3.4)	5 (± 2.2)

Key: Figures in the parentheses are standard errors
[1]22% of them agreed conditionally
Species names are given in Appendix 2.

The tree attributes recognised by farmers as causing high soil nutrient enrichment are highly consistent with the knowledge base. Three attributes were recognised as causing a high soil nutrient effect (Table 4.29). All three attributes were contained in the knowledge base.

Table 4.29 Percentage of farmers citing different tree attributes as causing high soil nutrient enrichment.

Attribute	*Gliricidia*	*Erabadu*
High leaf nutrient content	76 (± 4.3)	77 (± 4.2)
High leaf fall rate	44 (± 5.0)	14 (± 3.5)
Low leaf coarseness	33 (± 4.7)	25 (± 4.3)

Key: Figures in the parentheses are standard errors
Species names are given in Appendix 2.

As in the previous case, the tree attributes quoted by farmers as causing low soil nutrient enrichment were largely consistent with the information in the knowledge base. These attributes are presented in the Table 4.30. Farmers cited four attributes as significant. All four attributes were contained in the original knowledge base.

Table 4.30 Percentage of farmers citing different tree attributes as causing low soil nutrient content.

Attribute	Tamarind	Jak	*Hawari-nuga*
High root density in the top soil	93 (± 2.6)	79 (± 4.1)	4 (± 2.0)
High tree growth rate	0	0	83 (± 3.8)
High leaf coarseness	0	52 (± 5.0)	0
Low leaf nutrient content	0	37 (± 4.8)	4 (± 2.0)

Key: Figures in the parentheses are standard errors
Species names are given in Appendix 2.

Five tree attributes were considered by farmers (irrespective of species) as affecting soil nutrient enrichment (Table 4.31). All five attributes were contained in the original knowledge base suggesting that it was reasonably representative of the knowledge held by the farmers in the study area. Nearly all farmers cited root density in the top soil, about three quarters leaf nutrient content, tree growth rate and leaf coarseness and about a half, leaf fall rate as tree attributes affecting soil nutrient enrichment. These differences could be attributed to the fact that some tree attributes are known to more people in the community than, other attributes.

Table 4.31 Tree attributes considered by farmers irrespective of species as affecting soil nutrient enrichment.

Tree attribute	Percentage of farmers
Root density in the top soil	94 (± 2.4)
Leaf nutrient content	83 (± 3.8)
Tree growth rate	83 (± 3.8)
Leaf coarseness	69 (± 4.6)
Leaf fall rate	47 (± 5.0)

Key: Figures in the parentheses are standard errors

4.3.2.3 Direct questioning approach

As stated earlier representativeness of the knowledge base was also evaluated through a direct questioning approach (Section 4.2.3.1). Here, the farmers reactions to knowledge already collected and represented in the knowledge base were assessed. The questionnaire developed for this purpose was presented in the Appendix 7.

1. Evaluation of isolated statements

The first section of the questionnaire (Appendix 7) evaluated the representativeness of isolated statements selected randomly from the knowledge base. The farmers responses to these questions were analysed and categorised according to their different responses (Table 4.32). All farmers agreed to seven statements. Some farmers identified some of the statements as only being valid under certain conditions, that is, 27% farmers to statement five, 14% to statement twelve, 33% to statement sixteen and 18% to statement nineteen. Identification of these conditions led to some improvement in the precision of these knowledge statements. Conditions associated with the knowledge statement are essential to know in order to use them effectively in the decision making. Only some knowledge is valid under wider circumstances, while other knowledge is true under limited situations. Decisions made using the knowledge, therefore, could easily proceed beyond its scope when conditionality associated with this knowledge is not available. Eliciting conditions associated with knowledge, therefore, is essential to use them effectively.

Table 4.32 Percentage of farmers agreeing on the twenty isolated statements as represented in the knowledge base.

Statement number	Farmers response			
	Agree	Agree with conditions	Disagree	Don't know
1	95 (± 2.2)	0	5 (± 2.2)	0
2	92 (± 2.7)	0	4 (± 2.0)	4 (± 2.0)
3	95 (± 2.2)	0	5 (± 2.2)	0
4	100 (± 0)	0	0	0
5	73 (± 4.4)	27^1 (± 4.4)	0	0
6	93 (± 2.6)	0	7 (± 2.6)	0
7	95 (± 2.2)	0	5 (± 2.2)	0
8	91 (± 2.9)	0	9 (± 2.9)	0
9	100 (± 0)	0	0	0
10	95 (± 2.2)	0	5 (± 2.2)	0
11	97 (± 1.7)	0	0	3 (± 1.7)
12	86 (± 3.5)	14^2 (± 3.5)	0	0
13	99 (± 1.0)	0	0	1 (± 1.0)
14	100 (± 0)	0	0	0
15	100 (± 0)	0	0	0
16	55 (± 5.0)	33^3 (± 4.7)	12 (± 3.3)	0
17	100 (± 0)	0	0	0
18	100 (± 0)	0	0	0
19	82 (± 3.8)	18^4 (± 3.8)	0	0
20	100 (± 0)	0	0	0

Key: Figures in the parentheses are standard errors.
The conditions under which farmers agreed to different statements
Statement 5: ^{1} only during a extra ordinary dry season
Statement 12: ^{2}only on flat or moderately sloping land
Statement 16: ^{3}only when the trees are young
Statement 19: ^{4}only when diameter growth rate is low

The proportion of farmers disagreeing with original knowledge base was less than 5% with relation to questions one, two, three, seven and ten, whilst it was non-negligible, 7%, 9% and 12%, respectively in relation to statements six, eight and sixteen (Table 4.32). Further knowledge elicitation related to knowledge statements six, eight and sixteen may be required to clarify those disagreements.

The average percentage for don't know response was only 0.4% (Table 4.33). The average proportion of farmers who disagreed with these isolated statements was 2.6% whilst those who agreed with conditions were 4.6%. The percentage of farmers estimated as responding with 'agree' to all twenty questions were 92.4%. Therefore, the randomly selected set of statements considered here obtained a representative value of 92.4% indicating that the knowledge represented in the original knowledge base is largely in agreement to that held by the wider community.

Table 4.33 Farmers responses to the questions shown as an average percentage for all statements.

Farmers response	Average percentage[1]
Agree	92.4 (± 11.01)
Agree with conditions	4.6 (± 9.78)
Disagree	2.6 (± 3.57)
Dont' know	0.4 (± 1.07)

Key: Figures in the parentheses are standard errors.
[1]The percentage of farmers categorised under each different response averaged over all questions

2. Evaluation of link statements

As stated earlier (Section 4.2.3.2) three sub sets of knowledge relating to three topics selected from the knowledge base, (where the statements in each set were linked) were evaluated (Appendix 7). The reasoning process and conclusions drawn from these chains were evaluated for consistency with the wider community in the present section.

a. Statement set I: Factors affecting tree form

The farmers response to the first set of link statements are presented in the Table 4.34. The results show that conclusions drawn from those chains and reasoning procedures is widely confirmed by the community. More than 80% of farmers agreed with all statements in the first set of link statements. 8% and 4% of farmers disagreed with one or two links, respectively and also, 8% said they did not know about one statement, therefore they didn't confirm the conclusion drawn and the reasoning underlying the conclusions.

Table 4.34 Different farmer categories and their percentages based on their responses with relation to first set of link statements.

Degree of confirmation	Statement number	Percentage
Confirmed all statements	All	83 (± 3.8)
Disagreement with one statement	11	08 (± 2.7)
Disagreement with two statements	6 and 9	01 (± 1.0)
Don't know about one statement	8	03 (± 1.7)
	11	05 (± 2.2)

Key: Figures in the parentheses are standard errors.

The 11th statement, which was, "decreasing branch number causes an increase in branch initiation rate" was found to be unconfirmed by a non-negligible proportion (about 13%) of farmers. Hence, further knowledge elicitation is required related to 11th statement to clarify the disagreements.

Thus the conclusions drawn from the first statement set and reasoning are largely confirmed by the wider community.

b. Statement set II: Effect of branch pruning on micro climate

Farmers' reaction to the statement set II are presented in the Table 4.35. It shows that 89% of farmers confirmed all statements in the statement set II. Those farmers therefore, have confirmed the reasoning process and conclusions drawn from the set of statements. Disagreement was found with relation to statement seven, nine and ten but was only with a negligible proportion of farmers.

Table 4.35 Different farmer categories and their proportions based on their responses with relation to statement set II.

Degree of confirmation	Statement number	Percentage
Confirmed all statements	All	89 (± 3.1)
One statement unconfirmed	10	03 (± 1.7)
Two statements unconfirmed	7 and 9	01 (± 1.0)
Don't know about one statement	10	04 (± 2.0)

Key: Figures in the parentheses are standard errors

c. Statement set III: Effect of micro climate on crop yield

It is clear from the farmers reaction to the statement set III that the reasoning process and conclusions drawn by the third statement set is largely agreeable with the wider community. About 95% of farmers confirmed all statements in the statement set and the proportion of farmers who disagreed was negligible (Table 4.36).

Table 4.36 Different farmer categories and their percentages based on their responses to the third link set of statements.

Degree of confirmation	Statement number	Percentages
Confirmed all statements	All	95 (± 2.2)
Did not confirmed one statement	5 7	01 (± 1.0) 02 (±1.4)
Did not confirmed two statements	4 and 9	01 (± 1.0)
Don't know about one statement	9	01 (± 1.0)

Key: Figures in the parentheses are standard errors.

4.4 CONCLUSIONS

4.4.1 Strategies for elicitation and representativeness of knowledge

The results from the evaluation of representativeness of the knowledge base provided evidence to suggest that the ecological knowledge, represented in the knowledge base relating to the pruning of tree species and derived from a small purposive sample of farmers, was largely consistent with the knowledge of the general farming population of the study area. The test using non-leading questions related to specific areas selected for convenience from the tree pruning knowledge base, found that knowledge articulated by the wider community was highly consistent with that in the knowledge base. Further, evaluation of representativeness for randomly selected statements from the knowledge base, using leading questions, facilitated calculation of a general value for the representativeness of the knowledge base.

Both approaches have given some indication of the distribution of knowledge across members of the farming community. The responses of farmers regarding tree and crop attributes were found to be more variable with the non leading than the direct questioning approach. This could be attributed to the fact that the questions in the non-leading approach were developed in relation to particular tree species. The detailed knowledge about species-specific tree attributes which influenced the practical decisions in garden management, varied among farmers, obviously associated with which particular species they had experience of cultivating. This suggests that sampling strategies for knowledge elicitation should consider which species people cultivate and be stratified accordingly.

Both the direct and indirect approaches yielded new knowledge. The non leading approach succeeded in uncovering several attributes in addition to those collected during knowledge elicitation. This could be attributed to the fact that the knowledge elicitation strategy was not specifically based on tree species, but on asking more general questions about the effects of trees on other elements of the system. During the application of the direct questioning approach additional conditional information relating to some statements were found. Direct questions appeared more effective in identifying that some statements were only valid under certain conditions than when adhering to a non-leading elicitation strategy. Conditionality of knowledge statements is vital for the knowledge to be of practical use. This suggests that a phase of direct questioning, specifically designed to elicit conditions, might sensibly be included in a knowledge acquisition strategy.

This is consistent with a changing view of the knowledge acquisition process more generally in artificial intelligence from one of extracting knowledge directly from a source to the construction of a model of the knowledge held by the source (Ford and Adams-Webber, 1992).

4.4.2 General conclusions

This chapter has considered farmers' ecological knowledge underlying the practice of tree pruning to improve timber volume and quality and manage tree-crop interactions. It was clear from the survey that farmers in the study area possessed detailed ecological knowledge; this included causal mechanisms and species-specific information, which enabled them to classify tree species and make predictions about their management and use.

Important knowledge related to branch pruning for improvement of quality and volume of wood was uncovered during the knowledge elicitation. This included mechanisms underlying manipulation of wood quality and tree form through pruning, some details about pruning techniques, and also the ecological basis on which farmers make decisions about pruning with respect to different species. The knowledge base also provided insights into explanations for the branch pruning practised by farmers to manage tree-crop interactions. Tree and crop attributes as well as detailed explanations of the causal mechanisms involved in ecological interactions relating to shade, leaf drip, stem flow, branch fall, fruit fall and soil fertility were also identified.

The type and form of knowledge obtained from farmers is similar in broad terms to that obtained by Thapa *et al.*, (1995) using similar methods from farmers in the mid-hills of Nepal, although it is far less detailed in terms of its explanatory power. This may reflect a difference in terms of what it is necessary to know to manage a largely perennial multilayered homegarden as a supplementary activity in the humid and relatively fertile conditions pertaining in Kandy as opposed to integrating intensively pruned fodder trees onto farmland where subsistence cropping is practised. This leads to a sensible, if tentative, conclusion that depth of indigenous knowledge about ecological processes is likely to relate to the intensity of management of trees and associated crops and the socio-economic importance to the farmers of managing such interactions.

Another influence on the level of detail in ecological knowledge articulated by farmers can be related to the ease with which ecological processes can be observed by farmers. Thapa *et al.*, (1995) found that farmers in Nepal knew far less about below-ground interactions that were difficult for them to observe than above-ground interactions that were visible. Similarly, Bentley (1994) reports that farmers in Honduras, although interested and knowledgeable about biological pest control in general, were unaware of the existence and behaviour of parasitoids and entomopathogens, indicating that issues relation to the scale and level of organisation at which farmers are able to observe phenomena and thus develop understandings is important. In the case of the multilayered garden it is perhaps the complexity at the agroecosystem level that limits observation or makes it difficult for farmers to articulate disaggregated items of ecological knowledge that can be acquired in elicitation using a knowledge-based systems approach. In agreement with other researchers who have sought emic explanations of Kandy homegarden management (Southern, 1994; Jinadasa, 1995) this study has found some knowledge of ecological processes but not the sort of comprehensive understanding anecdotally suggested by researchers seeking to explain what they consider close to optimal utilization of environmental resources by vegetation in such systems in Sri Lanka (Jacob and Alles, 1987) and elsewhere (Michon, 1983) as the consequence of farmer decisions. Indeed, examination of garden structure in the light of knowledge elicited suggests that low input, laissez-faire garden management, while possibly leading to biodiversity and sustainability may do so partly because economic output is not maximised hence there are many species in the gardens with no apparent utility (Perera and Rajapakse, 1991) and researchers have suggested that productivity could be increased by more intensive management (McConnell and Dharmapala, 1973) for which model plant arrangements, densities and management strategies have been proposed (DMEC, 1986). The essential point here is that farmers' attitudes and socio-economic interests may not be best served by investing labour in maximising output given the supplementary nature of the garden in the farming system and they may not, therefore, require or use knowledge relevant to this end. There are parallels elsewhere Gladwin (1980), for example, reporting why farmers' did not adopt fertilizer recommendations in Mexico, used ethnoscientific techniques to elicit the cognitive strategies underlying farmer decisions using a decision tree approach and was able to show that an amalgam of individual ecological knowledge and conditions such as attitude to risk and the perceived likelihood of significant increases in productivity were involved. The important point was that while researchers who had developed recommendations appeared to have been aware of local agronomic conditions and the implications of their intervention, they had failed to realise that farmers reasoned differently than they did with the same information. In the present context, the similarity of homegardens with the structure of natural forest that some authors have remarked on (Perera and Rajapakse, 1991) may be as much to do with the degree of natural process involved as with the degree of farmers' knowledge of ecological processes driving their management decisions. However, it is also clear that farmers do possess mechanistic knowledge of some aspects of garden ecology related to productive output (for example timber quality and productivity) that supports Richards (1994) assertion that farmers generate knowledge that is comparable with general scientific principles, but which, because it embodies site-specific experience may implicitly incorporate risk factors in production decisions. In this respect the fact that farmers articulated detailed knowledge about the pruning and timber value of species such as *gini-sapu* which are unfamiliar to science and the forestry profession suggests a degree of complementarity with scientific knowledge worth further investigation. The ensuing chapters explore whether some of the farmers' knowledge that was not in the scientific domain is in conformity with scientific principles and can be validated through experimentation (Chapter 5) and whether currently available scientific knowledge or that generated by research suggested by obvious gaps in farmers' knowledge can usefully augment what farmers already know (Chapter 6). Such a strategy by targetting and seeking to enhance the farmers' knowledge system leaves the decision taking to the farmer but seeks an incremental improvement to the basis he or she has for making decisions.

CHAPTER 5

VERIFICATION OF FARMERS' ECOLOGICAL KNOWLEDGE

5.1 INTRODUCTION

5.1.1 Purpose of the chapter

This chapter describes the results and lessons learned from two experiments conducted for the verification of farmers' ecological knowledge. The two experiments conducted for this purpose were based on farmer's ecological knowledge underlying:

i. the propagation of *gini-sapu* (*Michelia champaca*) from seeds, and

ii. bark incision of *gini-sapu* to induce an increased rate of development of trunk diameter.

5.1.2 Background and context

The knowledge-based systems approach (Walker *et al.*, 1995a) uses knowledge from various sources including indigenous and scientific sources. The use of local knowledge for the development of agroforestry practices is a relatively new concept, and there, are several issues which still need resolving before such knowledge can be used in a practical way. The validation of knowledge is a particularly important issue, and needs to be addressed before promoting the use of any type of knowledge for management purposes.

There are two aspects to validating indigenous ecological knowledge (Walker *et al.*, 1991). Firstly, validating the knowledge for accuracy (in terms of representation of same knowledge), completeness and internal consistency. Difficulties arise from the uneven distribution of knowledge, and the difficulties associated with the cross cultural translation of knowledge, including the ability of informants to communicate their knowledge. This problem can be resolved by repeated interviews with the same informants, and group interviews with a large number of people from the community. In the present research, verification of knowledge to resolve such issues was conducted throughout the knowledge elicitation process. This was ensured by using distinct stages in the collection of knowledge: the main knowledge elicitation, clarification and conflict resolution stages and knowledge representation (Section 4.2.2.1). Finally, the knowledge base developed from the key informants was evaluated for consistency with the knowledge held by the wider community using two contrasting approaches (Section 4.3.2).

The second aspect of validation is to establish the extent to which implementation of the knowledge is appropriate and valid in a real world context and not just internally consistent (Walker *et al.*, 1991). Such evaluation of knowledge regarding the ecology of agroforestry is difficult but may, in some circumstances, be attempted through standard scientific experimentation.

5.1.3 Objectives of the research

To explore the validity of indigenous ecological knowledge in a real world context, two fairly specific items of knowledge that were not in the scientific domain were selected. The objective of the research described in the present Chapter was, therefore, to examine the validity of knowledge underlying two farming practices:

- propagation of *gini-sapu* from seeds
- bark incision to induce an increase in the rate of trunk diameter growth of *gini-sapu*

5.2 LOCAL AND SCIENTIFIC KNOWLEDGE

The local knowledge evaluated in the present chapter and the scientific knowledge relating to it is presented below.

5.2.1 Propagation of *gini-sapu* from seeds

5.2.1.1 Farmers' knowledge

Farmers believed that *gini-sapu* seeds remained dormant until passed through the digestive tract of certain birds including common grackle (*Eulabes religiosa indica*), common crow, mynah bird and hornbills. For the common grackle the mesocarp of ripened *gini-sapu* seeds is amongst its most favoured food. The body heat of the bird and strength of the digestive fluids were considered to be the factors which contributed to changing the nature of the seeds. In particular, the digestion of the mesocarp was considered to break seed dormancy. Farmers stated that birds selected and ate seeds with a bright red mesocarp, a colour which indicates that the fruit is ripe and mature. One farmer was producing *gini-sapu* seedlings from seeds collected after feeding fruiting bunches to a common grackle which he had in captivity. Although common grackle is considered an endangered bird species, it is found in large numbers in the Galagedara RSD and is commonly kept as a pet in the area.

5.2.1.2 Scientific knowledge

Ranwala (1986) reported that the dormancy of *gini-sapu* seeds can be broken by removing the mesocarp of the seed, either manually, using a scalpel, or by rubbing them on a rough surface. Seeds planted on a germination towel with their mesocarp intact had a 100% failure. Ranwala (1986), also stated that the viability of seeds declines rapidly if they are stored with the mesocarp intact.

5.2.2 Bark incision to induce diameter growth of *gini-sapu*

5.2.2.1 Farmer's knowledge

In their management of *gini-sapu* trees, farmers in the Galagedara RSD cut a slit in the bark of the trunk, close to the base, to enhance diameter growth. They believed that tree bark restricts the expansion of the trunk and that making an incision would reduce the pressure of the bark on the trunk inner tissues, thus allowing them to grow. The cuts were made vertically, using a knife with a bent end, and extended to about two metres from the base of the tree. Very little weight was put on the knife to avoid damaging the tissues under the bark. The intensity of treatment varied with the size of the tree as shown in Table 5.1. Once the incision wounds were healed, the bark was slit again in a different place parallel to the previous cut. This process was repeated until the tree was harvested. The farmers also believed that there was no decrease in the quality of the wood as a result of this process.

Table 5.1 The intensity of bark slitting treatment for trees of different sizes.

Size	DBH (cm)	Treatment
1. Saplings	>9	Not treated
2. Small trees	9-15	One, 2m long vertical cut, from the base of the trunk
3. Medium trees	15-20	Two, 2m long vertical cuts, evenly spaced, from the base of the trunk
4. Large trees	20-27	Three, 2m long vertical cuts, evenly spaced, from the base of the trunk

Key: DBH-Diameter at breast height (1.3m above ground level)

5.2.2.2 Scientific knowledge

The inner bark of the tree possesses phloem tissue which is a live tissue involved in the translocation of food to all parts of the tree (Shigo, 1991). The outer bark contains dead tissues, the main purpose of which is to provide protection to the inner parts of the stem from various micro-organisms and physical damage. Therefore, damaging the bark by making an incision can increase the chance of stem rot due to microbial infections, and lower growth rates in the lower parts of the tree if the phloem tissue is damaged due to a reduction in food transportation (Shigo, 1991).

5.3 METHODOLOGY

Based on the objectives of this chapter stated in section 5.1.3, the following experiments were conducted:

5.3.1 Propagation of *gini-sapu* from seeds

The experiments were conducted between March and June 1994, following the commencement of the fruiting season. 50 healthy *gini-sapu* trees were selected (i.e. five trees from each of 10 villages) within the Galagedara RSD. *Gini-sap*u fruit (i.e. follicetum) bunches were collected the day before the seeds were treated. Only open, undamaged bunches of fruits with a bright red coloured mesocarp, were selected. They were mixed and randomly selected for the experiment.

i. Germination percentage

Five treatments were considered,

- seeds treated in the scientifically proven method (as a comparison to the local method)

- seeds collected after feeding normal seeds to a chicken to examine whether seeds could be treated by birds other than those identified by farmers
- seeds collected after feeding the fruit with the mesocarp removed to a chicken
- untreated seeds (as a control, to examine whether seed treatment had a significant effect on the germination percentage), and
- seeds treated by the local method, that is, feeding normal seed to a common grackle.

The treatment structure of the experiment was as follows:

1. Local method: Ten caged common grackle birds (i.e. ten replicates) were used for the experiment. Approximately 10 bunches of fruit were placed in the bird cages in the early morning (between 6.30-8.00 am); the resulting excreta was collected up to two days after feeding, from polythene sheets previously placed under the cages. Seeds treated by each bird were collected separately, and forty seeds from each of these ten replicates were used for the experiment.
2. Intact seeds fed to chickens: 10 chicken (i.e. replicates) were fed approximately 100 seeds five times a day (i.e. 500 seeds per chicken), and their excreta was collected up to two days after feeding.
3. Seeds with mesocarp removed fed to chickens: 10 chicken (i.e. replicates) were fed approximately 100 seeds five times a day (i.e. 500 seeds per chicken) and their excreta was collected up to two days after feeding.
4. Scientific method: Ten replicates of forty seeds each were randomly selected from the seed bulk. Their mesocarps were removed by rubbing them on a muslin cloth.
5. Untreated seeds (i.e. intact seeds): Ten replicates of forty seeds each were randomly selected from the seed bulk for the experiment.

Treated seeds were planted on large sand filled plastic trays at a 10cm x 15cm spacing allowing enough room for seedlings which germinated to grow for three months. Forty seeds from each replicate were planted (one tray per replicate) and each treatment was replicated 10 times. Fungicides were applied to the sand medium in order to kill any soil-borne fungi. The trays were kept under controlled conditions in a greenhouse. Seed germination was counted at weekly intervals for twelve weeks after planting, in order to calculate the germination percentages.

Mean germination percentages were analysed statistically using analysis of variance, and LSD values were computed to compare the means at weekly intervals (Sokal and Rohlf, 1995). Absolute values were used in the analysis since the results were similar to those obtained achieved when using data that had been subjected to angular transformation procedure.

ii. Seed weight

The hundred seed weight (g) of the following seed lots was measured on an electronic scale by taking ten samples (ten replicates each containing fifty seeds), and then comparing:

- The fresh weight of the *gini-sapu* seed from intact fruit and those where the mesocarp was removed manually (Treatment 4).
- The dry weight of the seeds where the mesocarp was removed manually after drying in an oven at 105°C overnight (Treatment 4).
- The fresh weight of the mesocarp-removed seeds collected after being treated by common grackle birds (Treatment 1).
- The dry weight of the mesocarp removed seeds after being treated by common grackle birds that were not used in the germination experiment (after drying in an oven at 105°C overnight) (Treatment 1).

The hundred seed weights (g), on a fresh and dry weight basis, of seeds in which the mesocarp was removed manually and collected after feeding to common grackle birds were compared using the Students' t-test at P=0.05 (Sokal and Rohlf, 1995).

ii. Seedling growth and mortality

Seedlings produced from seeds treated by the local method and the scientifically proven method were allowed to grow in plastic trays. Their growth and mortality rates were monitored at monthly intervals for a period of 3 months. This was done only with those replicates (i.e. plastic trays) in which more than 10 seedlings had survived after the planting of seeds. This experiment, therefore, only had seven replicates for each treatment.

Mean heights of the seedlings were compared at monthly intervals using the Students' t-test at P=0.05 (Sokal and Rohlf, 1995). The same test was used to compare mean mortality of the seedlings, after three months from germination of the seeds.

5.3.2 Effect of bark incision on the diameter growth of rate of *gini-sapu*

As stated earlier the objective here was to examine the validity of local knowledge underlying the cutting of slits in the bark of *gini-sapu* to induce a higher rate of diameter growth in the trees. The treatment structure used for the experiment is shown in Table 5.2. The experiment was conducted between June 1994 and March 1995.

A homegarden belonging to W.G. Jamis, located in the Poholiyadda village of the Galagedara RSD was selected for the experiment as it had a large number of regularly spaced *gini-sapu* trees relatively uniform topographic conditions in comparison to other homegardens in the experimental area. The DBH (trunk diameter at 1.3m above ground level) of single, healthy *gini-sapu* trees found in the homegarden was measured. and categorised into three groups, namely, small, medium and large, based on the size groups identified by farmers. Twenty trees from each group were selected randomly for the experiment. The mean diameter at breast height (DBH) and height of the trees used for the experiment are showed in the Table 5.3. Ten trees were treated while 10 were used as controls for each of the three size classes.

Table 5.2 The treatment structure for the experiment designed to evaluate farmers knowledge underlying the cutting of slits in the bark of *gini-sapu*.

Test	Tree size	Treatment
1	Small (DBH=9-15cm)	i. Treated (i.e. one, 2m long vertical cut, at the base of the trunk) ii. Non-treated
2	Medium (DBH=15-20cm)	i. Treated (i.e. two, 2m long vertical cuts, evenly spaced, at the base of the trunk) ii. Non-treated
3	Large (DBH=20-27)	i. Treated (i.e. three, 2m long vertical cuts, evenly spaced, at the base of the trunk) ii. Non-treated

Table 5.3 The mean DBH and heights of the *gini-sapu* trees selected for the bark slitting experiment.

Size class	Treatment	DBH (cm)		Tree height (m)	
		Mean	S.E	Mean	S.E
1. Small	Treated	12.13	0.459	13.83	0.866
	Non-treated	12.38	0.620	15.95	0.747
2. Medium	Treated	17.18	0.432	18.26	0.706
	Non-treated	17.29	0.475	18.30	0.795
3. Large	Treated	23.56	0.487	22.51	0.869
	Non-treated	23.43	0.691	21.57	0.934

Key: S.E.- Standard error

The DBH and tree height were measured at monthly intervals for all three size classes throughout the duration of the experiment. These two growth parameters are the most important in terms of timber production. DBH was measured using a diameter tape and the height using a clinometer.

The mean monthly and total increment of DBH and heights of treated and non-treated trees were compared statistically using the Students t-test (Sokal and Rohlf, 1995).

In addition the timber of treated and untreated trees was examined at a saw mill in the Galagedara RSD in order to assess whether there was any damage to the internal parts of the tree as a result of bark slitting.

5.4 RESULTS AND DISCUSSION

5.4.1 Propagation of *gini-sapu* from seeds

5.4.1.1 Germination percentage

The cumulative germination percentages taken at weekly intervals, of *gini-sapu* seeds subjected to the various treatments are shown in Table 5.4. The seeds fed to chicken (treatments two and three) were not recovered, most probably having been broken down in their digestive tracts. The cumulative germination percentages increased until the 7th week but did not increase above 15% with any of the treatments. This suggests that the percentage of viable seeds decreased rapidly and reached zero by the 7th week. Hence an important area of research would be to examine the change in seed viability over the first 7 weeks after harvesting from the mother tree.

With treatments one, four and five, germination commenced in the second, third and fourth week, respectively and in all treatments was completed by the 7th week. Although the difference between the mean final germination percentages for treatment one and four was not significant (P=0.05), cumulative germination percentages were different after the second and third weeks from planting. This result indicates that germination commences earlier with seeds treated by birds than for seeds where the

Table 5.4 The cumulative germination percentage at weekly intervals of *gini-sapu* seeds subjected to different treatments.

Treatment	Week 1		Week 2		Week 3		Week 4		Week 5		Week 6		Week 7	
	Mean	S.E	Mean	S.E	Mean[1]	S.E	Mean	S.E	Mean	S.E	Mean	S.E	Mean	S.E
Treatment1: Local method	0.00	0.00	1.26	0.37	5.28^{a}	0.75	11.37^{a}	1.64	11.65^{a}	1.62	12.42^{a}	1.67	12.78^{a}	1.76
Treatment 2: Intact seeds treated with chicken	-	-	-	-	-	-	-	-	-	-	-	-	-	-
Treatment 3: Mesocarp removed seeds treated with chicken	-	-	-	-	-	-	-	-	-	-	-	-	-	-
Treatment 4: Scientifically proven method	0.00	0.00	0.00	0.00	1.25^{b}	0.56	9.75^{a}	1.51	10.50^{a}	1.33	12.00^{a}	1.28	12.50^{a}	1.24
Treatment 5: Intact seed (normal seeds)	0.00	0.00	0.00	0.00	0.00^{b}	0.00	1.00^{b}	0.55	2.00^{b}	0.62	2.75^{b}	0.69	3.25^{b}	0.65
LSD (P=0.05)	-	-	-	S	1.27	S	3.14	S	2.98	S	3.03	S	3.06	S

Key: LSD-Least Significant Difference, NS-Not significant, S-significant, P-Significance Level, S.E-Standard error

[1]In a column, differences between means identified by different letters are significant while differences between means identified by the same letters are not significant.

mesocarp is removed manually. This shows that passing through the digestive tract of birds has a significant effect on the germination rate of *gini-sapu* seeds. For treatment five, maximum germination percentages were significantly lower (P=0.05) and in addition, the process started much later than with treatments one and four. This low rate and percentage of germination of seeds in treatment five may be attributed to a rapid decline in seed viability caused by the presence of the mesocarp. Gradual disappearance of the mesocarp may have enabled some seeds to preserve their viability and germinate, but at a later stage than for the seeds whose mesocarps had been removed prior to planting.

5.4.1.2 Seed weight

It was observed that the mesocarp of the *gini-sapu* seed completely disappeared during its passage through the digestive tract of the common grackle. Although, the hard seed coat was apparent , it was not clear whether some part of it or any other tissues may have been digested during its passage through the bird. The mean dry and fresh weights of seeds where the mesocarp had been removed manually and those seeds which had passed through the common grackle are shown in Table 5.5. The results show that the mean fresh weight of the seeds treated by common grackle were significantly higher than that of seeds in which the mesocarp was removed manually. This can be attributed to the absorption of moisture by seeds during the passage through the digestive tract. The difference between the mean dry weights was not significant (P=0.05). This indicates that there was no significant reduction in the dry matter content of seeds during their passage through the digestive tract of the common grackle other than the loss of the mesocarp. However, this cannot completely rule out the possibility that other chemical and physical changes had taken place while the seeds were inside the birds.

Table 5.5 The weight of *gini-sapu* seeds before and after treatment by the common grackle.

Treatment	Fresh weight (g)		Dry weight (g)	
	Mean	SE	Mean	SE
Treatment 1: Mesocarp removed by feeding to the birds	7.03	0.107	1.59	0.089
Treatment 4: Mesocarp removed manually from seed	6.53	0.075	1.70	0.096
T-test (P=0.05)	S	-	NS	-

Key: SE-Standard Error, S-Significant, NS-Not Significant, P-Significance Level

5.4.1.3 Seedling growth and mortality

The mean heights of seedlings produced from seeds treated (i) by common grackle, and (ii) by removing the mesocarp manually are presented in Table 5.6. The results show that the differences in height between seedlings produced from the two treatments was not significant (P=0.05).

Table 5.6 The height of the seedlings (cm) at monthly intervals.

Treatment	1 MAG		2 MAG		3 MAG	
	Mean	SE	Mean	SE	Mean	SE
1. Seedlings of seeds treated with local method (Treatment 1)	4.57	0.203	8.57	0.396	11.37	0.675
2. Seedlings of seeds treated with scientifically proven method (Treatment 4)	4.89	0.278	8.44	0.253	12.21	0.598
T-test (P=0.05)	NS	-	NS	-	NS	-

Key: NS-Not significant, SE-Standard error of the mean, P-Significance Level, MAG-Months after germination

The seedling mortality rate at three months from the germination of seeds treated by the local and scientifically proven methods are shown in Table 5.7. The figures indicate that the differences in mean mortality rates of seedlings produced from the two different seed treatments were not significant (P=0.05).

Table 5.7 *Gini-sapu* seedling mortality after three months from germination of seeds.

Treatment	Seedling mortality rate	
	Mean	SE
1. Seedlings of seeds treated by the local method (Treatment 1)	10 %	3.33
2. Seedlings of seeds treated by the scientifically proven method (Treatment 4)	8 %	2.49
T-test (P=0.05)	NS	-

Key: NS-Not significant, SE-Standard error, P-Significance Level

This result provides evidence to suggest that the difference in vigour of seedlings from the two different treatments was not significant (P=0.05).

5.4.2 The effect of bark incision on the diameter growth rate of *gini-sapu*

5.4.2.1 Diameter growth of trees

The mean monthly and total increment in DBH of treated (i.e. bark slit) and non-treated small *gini-sapu* trees are presented in Table 5.8. The results show that differences in mean monthly DBH growth for treated and non treated trees were not significant (P=0.05). Furthermore, total increment in DBH after nine months from the date of treatment was likewise, not significant.

Table 5.8 Mean monthly DBH (cm) increment for treated and non-treated *gini-sapu* trees of small size class (9-15cm DBH).

Months after treatment	Treated		Non-treated		T-test
	Mean (cm)	S.E	Mean (cm)	S.E	(P=0.05)
1	0.18	0.033	0.13	0.030	NS
2	0.20	0.026	0.24	0.031	NS
3	0.11	0.031	0.08	0.033	NS
4	0.09	0.031	0.07	0.021	NS
5	0.09	0.023	0.09	0.035	NS
6	0.09	0.031	0.14	0.037	NS
7	0.11	0.031	0.14	0.037	NS
8	0.26	0.037	0.19	0.035	NS
9	0.20	0.047	0.13	0.030	NS
Total DBH increase (cm)	1.33	0.075	1.21	0.105	NS

Key: SE-Standard Error, NS-Not significant, P-Significance Level

The mean monthly and total increment in DBH of treated (i.e. bark slit) and non-treated small *gini-sapu* trees of medium sized *gini-sapu* trees are shown in Table 5.9. At the end of seventh and eighth months, mean DBH increments for treated trees were significantly higher than for non-treated trees. Further, during the remaining seven months, no-significant difference was recorded in the DBH increment, and likewise, total DBH growth over the nine months was found not to be significantly different (P=0.05).

Table 5.9 Mean monthly DBH (cm) increment for treated and non-treated *gini-sapu* trees of medium size class (15-20cm DBH).

Months after treatment	Treated		Non-treated		T-test
	Mean (cm)	S.E	Mean (cm)	S.E	(P=0.05)
1	0.18	0.033	0.21	0.023	NS
2	0.27	0.040	0.25	0.034	NS
3	0.11	0.031	0.09	0.023	NS
4	0.07	0.021	0.12	0.025	NS
5	0.13	0.030	0.12	0.020	NS
6	0.23	0.030	0.21	0.028	NS
7	0.20	0.026	0.13	0.026	S
8	0.23	0.026	0.17	0.021	S
9	0.22	0.025	0.25	0.040	NS
Total DBH increase (cm)	1.64	0.095	1.55	0.090	NS

Key: SE-Standard Error, NS-Not Significant, P-Significance Level

Differences in mean monthly DBH increments of treated and non-treated large *gini-sapu* trees were found to be significant (P=0.05) in only the second and fifth months from treatment (Table 5.10). At the end of the second month, mean DBH increments for non-treated trees were significantly higher than for treated trees but the opposite was true during the fifth month. Further, during the remaining seven months, no significant difference was recorded in the DBH increment, and likewise, total DBH growth over the nine months was found not to be significantly different (P=0.05).

Table 5.10 Mean monthly DBH (cm) increment for treated and non-treated *gini-sapu* trees of large size class (20-27cm DBH).

Months after treatment	Treated		Non-treated		T-test
	Mean (cm)	S.E	Mean (cm)	S.E	(P=0.05)
1	0.19	0.038	0.24	0.031	NS
2	0.14	0.016	0.22	0.020	S
3	0.11	0.028	0.10	0.026	NS
4	0.12	0.025	0.13	0.030	NS
5	0.19	0.023	0.12	0.020	S
6	0.17	0.026	0.14	0.022	NS
7	0.17	0.015	0.15	0.027	NS
8	0.14	0.027	0.20	0.033	NS
9	0.22	0.033	0.22	0.020	NS
Total DBH increment (cm)	1.45	0.062	1.52	0.044	NS

Key: SE-Standard Error, S-Significant, NS-Not Significant, P-Significance Level

These results indicate that there is very little evidence to suggest that making incision in the bark has any effect on the trunk diameter growth rate of *gini-sapu* trees (all sizes) during the first nine months after treatment.

5.4.2.2 Height growth of trees

Mean monthly and total height increment during the experimental period for treated (i.e. bark slit) and non-treated small sized *gini-sapu* trees are presented in Table 5.11. The differences in mean monthly height increment for treated and non-treated small trees were not significant (P=0.05).

Table 5.11 Mean monthly height (m) increment for treated and non-treated *gini-sapu* trees of small size class (9-15cm DBH).

Months after treatment	Treated		Non-treated		T-test
	Mean (m)	S.E	Mean (m)	S.E	(P=0.05)
1	0.21	0.031	0.23	0.030	NS
2	0.22	0.033	0.19	0.031	NS
3	0.21	0.031	0.23	0.037	NS
4	0.20	0.033	0.21	0.041	NS
5	0.47	0.040	0.44	0.048	NS
6	0.49	0.043	0.41	0.046	NS
7	0.26	0.027	0.25	0.034	NS
8	0.21	0.031	0.24	0.034	NS
9	0.23	0.030	0.20	0.026	NS
Total height increment (m)	2.50	0.093	2.40	0.105	NS

Key: SE-Standard Error, NS-Not Significant, P- Significance Level

Mean monthly and total height increment during the experimental period for treated and non-treated medium sized *gini-sapu* trees are presented in the Table 5.12. Except during the second month, differences in the mean monthly height increment were found to be non-significant (P=0.05) as were total height differences.

Table 5.12 Mean monthly height (m) increment for treated and non-treated *gini-sapu* trees of medium size class (15-20cm DBH).

Months after treatment	Treated		Non-treated		T-test
	Mean (m)	S.E	Mean (m)	S.E	(P=0.05)
1	0.22	0.036	0.25	0.040	NS
2	0.17	0.026	0.26	0.040	S
3	0.22	0.033	0.19	0.031	NS
4	0.19	0.023	0.24	0.043	NS
5	0.41	0.057	0.36	0.040	NS
6	0.34	0.034	0.41	0.062	NS
7	0.27	0.026	0.23	0.034	NS
8	0.21	0.031	0.25	0.037	NS
9	0.20	0.021	0.20	0.033	NS
Total height increment (m)	2.23	0.106	2.39	0.084	NS

Key: SE-Standard Error, S-Significant, NS-Not Significant, P-Significance Level

Mean monthly and total height increment of large treated and non-treated *gini-sapu* trees are presented in Table 5.13. Differences in height increases between treated and non-treated trees were not significant (P=0.05).

Table 5.13 Mean monthly height (m) increment for treated and non-treated *gini-sapu* trees of large size class (20-27cm DBH).

Months after treatment	Treated		Non-treated		T-test
	Mean (m)	S.E	Mean (m)	S.E	(P=0.05)
1	0.18	0.025	0.20	0.033	NS
2	0.08	0.025	0.13	0.030	NS
3	0.11	0.023	0.12	0.039	NS
4	0.13	0.037	0.23	0.045	NS
5	0.07	0.026	0.10	0.033	NS
6	0.22	0.033	0.24	0.043	NS
7	0.12	0.025	0.12	0.036	NS
8	0.11	0.031	0.12	0.036	NS
9	0.13	0.037	0.14	0.031	NS
Total height increase (m)	1.15	0.073	1.40	0.129	NS

Key: SE-Standard Error, NS-Not Significant, P-Significance Level

In conclusion, there is very little evidence to suggest that making incisions in the bark has any significant influence on the height growth rate of *gini-sapu* trees (all sizes) up to nine months after treatment.

5.4.2.3 Wood quality

It became evident that the scar left by the slit wound, although prominent (i.e. long and concave in shape), healed completely with the growth of new tissues in all three size classes of *gini-sapu* trees. There was no visible sign, externally, of a wound outgrowth such as a canker, or of an infection. Visual observation of the wood indicated no detectable difference in wood quality between trees where the bark had been slit and the non-treated trees. This suggests that making incisions in the bark does not cause serious damage to the wood of the tree.

5.5 CONCLUSIONS

It is evident from the germination experiment that the farmers' ecological knowledge underlying the propagation of *gini-sapu* seeds is valid in a real world context and can be implemented. The results also indicate that the dormancy of seeds can be broken faster using the local method than by the scientifically proven method. However, the scientifically proven technique is much simpler and, therefore, easier to implement, while the differences in the mean maximum germination percentage, the growth rate of seedlings and the percentage survival between local and scientific techniques were not significantly different, the values for all these variables were higher for the scientific method.

Results from the bark incision experiment indicate that the practice has no significant effect on the growth rate of the trunk diameter or tree height up to nine months after the treatment. Farmers normally continue this treatment for approximately 3-4 years. Hence the experimental period may not have been long enough to draw any final conclusions about the technique. Furthermore, visual observation of the outside and inside of the trunk indicates that cutting slits in the bark does not have any adverse effect on the wood, as would be suggested by the scientific literature.

The above results indicate that of the two cases, one confirmed the ecological rationality of farmers knowledge and the other neither conclusively confirmed nor refuted it, although a longer time frame may enable this to be done. In terms of complementarity, in one case scientific and local methods of seed treatment were equally effective (although scientific procedures were easier to implement), in the other case the general scientific principle that wounding bark would be detrimental was not borne out in practice (confirming that local practice did not have the negative impact that could have been predicted). However, the local knowledge that wounding enhanced growth was not proven either and there is no evidence to either refute or confirm the local explanations for the expected enhancement. This indicates that farmers may benefit from scientific knowledge in these areas and that local knowledge, even if in conflict with science, may be worth investigation. Since professional foresters may wrongly believe that wounding would be detrimental, even if the local practice may not improve growth rate, the point is that it does not reduce it. Such an awareness, may help improve communication between development professionals, and farmers.

Understanding the validity of local knowledge may have two useful impacts in a research and development context. Firstly, knowledge that is new to science, and confirmed, may be of general use and be subsequently applied elsewhere. There was little evidence of important gains in this respect from the present work (the local seed treatment was no more effective than the scientific method and more difficult to implement; the bark wounding was not confirmed as a method of enhancing growth, although the fact that it did not damage the tree is a possible gain in species-specific knowledge). Secondly, however, communication between development professionals and farmers may be improved. In this respect, the fact that the local seed treatment method was effective is significant; it may lead to professional foresters respecting the local practice, but more importantly knowledge that wounding does not damage *gini-sapu* may prevent professionals from incorrectly suggesting to farmers that it would. Furthermore, if local knowledge is proved not to be borne out in practice, for example if it were to turn out that there is no long term gain from bark wounding, then farmers may wish to re-evaluate their knowledge in the light of such a demonstration. Thus, having treated the local knowledge with respect and an open-minded approach, researcher-led experimentation may lead to farmers enhancing their knowledge both by the introduction of scientific alternatives where these are seemed appropriate and by the re-evaluation of their own knowledge.

CHAPTER 6

SCIENTIFIC KNOWLEDGE TO IMPROVE AGROFORESTRY PRACTICES

6.1 INTRODUCTION

6.1.1 Purpose of the chapter

The purpose of this chapter is to explore the possibility of introducing new knowledge to farmers based on an analysis of what they already know (Chapter 4). Walker *et al.*, (1995b) suggest that analysis of the state of knowledge possessed by a farming community can be used to identify both existing scientific knowledge that might fill gaps in the local knowledge system and also areas of research required to generate new knowledge, where the requirement cannot be met from what is already known from sources outside the community. While Thapa *et al.*, (1995) illustrated gaps in Nepali farmers knowledge that might be plugged in this way, they did not attempt to introduce any new knowledge. It is, therefore, relevant to attempt to introduce new knowledge to the community on a case study basis here and evaluate whether or not this is useful to farmers in improving their agroforestry practices.

6.1.2 Background and context

As stated above identification of gaps in farmers' knowledge might be achieved through an analysis of their knowledge and comparison of this knowledge with relevant scientific information. The gaps can be filled by identifying relevant knowledge from existing scientific material and through the generation of new scientific knowledge.

The next important step in the use of scientific knowledge for improving agroforestry practices is to examine the extent to which the collected knowledge is useful to farmers. This can be achieved through comparison of decisions made by farmers with those based on new information and against an independent standard, in the present case an experienced arboriculturist.

6.1.3 Objectives of the research

As stated earlier, the frequency of pruning of timber tree species grown in homegardens was very low (Section 2.4.3.3). The knowledge-based systems approach applied at Galagedara RSD provided the opportunity to identify indigenous ecological knowledge underlying the pruning of timber tree species in homegardens (Chapter 4). Analysis of this knowledge identified some gaps which may have constrained the pruning of timber trees in homegardens.

The objectives of the research were, therefore, to acquire from existing scientific literature, and through new experimentation, knowledge to fill these gaps that might improve pruning of timber trees in the homegardens. The usefulness of some of the scientific knowledge so identified in filling the gaps was also evaluated. The following, research activities were therefore undertaken:

- Knowledge to fill these gaps was identified through:
  i. analysis of the existing scientific literature about pruning of timber species
  ii. undertaking scientific experiments
- The usefulness of scientific knowledge was evaluated by means of a decision tree developed with simple outputs to assist farmers in making better decisions about pruning.

6.2 METHODOLOGY

The following methods were used in experiments undertaken to meet the objectives listed above:

6.2.1 Existing scientific knowledge relating to the pruning of timber tree species

Attempts were made to collect site specific scientific information on the branch pruning of timber tree species grown in KHGs through a literature search of local scientific journals on forestry and interviews with Assistant Conservators of the Forest Department in the divisions of Kandy and Kurunegala, and Research Officers at the Forestry Research Station in Kumbalpola, Kurunegala. Knowledge of the general scientific principles for pruning timber trees was gathered from standard texts and journals relating to forestry and was represented in a separate knowledge base.

6.2.2 Experiments to generate new knowledge

6.2.2.1 Growth of *gini-sapu* seedlings under different light environments

i. Introduction

The method of pruning adopted for timber tree species in the homegardens of Galagedara RSD (Section 4.3.1.1) is an expensive operation. Undoubtedly, the cost is high for skilled labour to climb and chop branches, and the lack of skilled labour has led to a decrease in the intensity of pruning (Section 2.4.3.3). The necessity for pruning can be minimised if seedlings are established under low light intensities, as this promotes the self pruning of branches and hence produces a tree of suitable form for timber production.

As identified earlier (Section 4.3.1.1), farmers are well aware of the concept of self pruning in closed canopy conditions.

The objective of this study was, therefore, to evaluate the growth of *gini-sapu* (*Michaelia champaca*) seedlings in different light environments within homegardens in order to assess the potential for locating them in dark corners and allowing them to self prune. It was hoped that this might provide more options for farmers in selecting locations for the establishment of *gini-sapu* trees in the homegardens.

ii. Methodology

20 homegardens were randomly selected from the Galagedara RSD using the Farmer Register of the Galagedara ASC. From these, five were selected after considering the following factors:

- Size of the homegarden: homegardens which were over 0.4 ha and had diverse vegetation were selected in order to find areas with different light intensities.
- Willingness to participate in the study: the researcher had to visit the trial frequently to manage the experiment and also to use some of the valuable space in the homegarden; farmers had to be willing to tolerate this.
- The availability of protection for plants and other structures from herbivores, other animals, and theft.

Four sites with different light intensities[1] were selected in each homegarden to establish the seedlings (Table 6.1). Attempts were made to locate sites of similar topography and soil conditions within the homegarden.

Seeds were collected from a large number of trees in Galagedara RSD (Section 5.4.1) and planted in sand bed nurseries. The seedlings were transplanted to polythene bags when they were approximately one month old. This stage of the experiment was conducted at the University Experimental Station, Dodangolla. The seedlings were

[1] Light intensities were measured using a '400nm-700nm quantum sensor'(Skye Instruments, Llandrindod Wells, Powys, Wales).

transported, and planted in the field when they were approximately two months old. An imported soil was used in addition to the local soil in order to minimise soil variation across the sites. Normal soil from the University Experimental Station, Dodangolla was used as the imported soil. Root barriers made from polypropylene sacks of thick gauge, were used in order to minimise variation in underground competition for resources. Each sack was filled with 25kg of soil (dry weight basis). The experiment was laid out as a (4 x 2 x 2) split-split-plot design with 5 replications (Sokal and Rohlf, 1995), generating 16 treatment combinations. There were eight seedlings for each replicate, each homegarden forming one replicate. The treatment structure of the experiment is shown in Table 6.2.

Table 6.1 Canopy vegetation with different light intensities of the four points selected sites in the five selected KHGs.

Replicate / Farmer	Light intensity level			
	LI-1 100%	LI-2 50-75%	LI-3 25-50%	LI-4 0-25%
Replicate 1 Amunupura	Open	*Hawarinuga*	Coconut, cocoa	Jak
Replicate 2 Gnanaratne	Open	Coconut	*Gini-sapu*, coffee	Clove
Replicate 3 Madawala	Open	*Gini-sapu*	*Kududavula*	Jak, cocoa
Replicate 4 Ratnayake	Open	Coconut	Coconut, coffee	Clove
Replicate 5 Udalagama	Open	Coconut	Coconut, coffee	Nutmeg

Key: Species names are given in Appendix 2.

Table 6.2 Treatment structure for an experiment designed to evaluate seedling growth of *gini-sapu* under varying light intensities.

Factor level	Factor A: Light intensity	Factor B: Soil type	Factor C: Root barriers
Level 1	Light intensity 100%	Imported soil	With root barriers
Level 2	Light intensity 50-75%	Local soil	Without root barriers
Level 3	Light intensity 25-50%	-	-
Level 4	Light intensity 0-25%	-	-

Light quality (R/FR) was measured at monthly intervals at the sites where seedlings were planted (Appendix 9) using a '660nm-730nm sensor[1]'. This was done to eliminate the variability of seedling growth due to differences in the light quality at various points at which seedlings were established. The average reading at the beginning and at the end of the months were used as co-variates (Sokal and Rohlf, 1995).

The height of the seedlings and the percentage survival rate were recorded at monthly intervals. Survival data were transformed using angular transformation and the analysis was carried out using absolute values since percentage results did not differ from those achieved when using absolute values. The results were first analysed as a 4 x 2 x 2 three-factor factorial with five replicates, taking light quality as the co-variate (Sokal and Rohlf, 1995). Results indicated that only the main effect , 'A' (light intensity), was significant while the other two factors (soil type and root barriers) were not significant as interactions or as co-variates (Appendix 10). They were, therefore, re-analysed as a single factor (i.e. light intensity) experiment and the means at different light intensities were compared using Least Significant Difference at a significance level of 0.05.

[1] Skye Instruments, Llandrindod Wells, Powys, Wales.

6.2.3 Effectiveness of the scientific knowledge identified in improving agroforestry practices

6.2.3.1 A pruning schedule using scientific knowledge

i. Introduction

As stated earlier the frequency for pruning of timber trees was low, hence, a decision tree was developed (using scientific knowledge) and evaluated for its potential to assist extension workers in advising farmers on improvements to their pruning operations in homegardens. A pruning schedule using scientific knowledge, was thus developed and presented as a decision tree (Figure 6.1). To assess the usefulness of the decision tree, a selected tree stand was evaluated by an expert in this field, the farmers, and also the researcher, using the decision tree model. The outcome of these evaluations were analysed.

ii. Pruning schedule

A pruning schedule for use by extension workers has already been developed from scientific knowledge (Evans, 1982) so that they might have a positive interaction with farmers, and to assist them in making more informed decisions regarding tree pruning (Figure 6.1). This decision tree was designed to answer the following two questions:

- should a particular tree be pruned, and
- if so, how should it to be pruned

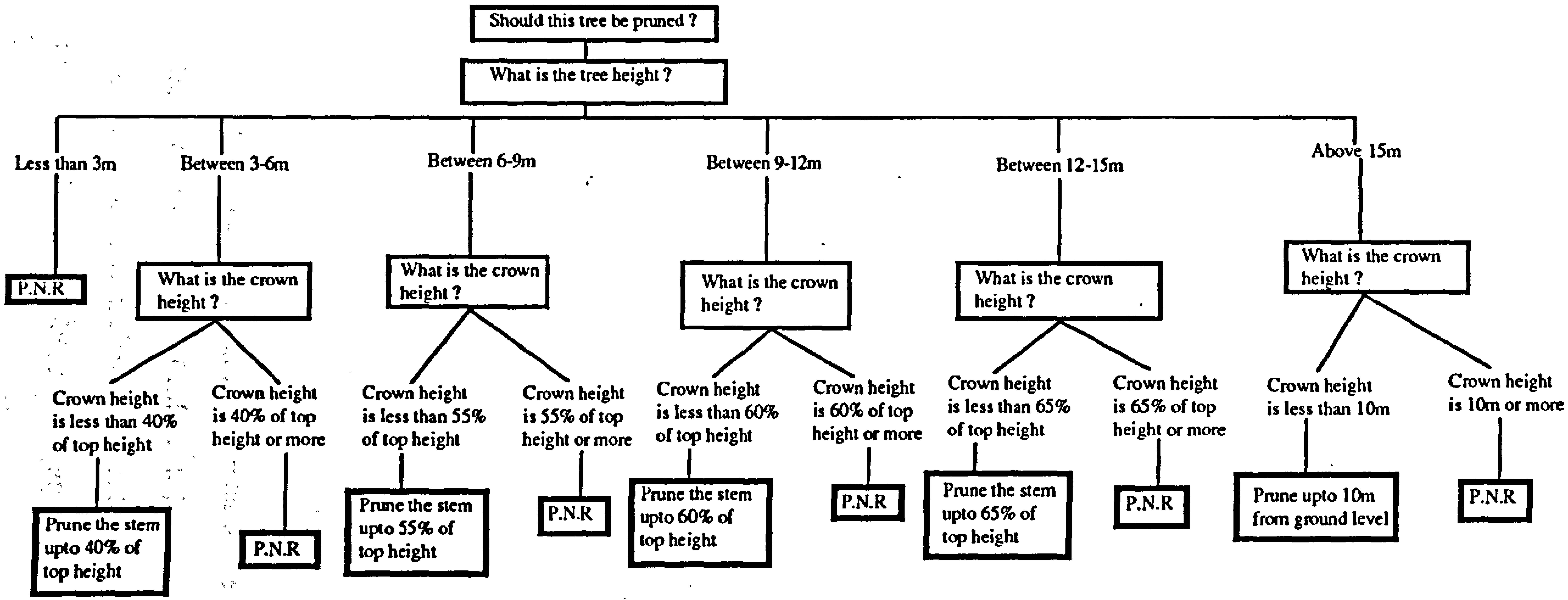

Figure 6.1 Pruning schedule developed based on the scientific knowledge to produce a 10m clear stem (after, Evans, 1982).

Key: P.N.R- Pruning not required

Crown height: height of the base of the live crown from the floor

iii. Selection of site and trees

10 homegardens with over 100 *gini-sapu* trees were selected in the Galagedara RSD. *Gini-sapu* was selected for the investigation since it is the main timber species in the area. Selection was based on the following criteria:

- Easy access to the homegarden since farmers have to visit the site for tree evaluation
- Willingness of owners to provide access to the site and allow examination of their timber trees.
- Homegardens with few understorey crops: the pruning of timber trees in this evaluation was purely to improve the quality of wood. If there had been an understorey, farmers might have confused the situation by including objectives of pruning to minimise the competition imposed upon understorey crops.
- Homegardens with a high density of *gini-sapu* trees. This was to enable the researcher and farmer to select trees within a reasonably small area, and so save time.

The site which satisfied all these criteria was located in Thahalpitiya, Galagedara RSD. Healthy, unbranched, single trees were selected in the homegarden and their DBH measured. The trees were categorised into diameter classes 0-10cm, 10-20cm, 20-30 and above 30-40cm and 10 trees from each diameter class were selected and numbered for the study.

iii. Evaluation of trees

a. Experts evaluation

Mr. Upali Dhanasekara, Curator of the Royal Botanical Garden, Peradeniya was selected as an expert in the field due to his long experience as an aboriculturist in addition to his formal training at Kew Gardens, London. He was asked to examine the 40 selected trees and give his opinion concerning their pruning requirements.

b. Farmers evaluation

75 farmers were selected, fifteen from each of the five neighbouring villages of Poholiyadda, Palanegama, Medagama, Udahenepola and Atambegoda. They were selected using the Farmer Registers of the Village Services Officers of these villages. From these fifty (ten from each village) were selected for the study based on the following criteria:

i. Farmers who believed pruning was a useful operation to improve the volume and quality of wood

ii. Willingness to participate in the study

iii. Male farmers, over 35 years old and involved in growing and managing *gini-sapu* as timber trees

Farmers were asked, one at a time whether each of the selected trees were due for pruning. The farmers, responses for each tree were tested separately using the chi-squared test in order to examine the degree of consistency with the expert's decisions on tree pruning. The null hypothesis was, therefore, decision making in the farming community is consistent with the expert when 80% or more of the farmers agree with the expert's decision

c. Evaluation by researcher using the decision tree

The same trees were also evaluated by the researcher with the assistance of the pruning schedule presented as a decision tree.

d. Analysis of data

The responses of the expert, the farmers and the researcher were compared using the following procedure to evaluate the usefulness of the decision tree in assisting farmers to make better decisions regarding pruning of timber trees:

Proportion (A)=	For how many trees was the expert's response consistent with the decision tree
Proportion (B)=	For how many trees was the expert's response consistent with the farmers' pruning decisions

If A>B, assuming the expert is right, then the decision tree is useful in assisting farmers to make better decisions about tree pruning.

6.3 RESULTS AND DISCUSSION

6.3.1 Scientific knowledge on branch pruning of timber species

No references to branch pruning of specific timber tree species were found in the scientific literature nor from interviews with forest officers, although there was a large body of literature on pruning timber species in general. A scientific knowledge base relating to branch pruning was developed from four key silvicultural texts (Cannell, 1983; Evans, 1982; Savill and Evans, 1986; Smith, 1986).

6.3.2 Existing scientific knowledge for filling gaps

The local knowledge relating to branch pruning covered the most important aspects of pruning timber trees. It appears that the community's knowledge on pruning timber trees is comprehensive and robust over most aspects of pruning. However, some specific gaps were identified which may constrain the pruning of timber trees in Kandyan homegardens.

With the gaps identified and the scientific knowledge collected, it was possible to put forward the following extension recommendations:

6.3.2.1 Branch pruning and tree growth

There was uncertainty among farmers about whether pruning reduces tree growth (i.e. a decrease in the number of branches causes a decrease in tree vigour). The main aim was to produce a marketable log of maximum timber quality. Two key informants (J.G. Piyadasa and H.G. Jamis) (Section 4.3.1.1) and also about 31% of the farmers encountered during the representative evaluation (Section 4.3.2.2) did not consider it prudent to prune timber trees while others considered pruning a desirable operation in the management of timber trees. It seems reasonable to conclude that this uncertainty may result in few trees being pruned and a low pruning frequency.

Decrease in productivity due to removal of basal branches may be lower than expected because of the following reasons:

- There can be increases in net photosynthesis by the remaining leaves after pruning, possibly owing to the receipt of a greater share of root originated metabolites (Cannell, 1983).
- The proportion of dry matter partitioned to different parts of the plant depends on the size of the bole cambial sink of those parts (Cannell, 1983). Therefore, in the absence of pruning, the bole will be small, branching will be encouraged and a relatively small proportion of the total dry matter increment will be used to produce bolewood. If, however, trees are allowed to grow tall, and branching is discouraged by pruning, a large proportion of the current dry matter increment will be used to produce bolewood.

6.3.2.2 Strength properties of wood

There is very little understanding in the community about the common defects and the strength of wood. Knowledge of such information could promote the production of clean timber.

6.3.2.3 Stem rot

The large branches of trees are pruned to control shading of the understorey, to stop them breaking and prevent damage to houses and understory crops during the fruiting season (due to the heavy weight) and during the rainy season (due to heavy weight and high winds) (Section 4.3.1.2). However, it became clear from the knowledge base that farmers do not seal the wounds to prevent fungal infestations after pruning of trees grown in KHGs. Farmers said that stem rots cause a reduction in timber volume and quality of many trees grown in KHGs, especially of jak (*Artocarpus heterophyllus*) which is the most valuable timber species grown in the homegardens.

6.3.2.4 Location of pruning cut

The ideal place to make the pruning cut is close to the collar of the branch because that provides the best chance for the wound to heal (Shigo, 1991). However, it is clear from the pruning regime described in Section 4.3.1.1 that farmers cut branches about 15-30 cm away from the node.

6.3.3 Research to create new knowledge

The gaps identified and the research needed to create new knowledge (where current scientific knowledge is inadequate) for extension advice are presented below.

6.3.3.1 Pruning method

Pruning is an expensive operation and skilled labour for climbing trees is difficult to obtain or afford. Most farmers cannot climb trees themselves, therefore, pruning is delayed or not practised. It would be useful to develop a tool for pruning branches in the upper canopy from the ground. The farmer himself can then undertake the pruning operation. Developing a mechanised tool such as a chain saw which could be then hired through the ASC and a tool for climbing trees safely may be useful options.

6.3.3.2 Stem canker

It is clear from the knowledge base that the community did not possess methods for controlling stem canker of *gini-sapu*. Some farmers assumed that there was some relationship between canker and pruning because cankers were commonly observed around the scars of pruned branches. This however needs further investigation in order to establish any causal mechanisms as well as to develop methods to control and identify practices to minimise stem canker.

6.3.4 New scientific knowledge

6.3.4.1 Growth of *gini-sapu* seedlings under different light environments

i. Seedling growth

As stated earlier (Section 6.2.2.1), when the seedling heights were analysed (as a three-factor 4 x 2 x 2 factorial analysis of variance), neither the main effects B and C (soil type and root barrier, respectively), nor the interactions, nor the co-variate (Red/Far red ratio) were found to be significant (P=0.05) in explaining the variation in seedling height

(Appendix 10). This indicates that the effect on seedling growth of different soil types at four different sites within the homegardens are similar (non significant). Likewise, the effect on seedling growth of underground competition at four different sites are similar (non significant). Further, statistical analysis indicates that the effect of light quality on height growth of *gini-sapu* seedlings was again, non significant.

The mean seedling heights at monthly intervals were analysed as a single factor experiment (where only Factor A: Light intensity, was considered). The results are presented in Table 6.3. Height was not recorded after the third month, for the seedlings planted in the fourth light level, as their survival rate fell below 25% for seven of the replicates out of 16 during the fourth month from field establishment. Results indicate that differences in the mean height of seedlings grown under different light intensities were significant at monthly intervals starting from the first month. The Least Significant Difference indicates that up to three months from planting, mean seedling heights can be categorised in to two groups. There was no significant difference between the effect of light intensity level one and two on seedling height (P=0.05), nor between light levels three and four, but heights of seedlings grown under light levels one and two are significantly higher than those grown under light levels three and four.

From the third month onwards, up to the ninth month, a constant pattern was observed. The mean heights of seedlings at each monthly interval fell into three discrete groups based on Least Significant Differences (LSD). This indicates that mean heights of seedlings grown under light level one are higher than those of two, while seedlings grown in light level two are higher than those of level three. This result shows that the growth rate of seedlings increases with increased light intensity in a range starting from very low levels (0-25%) up to the highest level, where full sunlight was available to the seedling.

ii. Seedling survival

Percentage survival figures show a similar trend to that of the seedling height data when analysed as a three-factor (4 x 2 x 2) factorial analysis of variance. The main

Table 6.3 Height of the *gini-sapu* seedlings (cm) at monthly intervals, grown under different light intensities in KHGs.

Treatment	1 MAFP		2 MAFP		3 MAFP		4 MAFP		5 MAFP		6 MAFP		7 MAFP		8 MAFP		9 MAFP	
	Mean	SE	Mean	SE	Mean	SE	Mean	SE	Mean	SE	Mean	SE	Mean	SE	Mean	SE	Mean	SE
Light level 1	11.95^{a}	0.61	17.31^{a}	0.81	24.20^{a}	1.14	36.39^{a}	1.65	41.88^{a}	2.18	46.95^{a}	2.80	53.04^{a}	3.48	66.71^{a}	3.24	83.90^{a}	2.99
Light level 2	12.46^{a}	0.65	15.15^{a}	1.06	21.68^{a}	1.07	28.04^{b}	1.45	31.35^{b}	1.42	33.60^{b}	1.35	35.88^{b}	1.39	41.59^{b}	1.72	51.27^{b}	2.63
Light level 3	9.60^{b}	0.31	11.06^{b}	0.39	12.70^{b}	0.35	14.40^{c}	0.43	15.53^{c}	0.51	16.50^{c}	0.55	17.48^{c}	0.59	20.06^{c}	0.92	22.80^{c}	1.29
Light level 4	9.95^{b}	0.18	11.28^{b}	0.26	13.17^{b}	0.46	-	-	-	-	-	-	-	-	-	-	-	-
LSD (P=0.05)	1.52	S	2.29	S	2.63	S	4.09	S	4.85	S	5.76	S	6.93	S	6.91	S	7.64	S

Key: MAFP-Months After Field Planting, SE- Standard Error of the mean, LSD- Least Significant Difference, P-Significance Level, S- Differences of the means are significan
In a column, differences between means identified by different letters are significant while differences between means identified by the same letters are not significant.

effects, B and C (soil type and root barrier, respectively), and their interactions, and also the co-variate (Red/Far Red ratio) were found to be non-significant (P=0.05) in explaining the variation of percentage survival in seedlings. This indicates that the effect on percentage survival of different soil types at four different sites within the homegardens are similar (non significant). Likewise, the effect on percentage survival of underground competition was also non significant. Further, statistical analysis indicates that the effect of light quality on percentage survival of *gini-sapu* seedlings was also non significant.

The mean percentage survival of *gini-sapu* seedlings at monthly intervals was, therefore, analysed as a single factor experiment (only considering Factor A: Light intensity) . The results are presented in Table 6.4. This shows that differences in mean percentage survival are not significant up to two months from field establishment, but were significant from the third month onwards.

The Least Significant Difference indicates that between the third and sixth months the means could be categorised into three groups with percentage survival under light level one and two in one group and the other two light levels into another two groups. Thus the effect of light levels one and two, on percentage survival was not significantly different, but they were different from the effect of light level three and four. Further, the mean percentage survival of seedlings grown under light levels one and two were higher than those grown under light levels three and four, and those grown under light level three are higher than those under light level four. The only exception was after the third month where the mean percentage survival under light level two can be categorised either with the mean of light level one or three. None of the seedlings under light level four survived beyond the sixth month.

From the seventh to the ninth months there was a constant trend. The mean percentage survival under light level one was significantly higher than that of two and the mean percentage survival of seedlings under light level two was significantly higher than that of three.

Table 6.4 Percentage survival of the *gini-sapu* seedlings at monthly intervals, grown under different light intensities in KHGs.

Treatment	1 MAFP		2 MAFP		3 MAFP		4 MAFP		5 MAFP		6 MAFP		7 MAFP		8 MAFP		9 MAFP	
	Mean	SE	Mean	SE	Mean	SE	Mean	SE	Mean	SE	Mean	SE	Mean	SE	Mean	SE	Mean	SE
Light level 1	100.00	0.00	100.00	0.00	100.00^{a}	0.00	96.2^{a}	2.00	95.00^{a}	2.30	93.75^{a}	2.48	93.75^{a}	2.48	91.25^{a}	2.73	87.50^{a}	3.39
Light level 2	100.00	0.00	98.8	1.20	95.00^{ab}	2.90	92.5^{a}	3.20	90.00^{a}	3.80	87.50a	4.25	83.75^{b}	4.89	76.25^{b}	5.58	72.50^{b}	5.41
Light level 3	100.00	0.00	97.5	1.70	88.80^{b}	3.40	77.50^{b}	5.40	75.00^{b}	5.10	70.00b	5.00	63.75^{c}	4.96	47.50^{c}	4.41	43.75^{c}	3.57
Light level 4	97.5	1.70	96.2	2.70	76.20^{c}	5.60	37.50^{c}	6.40	10.00^{c}	4.20	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
LSD (P=0.05)	-	NS	-	NS	8.45	S	10.88	S	9.44	S	8.29	S	8.73	S	9.00	S	8.65	S

Key: MAFP-Months After Field Planting, SE- Standard Error of the mean, LSD- Least Significant Difference, P-Significance Level, S- Differences of the means are significant
In a column, differences between means identified by different letters are significant while differences between means identified by the same letters are not significant.

The results indicate that *gini-sapu* seedlings establish and grow best under high light intensities, especially under full sun indicating pioneering ecological behaviour. Planting in dark corners to minimise pruning, would not, therefore, be successful.

6.3.5 Usefulness of scientific knowledge

6.3.5.1 Effectiveness of the decision tree for improving pruning

As stated earlier, forty *gini-sapu* trees were evaluated independently by an expert (i.e. experienced arboriculturist), by farmers, and also by the researcher using the pruning schedule represented as a decision tree. This was done in order to examine whether the decision tree, developed with scientific knowledge, was effective in assisting farmers to make better decisions about pruning timber trees. The results obtained were as follows:

i. Evaluation by expert

The summary of the expert's evaluation of the *gini-sapu* trees are presented in Table 6.5. He identified those trees due for pruning and the reasons underlying his decisions (i.e. to improve quality and yield of wood). He (Upali Dhanasekera) said that for trees where the length of stem was identified as low, pruning could be delayed.

Further, he recommended to pollard tree numbers 3.1, 3.2, 3.3, 3.5, 4.1, 4.6, 4.7, 4.8 and 4.9 because pollarding would stop height growth and induce diameter expansion since these trees had already produced the intended log size and sufficient crown volume as they had leading crowns (i.e. the central leader was still growing). Only trees from the large and very large diameter class either required no pruning or a low level of pruning (less than 1.5 m length of stem) were recommended for pollarding. Although, tree number 4.10 was in the very large diameter class and required no pruning, not recommended for pollarding as its crown found to be non leading.

Table 6.5 Expert's classification of *gini-sapu* trees for pruning.

Recommendation	Pruning not required		Pruning required	
Size class of trees (DBH)	Reasons for not pruning		Length of stem requires pruning	
	Crown height is sufficient	Low vigour/ suppressed tree	High (>1.5 m)	Low (<1.5m)
1. Small (0-10cm)	1.7	-	1.2,1.4,1.5, 1.6,1.10	1.1, 1.3, 1.8,1.9
2. Medium (10-20cm)	2.5, 2.9	-	2.1, 2.2, 2.6, 2.7, 2.8	2.3, 2.4, 2.10
3. Large (20-30cm)	3.1	3.4, 3.7	3.6, 3.8, 3.9, 3.10	3.2, 3.3, 3.5
4. Very large (30-40cm)	4.6, 4.7, 4.8, 4.10	-	4.2, 4.3, 4.4, 4.5	4.1, 4.9

Key: 1.1- Here, first digit refers to the size class and the second to the tree number

ii. Farmer's evaluation

A summary of farmers' decisions regarding pruning of the selected forty *gini-sapu* trees is presented in Table 6.6. The following are evident from these results:

- there was no significant difference between the overall response of farmers and the expert for 80% of the trees, although the number of farmers at variance with the 'expert decision' ranged from 0 to 22% for these 32 trees;
- for the remaining 20% of trees there was a significant disagreement between the overall response of farmers and the expert, with the percentage of farmers disagreeing with the 'expert decision' ranging from 36-74%.

Disagreement can be explained as follows:

i. A significant proportion of farmers (74%, 38%, 42%, 44% and 60%, respectively) said pruning of the trees numbered 2.3, 2.4, 3.2, 3.3 and 3.5 was not required. But the expert recommended a 'low' pruning of these trees.

ii. A significant proportion of farmers (42%) said that tree 2.9 required pruning but the expert recommended that this was not necessary as it had a sufficiently clean stem.

iii. A significant number of farmers (38% and 36%, respectively) said trees 3.4 and 3.7 required pruning, but the expert said that this was not suitable since they were suppressed trees.

Table 6.6 Farmers evaluation of *gini-sapu* trees for pruning.

Size class	Tree number	Farmers response: requires pruning	Agreement with expert: percentage agreed	Chi-square test (P=0.05)
1	1.1	90	90	NS
	1.2	88	88	NS
	1.3	94	94	NS
	1.4	86	86	NS
	1.5	90	90	NS
	1.6	92	92	NS
	1.7	08	92	NS
	1.8	94	94	NS
	1.9	96	96	NS
	1.10	90	90	NS
2	2.1	100	100	NS
	2.2	92	92	NS
	2.3	26	26	S
	2.4	62	62	S
	2.5	20	80	NS
	2.6	100	100	NS
	2.7	92	92	NS
	2.8	100	100	NS
	2.9	42	58	S
	2.10	100	100	NS
3	3.1	22	78	NS
	3.2	58	58	S
	3.3	56	56	S
	3.4	38	62	S
	3.5	40	40	S
	3.6	96	96	NS
	3.7	36	64	S
	3.8	94	94	NS
	3.9	100	100	NS
	3.10	100	100	NS
4	4.1	88	88	NS
	4.2	82	82	NS
	4.3	100	100	NS
	4.4	90	90	NS
	4.5	84	84	NS
	4.6	14	86	NS
	4.7	04	96	NS
	4.8	08	92	NS
	4.9	14	86	NS
	4.10	0	100	NS

Key: P=significance level, S-Significant, NS-Non significant

The percentage of farmers and their extent of disagreement with 'expert decision' are presented in the Table 6.7. These results indicate that:

- the extent of disagreement (with the expert) were found to be significant with 12% farmers, although the number of trees at variance with the 'expert decision' ranged from 20-22% for these six farmers.
- the extent of disagreement was non significant among the other farmers, and the number of trees disagreeing with the experts' decision ranged from 10 to 17% for these 44 farmers.

Table 6.7 Extent of disagreement with the 'expert decision' and farmer percentage.

Extent of disagreement: percentage of trees	Percentage of farmers
10	8
12	24
15	22
17	34
20[1]	4
22[1]	8

Key: [1]Chi-squared test indicates that disagreement is significant.

iii. Researchers evaluation using the decision tree

The results of the researchers evaluation of the *gini-sapu* trees carried out with the help of the decision tree are presented in Table 6. 8. The results indicate that the decisions made with the pruning schedule (i.e. using scientific knowledge) agreed with

Table 6.8 Top and crown height of trees and their pruning requirements based on the pruning schedule developed with scientific knowledge.

Size class	Tree number	Top height (m)	Crown height (m)	Intended crown height after pruning (m)	Approximate length of stem requiring pruning (m)	Length of stem requiring pruning	Agreement with expert
1	1.1	21.12	9.92	10.00	0.08	Low	Yes
	1.2	21.09	7.76	10.00	2.24	High	Yes
	1.3	3.48	1.40	1.44	0.24	Low	Yes
	1.4	16.73	5.51	10.00	4.49	High	Yes
	1.5	15.14	5.72	10.00	4.28	High	Yes
	1.6	17.78	5.08	10.00	4.92	High	Yes
	1.7	21.16	11.36	10.00	0	-	Yes
	1.8	5.08	1.68	2.11	0.43	Low	Yes
	1.9	7.48	2.06	3.10	1.04	Low	Yes
	1.10	16.78	5.47	10.00	4.53	High	Yes
2	2.1	14.90	2.02	9.83	7.81	High	Yes
	2.2	20.75	6.15	10.00	3.85	High	Yes
	2.3	23.68	10.35	10.00	0	-	No
	2.4	7.04	2.69	2.92	0.23	Low	Yes
	2.5	26.74	13.84	10.00	0	-	Yes
	2.6	13.16	2.09	8.69	6.60	High	Yes
	2.7	17.66	5.63	10.00	4.37	High	Yes
	2.8	6.17	1.25	3.39	2.14	High	Yes
	2.9	17.55	9.08	10.00	0.92	Low	No
	2.10	5.83	1.65	2.42	0.77	Low	Yes
3	3.1	17.21	11.21	10.00	0	-	Yes
	3.2	24.01	12.08	10.00	0	-	No
	3.3	23.25	8.70	10.00	1.30	Low	Yes
	3.4	17.67	7.50	10.00	2.50	High	No
	3.5	24.42	11.54	10.00	0	-	No
	3.6	24.31	6.36	10.00	3.64	High	Yes
	3.7	16.53	4.43	10.00	5.57	High	No
	3.8	12.38	2.25	8.17	5.92	High	Yes
	3.9	11.24	2.66	7.03	4.37	High	Yes
	3.10	13.10	4.10	8.65	4.55	High	Yes
4	4.1	13.98	7.82	9.23	1.41	Low	Yes
	4.2	16.11	4.71	10.00	5.29	High	Yes
	4.3	11.34	2.65	7.09	4.44	High	Yes
	4.4	13.94	2.95	9.20	6.25	High	Yes
	4.5	24.77	7.41	10.00	2.59	High	Yes
	4.6	29.65	13.73	10.00	0	-	Yes
	4.7	26.75	13.33	10.00	0	-	Yes
	4.8	27.60	12.72	10.00	0	-	Yes
	4.9	25.90	9.10	10.00	0.90	Low	Yes
	4.10	28.76	16.08	10.00	0	-	Yes

Key: Low- <1.5m, High- >1.5m

the expert's recommendation in 88% (35 out of 40) of the trees evaluated. Decisions were different only with five trees. The disagreement can be explained in the following ways:

i. Three trees (2.3, 3.2 and 3.5) were considered inappropriate for pruning by the schedule while the expert put them in the 'low' category.

ii. The pruning schedule considered that pruning was appropriate for two trees (3.4 and 3.7), but the expert said that they were suppressed and hence recommended pruning was inappropriate.

iv. Conclusions

The results indicate that the extent of disagreement with the 'expert decision' of some farmers (12%) was significant. This would suggest that pruning expertise varies among farmers and that there might be utility in extending information on pruning to less knowledgeable farmers. However, the cost effectiveness of this would then need to be considered.

More significantly the arboriculturist identified suppressed trees as requiring different treatment and emphasised the value of pollarding which was in neither the farmers' response nor the scientifically-based decision tree. This suggests that the arboriculturist's knowledge might be able to improve farmer practice by suggesting two new items of knowledge that appear to be useful, which, the knowledge abstracted from scientific literature did not. This may to some extent reflect the difference between scientifically-based understanding tempered by human judgement by an experienced practitioner and a fixed documented account applied rigidly. There are two elements to this contrast:

- the fact that the arboriculturist was able to take all of the circumstances of each tree into account in deciding whether or not to prune, and could consider whatever information was evident when considering each tree; the scientific decision tree could only consider a predefined set of variables.
- a lot of scientific literature is geared towards documenting an understanding of the principles that might underly decisions, rather than towards their application to

specific circumstances and there may, therefore, be genuine difficulties in converting from one to another.

6.4 CONCLUDING REMARKS

The experiment conducted to evaluate the growth of *gini-sapu* seedlings under different light environments, although addressing key constraints in the garden did not yield new knowledge that was useful in improving practice. It was discovered, that *gini-sapu* was light demanding and required high light levels for successful establishment and growth, ruling out planting in shaded situations as a method of inducing self-pruning. More complicated methods could be investigated such as the use of growth tubes or attempts to provide more sophisticated shading of the *gini-sapu* , for example by planting in the proximity of less tall manipulable trees such as *Gliricidia sepium* that can be readily pruned. The *Gliricidia sepium* could be pruned when *gini-sapu* was planted in order to provide high light levels for establishment and then allowed to shade the *gini-sapu* strategically up to a certain stem height since the *Gliricidia sepium* is easier to prune than the *gini-sapu*. However, further research would be required to confirm this and develop sensible recommendations on tree spacing and pruning strategies. Furthermore, it seems doubtful that such a sophisticated strategy would be adopted by farmers who have in general terms, a laissez-faire attitude to garden management.

Although the present example represents a single case, which makes general conclusions inappropriate, it does point to the potential for expending effort on research that does not result in improvements for farmers even if the research addresses constraints identified on the basis of analysing what farmers know and what constrains the system. However, there will always be an element of risk in research since if the answers were known at the outset then the research would not be required.

The experiment undertaken to examine the usefulness of extending new knowledge to fill gaps in the farmers' knowledge system indicated that: firstly, the experimental research did not yield practically useful knowledge in respect of garden management; secondly, the decision tree based on scientific knowledge of tree pruning did not represent a significant improvement on farmers' decisions about tree pruning when compared with an arboricultural expert; thirdly, the only new knowledge that was identified and appeared to have a clear practical utility, was the arboriculturist's knowledge relating to pruning of suppressed trees and the value of pollarding.

It may be that searching for simple practical interventions, such as was done here is unlikely to yield useful results since it might be expected that farmers would have devised these themselves, if they were indeed improvements. In this respect, it is useful to note that, Thapa *et al.*, (1995), working with farmers in Nepal, identified researchable problems in two sets of circumstances.

- Where farmers' practice violated their ecological rationality because trade-offs were made. For example, large leaved trees, known to have a propensity to cause soil erosion and reduce crop yield, were planted on crop terrace risers because of the high value fodder they provided at a key point in the season.
- Where farmers knew that there were important interactions in the system but did not know much about them because they were difficult to observe (for example, tree root competition with crops and effects of tree pruning (fodder lopping) on tree root distribution and competition.

Researchable problems in the first class are likely to require research into alternative technologies or genotypes, for example an alternative means of supplying the high value fodder without having a large leaved tree on the crop terrace riser, by breeding (such as breeding a small-leaved variety of the tree with similar fodder characteristics), or finding an alternative species. Research to address the second class of problem would, in contrast, be directed at employing the research capacity of institutions to enhance the knowledge base that farmers have and can use in making decisions. Interestingly, in the Nepalese case, the requirement was for fairly fundamental rather than applied research; to generate a general understanding about how tree roots could be manipulated by pruning, to complement the sophisticated understanding that farmers already had about how tree crown attributes affected atmospheric interactions.

In the present case in Sri Lanka, the farmers articulated far less detailed understanding of the ecological processes that could readily be observed than in the Nepalese case, and while it appears that pruning strategies could be improved, it may be that the constraints are as much to do with lack of motivation as lack of knowledge. A further complication in the present example was that the domain was deliberately restricted to consider pruning in relation to timber quality but in many gardens timber trees are grown in association with understorey crops so that the decision frame involves further trade-offs. In such complicated situations each decision requires the balancing of a number of competing factors, as in the Nepalese case cited earlier, it may be that items of knowledge that farmers can add to their knowledge base and use in their decision making are more appropriate interventions than recommendations about what should be done in particular circumstances. In this respect, the only new knowledge that was identified in the present study which appeared to have a clear practical utility, was the arboriculturist's knowledge relating to pruning of suppressed trees and the value of pollarding. These are knowledge items that might enhance the farmers' knowledge base and ultimately improve timber production from gardens. Further research involving longer-term monitoring of farmer behaviour would be required, however, to explore the effectiveness of the introduction of such knowledge items, the major concern at this stage being that the marginal benefits may possibly outweigh the effort involved in developing and implementing such introductions.

CHAPTER 7

SUMMARY OF CONCLUSIONS AND RECOMMENDATIONS FOR FURTHER RESEARCH

In this concluding chapter impressions gained from the present study and their implications for research and extension methods used for improving complex agroforestry practices using local knowledge are discussed. Areas which require further investigation are also indicated.

7.1 KNOWLEDGE BASED-SYSTEMS AND FSR/E METHODS

The application of farming systems research and extension methods facilitated identification of farming practices and problems, and identification of interventions to solve those problems (Chapter 2). Most of the interventions identified required implementation at an institutional level mainly by government sector institutions. It was revealed that this may pose a particular problem in implementing those interventions because of the structural problems in interdisciplinary collaboration and lack of resources for funding the institutions and agencies involved in agricultural research and extension in Sri Lanka.

However, the analysis of information from the diagnostic survey facilitated identification of motives behind the actions of the farming community thereby generating an understanding of interrelationships amongst socioeconomic forces and ecological knowledge. This enabled identification of areas in the land use system which were crucially important and had a high potential for improvement. Such an analysis was used to select a subject domain for collection of indigenous ecological knowledge thus acting as the specification stage in the application of a knowledge-based systems approach (Walker *et al.*, 1995a). Application of a knowledge-based systems approach, enabled identification of highly specific ecological knowledge which was used by farmers to manipulate biophysical processes in the management of ecological interactions in homegardens (Chapter 4). Analysis of this ecological knowledge led to identification of gaps in the farmers knowledge system, and hence external knowledge to fill those gaps or when such knowledge was not available, research to generate what was required (Chapter 6). The research and extension identified were highly focused due to the detailed nature of knowledge collected during the knowledge elicitation phase.

This shows that the two methodologies in the present research performed complementary roles with relation to agroforestry research and extension. Firstly they operate at completely different scales. The knowledge-based systems approach requires a tightly defined domain (Walker *et al.*, 1995a) and then seeks detailed knowledge about it, whereas conventional diagnostic procedures focus on problems and constraints at the system level. It is, therefore, immediately attractive to suggest that they are complementary.

The classification of land use systems using FSR/E methods did not, however, result in an effective grouping of Kandyan homegardens, in as much as there was no less variation amongst gardens within a land use system than between systems. This is not perhaps surprising given the complexity of garden structure and the supplementary role of gardens. This may reflect a high degree of individuality in people's attitude to and management of trees despite similar gross socio-economic circumstances as has been noted elsewhere (Brokensha and Riley, 1980; Den Biggelaar, 1995). In such circumstances the conventional hierarchical progression of a diagnostic process, starting with land use systems and then focussing on subsystems and practices may not, in fact, be appropriate for more complex practices with woody components. This may be particularly pronounced with multilayered tree gardens operated on a laissez-faire management basis as in Kandy. It is noteworthy in this regard that there appears to be far less sophisticated ecological knowledge amongst farmers operating the diverse forest gardens in Sri Lanka than amongst resource-poor farmers reliant on the integration of fodder trees on farmland for their survival in the mid-hills of Nepal (Thapa *et al.*, 1995). This suggests that the power of working up from asking simple questions about the knowledge system, which it has been suggested may be more effective than asking farmers about their problems (Thapa *et al.*, 1995) may be very site specific depending upon the sophistication of the knowledge held. An undoubted problem with diagnostic procedures in FSR/E is that the diagnosis has to be rapidly focussed towards particular aspects of the system where solutions may be found (Perrin *et al.*, 1976). The fact that different procedures have been developed for different commodity or subject foci such as maize (Byerlee and Collinson, 1980), agroforestry (Raintree, 1990) and most recently soil fertility (Swift, 1995) underlines the fact that although apparently starting with the farmer and defining the research agenda on the basis of farmer and system requirements, most diagnostic procedures are actually biased towards the type of solution that the organisation operating the diagnosis is seeking to develop. In many respects such deficiencies are being overcome in practise by the increasing prominence of participatory approaches, in which the agenda is set by the farming community rather than the research and development sector (Cornwall *et al.*, 1994). However, as with FSR/E methods more generally, the rhetoric and the actual performance of participatory approaches is variable and depends heavily on the people and institutional arrangements involved (Biggs, 1995; Chambers, 1995), and while appropriate for driving practical development at a local level when done well, may not be effective for informing more strategic research planning. In this respect the knowledge-based systems approach straddles conventional FSR/E and participatory approaches in that it forces a far more detailed interaction with the farming community but, in providing a rigorous framework within which this interaction takes place, both ensures a certain evaluable level of performance but with the corollary that the control of the interaction is driven and maintained by researchers rather than the farming community. There is no particular reason, however, for these methods to be in conflict, provided that clear and separate roles are defined for them. Thus it may be sensible to drive local development initiatives via participatory approaches at the same time as developing an explicit record of indigenous knowledge for informing research planning in support of this.

Scaling-up from the farm system is an important feature of current developments in diagnostic procedures in agroforestry, for example within the Characterisation and Impact Programme at ICRAF (Izaac, 1995) where geographic information system (GIS) techniques are being harnessed to achieve integration at landscape and regional scales. The present research, suggests that traversing scales below the farm system level may also be important. One way forward with this may be to incorporate more participatory approaches to grouping agroforestry units at the practice rather than the system level. Den Biggelaar (1995) adopted an innovative approach to selecting key informants for knowledge elicitation by adapting the wealth ranking game (Grandin, 1988) to obtain rankings of the most knowledgeable farmers in the community from an emic perspective. Investigation of the extent to which farmers in Kandy could group gardens, and the criteria they used to do so, would be a sensible starting point for research into the effectiveness of using indigenous classification of agroforestry practices as an alternative to researcher-driven systems analysis.

7.2 OTHER UTILITIES OF A KNOWLEDGE-BASED SYSTEMS APPROACH

(a) Source of ecological knowledge for scientists

In the present research, application of a knowledge-based systems approach yielded a large body of ecological knowledge relevant to improvement of the volume and quality of wood production and the management of tree-crop interactions in Kandyan homegardens (Chapter 4). Analysis of this knowledge indicated that some of the knowledge accumulated from the local community was new to scientists. Hence, this knowledge could be used by scientists to target their research more effectively in improving agroforestry elsewhere as well as facilitating communication amongst development professionals and farmers in the area from which the knowledge was acquired. Since development of complex agroforestry practices is currently limited by the inadequacy of understanding of ecological interactions involving different plant species (Anderson and Sinclair, 1993) and such knowledge requires expensive and sophisticated experimentation to obtain scientifically (Anderson *et al.*, 1993) this resource should be taken seriously as a complement (Richards, 1994) to scientific and professional knowledge. The role of local knowledge may be both as a source of useful information *per se* and a stimulus to lines of scientific enquiry.

(b) Source of ecological knowledge for farmers

It was found during the evaluation of the representativeness of knowledge that the distribution of ecological knowledge across the farming community although remarkably consistent in overall terms was variable with respect to species-specific information. Hence, an encyclopaedic knowledge base combining the knowledge of the whole community may be useful for extending some knowledge back to the same community. There is also scope to combine knowledge from other sources such as published scientific reports, knowledge of development professionals or scientists to fill the gaps identified in the knowledge base (discussed below in Section 7.3). Developing more complete and comprehensive knowledge bases in this way and making them available to the farming community would appear to be more effective than using knowledge from any one of these types of sources in developing recommendations.

7.3 INTRODUCING EXTERNAL KNOWLEDGE

The experience gained from the attempts to develop and introduce external knowledge to augment the farmers knowledge base indicated that simple recommendations about actions (such as pruning) related to a restricted domain (such as to improve timber value) may not be effective in making a significant impact on farming practices in the area, given the extreme complexity of the agroforestry practice involved. Two concepts were, however, identified that were of potential use to farmers; the identification of suppressed trees as a class of trees to be treated differently with respect to pruning decisions and the techniques of pollarding as opposed to basal or selective branch pruning. The underlying suggestion here is that augmenting the knowledge base which farmers use to make decisions may be more effective than extending recommendations about specific management actions. However, the case study was very tightly focussed on a specific aspect of garden management making it difficult to fully evaluate the scope for knowledge introduction. Thus, while illustrating the possibility in principle of finding knowledge that if introduced may impact on practice, only marginal benefits appeared possible in relation to the two items identifed. Further research would be required both to explore appropriate means of affecting introduction of new knowledge and considering a broader knowledge domain encompassing the integrated agroecosystem level recognised by farmers before conclusions about the practical efficiency of such an approach can be drawn.

7.4 RESEARCHER-LED EXPERIMENTS VALIDATE LOCAL KNOWLEDGE

The validation of farmers knowledge that was not in the scientific domain underlying local methods of seed treatment and bark incision for enhancing growth of *gini-sapu* through researcher-led experimentation identified specific situations where the scientist and farmer may benefit from re-evaluating their knowledge systems in light of the other's (Chapter 5). This concurs with recent developments elsewhere both in recognising the importance of knowledge generated through farmer experimentation (Richards, 1994) and opportunities for adding to what farmers know by introducing knowledge and experience from elsewhere (Bentley, 1994). Millar (1994) for example, illustrates how the results of farmer experiments with cereals and tubers were incorporated into development projects in the NGO sector in Ghana through dialogue between farmers and extension workers. Although, validation of local knowledge may not be necessary from the farmers perspective, such experiments involving farmers, further provide evidence for professional foresters to believe in farmers as 'experts', and such impressions could lead to the improvement of communication between farmers and professional foresters and an increase in mutual respect for each other.

Collaborative experimentation in this way may also harness rather different expertise from the farmer and researcher thereby leading to the possibility of generalising place-specific knowledge developed by farmers (Richards, 1994) while grounding scientific research in an adaptive context. The key difference to on-farm research that the knowledge-based systems approach engenders as opposed to conventional FSR/E is that it addresses more fundamental questions. Where farmers already possess a sophisticated understanding of the ecological processes underlying production, and are managing a complex practice, generating new knowledge at a fundamental level collaboratively with farmers, may be more appropriate than attempting to identify adaptive research to solve problems. Once again, the approach straddles FSR/E and more participatory approaches in entering into collaborative experimentation with farmers with an agenda set by rigorous analysis of an explicit record of knowledge.

7.5 CONCLUDING REMARKS

At the outset of this research a comparison of FSR/E and knowledge-based systems methods as alternatives was envisaged. It soon became apparent, however, in considering their application that the methodologies operated at different scales and might, therefore, be complementary, with a problem diagnosis at the system level serving as the specification stage of a knowledge acquisition strategy. In practice, however, the complexity of both the socio-economic and cultural motivations and the biology of the multilayered tree gardens in Kandy, as a supplementary activity in the farming system, were not amenable to classification at a system level. Thus, while it was demonstrated in principle that a knowledge-based systems approach could identify strategies for incremental improvement of a complex agroforestry practices, the focus derived from the initial problem diagnosis was too restrictive for this to be evaluated at the garden ecosystem level recognised by the farmer. During the life of the present research project the rise in the prominence of participatory approaches to rural development in agriculture and forestry has been a major development (Pretty and Chambers, 1994). In Sri Lanka, while the NGO sector has embraced this development, the far larger government machine has not done so effectively despite high profile projects that employ participatory language without transferring control over decisions and resources (Carter *et al.*, 1994). In this respect the knowledge-based systems methods investigated here sit somewhere between the conventional FSR/E approach driven by the research and development profession and participatory approaches ideally driven by local initiative. By providing a rigorous framework for knowledge acquisition, variability of performance associated with the application of informal FSR/E and participatory approaches is certainly evaluable and likely reduced and the explicit record of local knowledge produced is a robust tool that can inform more strategic research planning. Clearly, while forcing detailed interaction amongst researchers and farmers, the approach seeks to make explicit farmers knowledge to inform a research process more generally rather than this remaining implicit but utilised in a process of development controlled by farmers. A clear opportunity worth further investigation is to explore the role of knowledge-based systems as a bridge between participatory development and fundamental research stimulated by deficiencies in farmers' and scientific knowledge and often executed collaboratively with farmers. Such an approach may harness parts of the government research and development machine in Sri Lanka that are unlikely, for reasons of institutional inertia, to embrace participatory approaches. It may thus target institutional research at fundamental issues constraining farmer decisions rather than at solving immediate adaptive problems which may be more appropriately addressed by farmers' existing research strategies.

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Appendix 1 Data recording form used for the farm level diagnostic survey (adapted from, ICRAF, 1983b; ICRAF, 1987a).

Date:
Village:
Farmers' name:

1. Household composition and labour resources

Category	Total	Farm labour		Off-farm labour	
		Full time	Part time	Full time	Part time
Adult males					
Adult females					
Children					

Key: 1unit=1 full-time unit= 2 part-time labour units

Does the household ever hire labour? For what crops?

2. Land use history

3. Farm resources

i. Land
Lowland rice: KHG: Other:
ii. Livestock
Cattle: Buffalo: Chicken:
iii. Water resources
Drinking water people and livestock: Lowland rice:

4. Food subsystem (crops)

Components (KHG, lowland rice and food items purchased using cash income)
A. Lowland rice
Extent (ha):
Aththama: *Ande:*
Major season: Minor season:
Water supply in the minor season and its implications on crop yield:
Total production: Household consumption: Surplus:

i. Fertilizer use
Inorganic fertilizer:
Dosage: Timing:
Organic fertilizer (green manure, straw):
Quantity: Timing:
Supply problems and causal factors
ii. Rice seed for planting:
Source: Origin:
iii. Land preparation
Labour sources:
Family: *Ande:*
Buffaloes:
Supply problems and causal factors
iv. Transplanting
Labour sources:
Family: *Ande:* Hired:
Supply problems and causal factors

v. Weeding
Labour sources:
Family: *Ande:* Hired:
Supply problems and causal factors
vi. Harvesting
Labour sources:
Family: *Ande:* Hired:
Supply problems and causal factors
vii. Other problems e.g. Insect pest or wild boar damages

Sustainability issues:

B. Homegarden
i. Fruits:
Supply problems and causal factors
ii. Tuber crops:
Supply problems and causal factors
iii. Vegetables:
Supply problems and causal factors
C. Items purchased using cash income
Supply problems and causal factors

Sustainability issues:

5. Food subsystem (animals)

Components (KHG and food items purchased using cash income)
A. Dairy cattle production
Supply problems and causal factors
B. Poultry production
Supply problems and causal factors

Sustainability issues

6. Cash subsystem

Components (sale of produce from KHG and lowland rice plot and off-farm jobs)
A. Income
i. Cash crops:
Supply problems and causal factors
ii. Fruit crops:
Supply problems and causal factors
iii. Timber:
Supply problems and causal factors
iv. Off-farm:
Supply problems and causal factors

B. Expenditure
i. Inputs for rice:
Supply problems and causal factors
ii. Food:
Supply problems and causal factors
iii. Other (health, social expenditure, travelling, cloth, education for children etc.)
Supply problems and causal factors

Sustainability issues:

7. Energy subsystem

Components (lighting, cooking and drying harvests)
A. Lighting: Kerosene oil: Electricity:
i. Supply problems and causal factors
B. Cooking: Fuelwood: Electricity: Kerosene oil:
i. Supply problems and causal factors
C. Drying harvest
i. Supply problems and causal factors

Sustainability issues:

8. Shelter subsystem

Components (housing for people and animals, shade trees and live fences)
A. Housing for people
Supply problems and causal factors
B. Shade trees
Supply problems and causal factors
C. Live fence
Supply problems and causal factors

Sustainability issues:

Appendix 2 List of plant species described in the thesis (Source: Bandaranayake *et al.*, 1974; Mabberley, 1987).

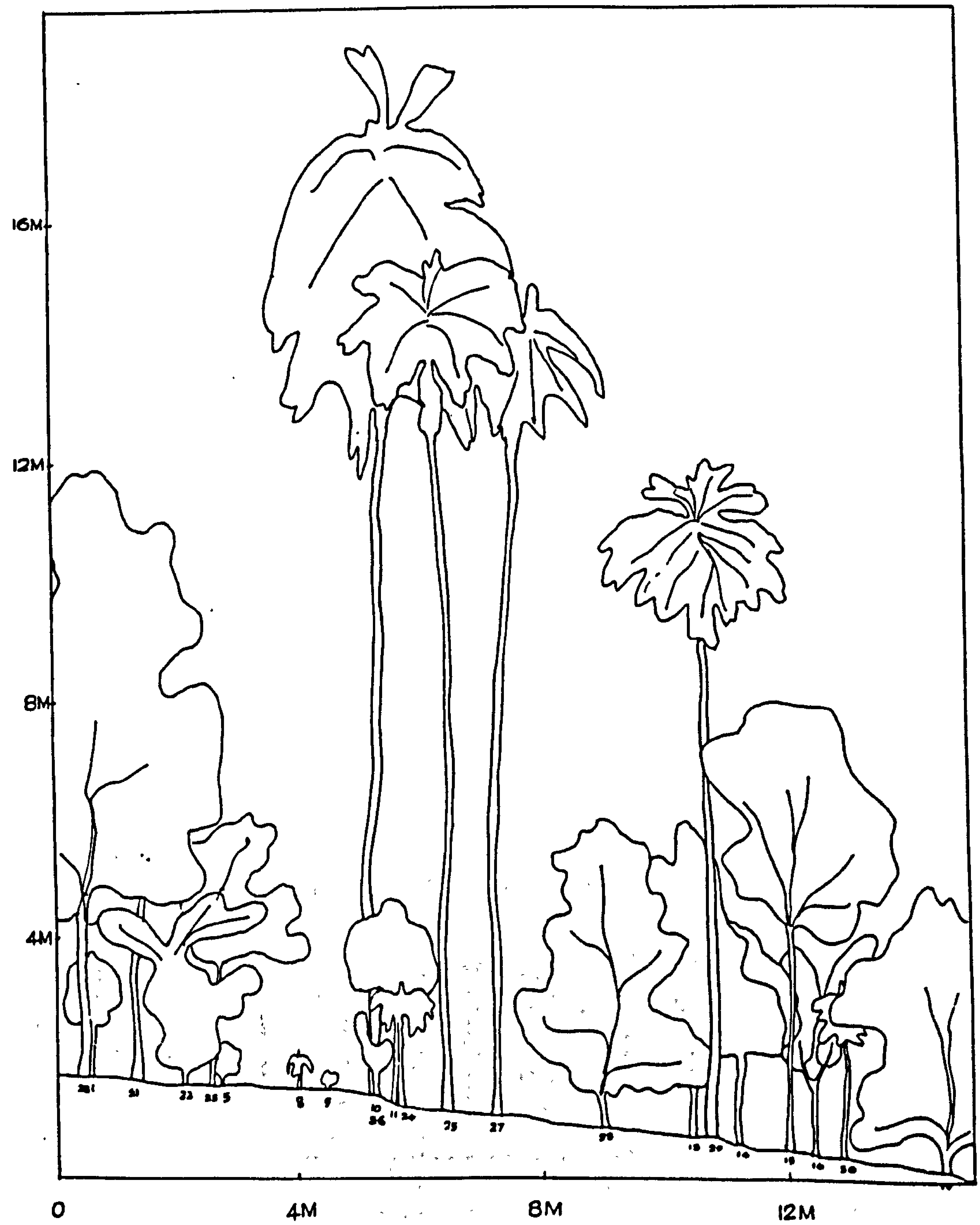
Common[1] name	Botanical name
Albizia	*Albizia falcataria* (L.) Fosb.
Anguna	*Dregea volubilis*(L.f.) Hook. f.
Anoda	*Abutilon asiaticum* (L.) G. Don
Arecanut / *puwak*	*Areca catechu* L.
Arrow root	*Maranta arundinacea* L.
Artichoke	*Helianthus tuberosus* L.
Avocado / *ali-pera*	*Persea americana* Miller
Bakamunu gammiris	*Piper sylvestre* Lam.
Banana / *kesel*	*Musa balbisiana* Colla
Beli	*Aegle marmelos* (L.) Corr. Serr.
Bread fruit / *del*	*Artocarpus altilis* (Z) Fosb.
Budalia	*Ficus asperrima* Roxb.
Cannas	*Canna* spp.
Cardamum / *enasal*	*Elettaria cardamomum* (L.) Matan
Cashew / *cadju*	*Anacardium occidentale* L.
Cassava / *maiyokka*	*Manihot esculenta* Crantz
Chilli / *miris*	*Capsicum annuum* L.
Clove / *karabu*	*Syzygium aromaticum* (L.) Merr. & Perry
Cocoa	*Theobroma cacao* L.
Coconut / *pol*	*Cocos nucifera* L.
Coffee / *kope*	*Coffea canephora* Pierre ex Frohner and *Coffea arabica* L.
Dothulu	*Laxococcus rupicola* (Thw.) Wendl. & Drude ex Hook. f.
Durian	*Durio zibethinus* Murray
Dadaps / *erabadu*	*Erythrina variegata* L.
Finger millet / *kurakkan*	*Eleusine coracana* (L.) Gaertner
Ginger / *iguru*	*Zingiber officinale* Roscoe
Gini-sapu	*Michelia champaca* L.
Gliricidia /*wetahira* / *ginisiriya*	*Gliricidia sepium* (Jacq.) Walp.
Gotukola	*Centella asiatica* (L.) Urban
Halmilla	*Berrya cordifolia* (Willd.) Burret
Hawari-nuga	*Alstonia macrophylla* Wall. ex G. Don
Hulan-kiriya	*Stachyphrynium zeylanicum* (Benth.) K. Schum.

Jak / *kos*	*Artocarpus heterophyllus* Lam.
Jambu	*Syzygium jambos* (L.) Alston
Kahata	*Careya arborea* Roxb.
Kanu	*Cassipourea ceylanica* (Gardn.) Alston
Karapincha	*Murraya koenigii* (L.) Sprengel
Kathuru-murunga	*Sesbania grandiflora* (L.) Poiret
Katu-anoda	*Annona muricata* L.
Kekuna	*Canarium zeylanicum* (Retz.) Bl.
Kenda	*Macaranga peltata* (Roxb.) Muell. Arg.
Ketakela	*Bridelia retusa* (L.) Spreng.
Kiriala	*Colocasia esculenta* (L.) Schott
Kirivel	*Ichnocarpus frutescens* (L.) Ait. f.
Kitul	*Caryota urens* L.
Kohila	*Lasia spinosa* (L.) Thwaites
Kolon	*Adina cordifolia* (Roxb.) Brandis
Koppa-kola	*Panax fruticosum*
Kotta	*Ceiba pentandra* (L.) Gaertner
Kududavula	*Neolitsea cassia* (L.) Kosterman
Lemon grass / *sera*	*Cymbopogon citratus* (Nees) Stapf
Ipil-ipil	*Leucaena leucocephala*
Lunu-midella	*Melia dubia* Cav.
Mahogany	*Swietenia macrophylla* King
Mango / *amba*	*Mangifera indica* L.
Milla	*Vitex altissima* L.f.
Mugunuwanna	*Alternanthera triandra*
Mustard / *aba*	*Brassica nigra* (L.) Koch
Nithulla	*Streblus asper* (Retz.) Lour.
Nolabe / molamba	*Strombosia ceylanica* Gardn.
Nutmeg / *sadikka*	*Myristica fragrans* Houtt.
Onion / *lunu*	*Allium cepa* L.
Papaw / *papol*	*Carica papaya* L.
Pavetta	*Pavetta indica* L.
Pepper / *gammiris*	*Piper nigrum* L.
Pineapple / *an-nasi*	*Ananas comosus* (L.) Merr.
Pohora-wel	*Peuraria phaseoloides*
Pohora-wel	*Centrocema pubescens*

Pota	*Pothos scandens* L.
Rambutan	*Nephelium lappaceum* L.
Rice / *wee*	*Oryza sativa* L.
Rubber	*Hevea brasiliensis* (A. Juss.) Muell.
Spinach / *nivithi*	*Basella alba* L.
Sweet potato / *batala*	*Ipomoea batatas* (L.) Lam
Tamarind / *siyambala*	*Tamarindus indica* L.
Tampala	*Amaranthus oleraceus* L.
Tea / *tee*	*Camellia sinensis* (L.) Kuntze
Teak / *tekka*	*Tectona grandis* L.f.
Thelambu	*Sterculia foetida* L.
Tobacco / *dum-kola*	*Nicotiana tabacum* L.
Turmeric / *kaha*	*Curcuma longa* L.
Uguressa	*Flacourtia inermis* Roxb.
Waldel	*Artocarpus nobilis* Thw.
Wana-sapu	*Cananga odorata* (Lam.) Hook.f & Thomson
Wewel	*Calamus rotang* L.
Yam / *wel-ala*	*Dioscorea* spp.

Key: [1]Local, English or generic name

Appendix 3 Vertical structure of vegetation in forestgarden areas in 5 m x 15 m plots from KHGs of LUS-1 (Species names are given in Appendix 2).

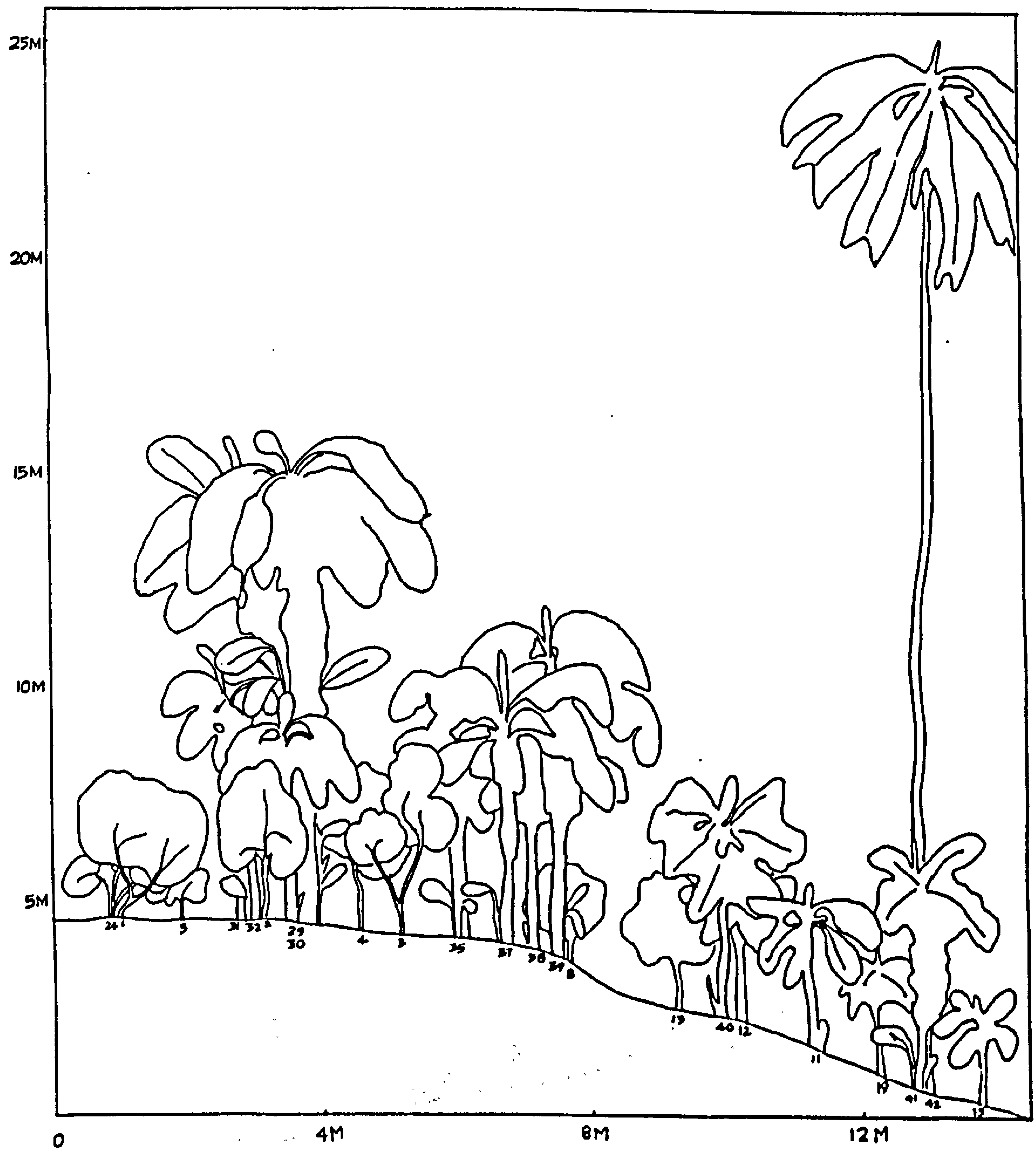


(a) Profile 1

Key: 1, 14, 15 and 21-Mahogany, 5-*Ketakela*, 8, 24, 25, 27, 29 and 30-Arecanut, 9-*Uguressa*, 10 and 16-*Gliricidia*, 11, 13, 20 and 23-*Gini-sapu*, 19 and 28-Clove, 22-Pepper / *Gliricidia*, 26-Coconut

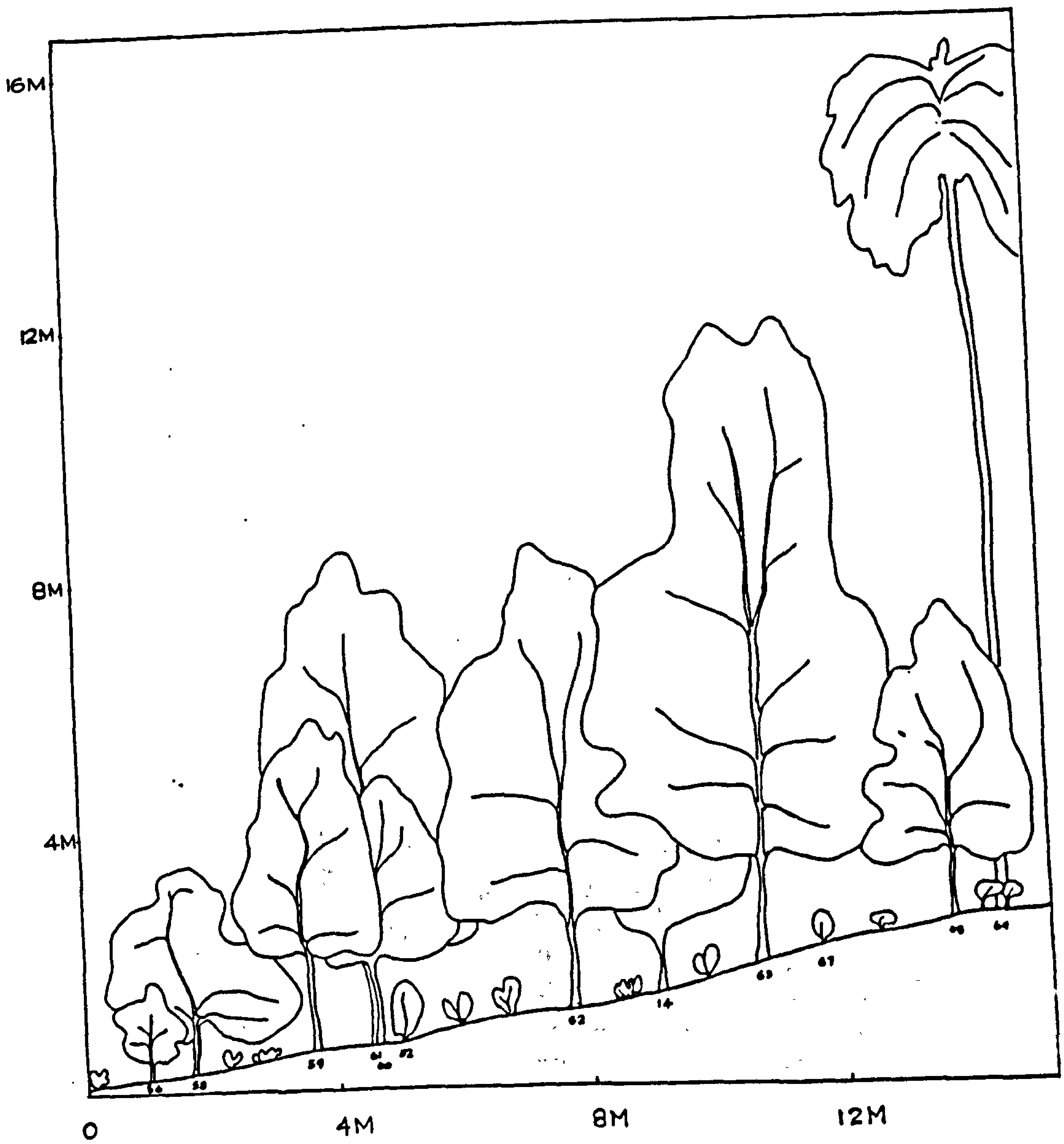
(b) Profile 2

Key: 1-Cashew, 6, 9, 19 and 29-Coffee, 11, 18, 23, 25 and 51-Arecanut, 12, 17, 20, 33, 34, 36, 38, 40, 44 and 48-Cocoa, 21-*Kanu*, 26-Jak, 41-*Wewel*, 45-Nutmeg, 49 and 50-*Waldel*



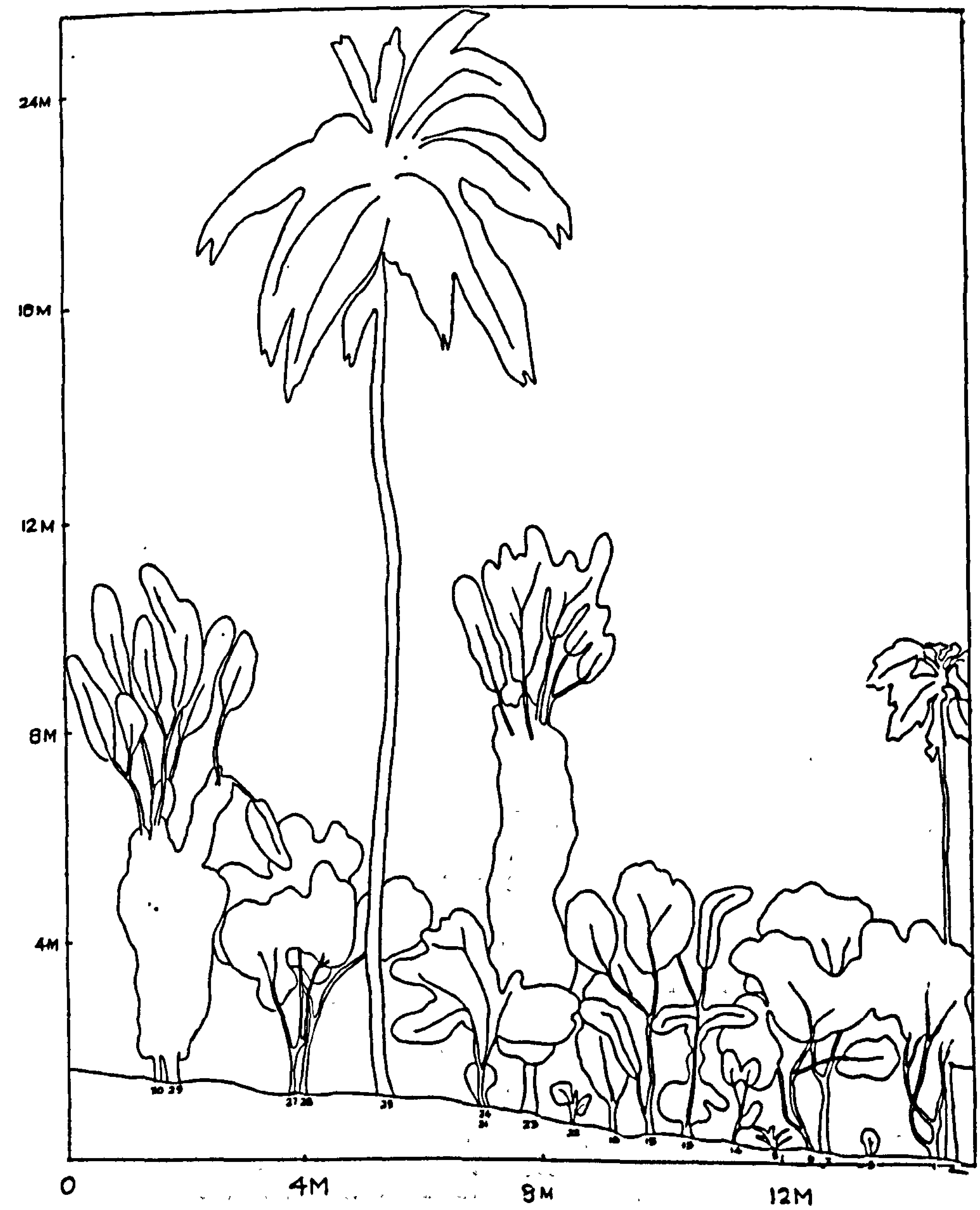
(c) Profile 3

Key: 1, 2, 3, 4, 5, 8, 11, 12, 13 and 15-Coffee, 19 and 42-Arecanut, 24-Cardamom, 29, 30, 31, 32, 35, 37, 38, 39, 40 and 41-Banana



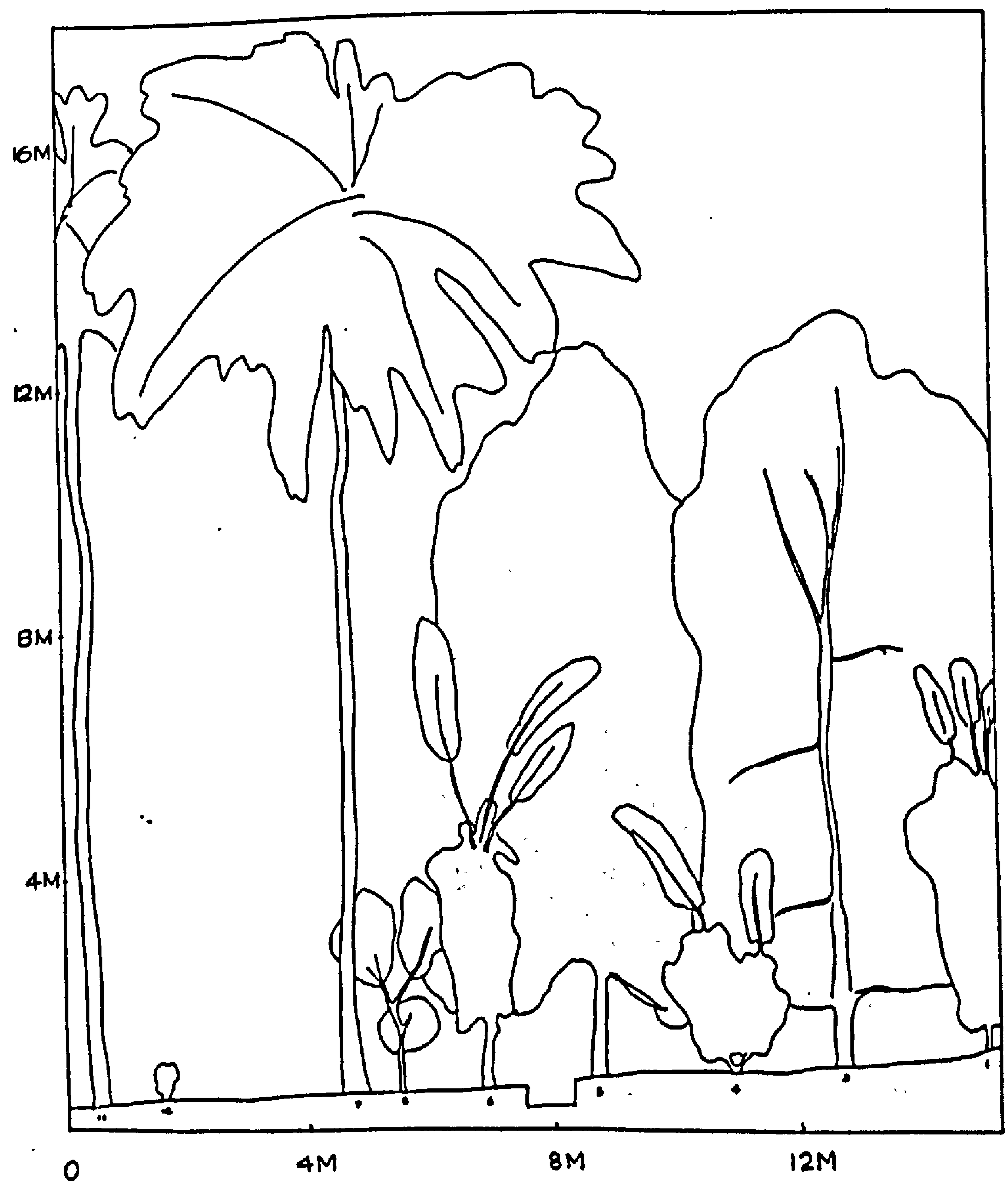
(d) Profile 4

Key: 14-Jak, 32-*Nolabe*, 56, 58, 60, 63 and 67-Coffee, 59, 61, 62 and 68-Clove, 69-Arecanut



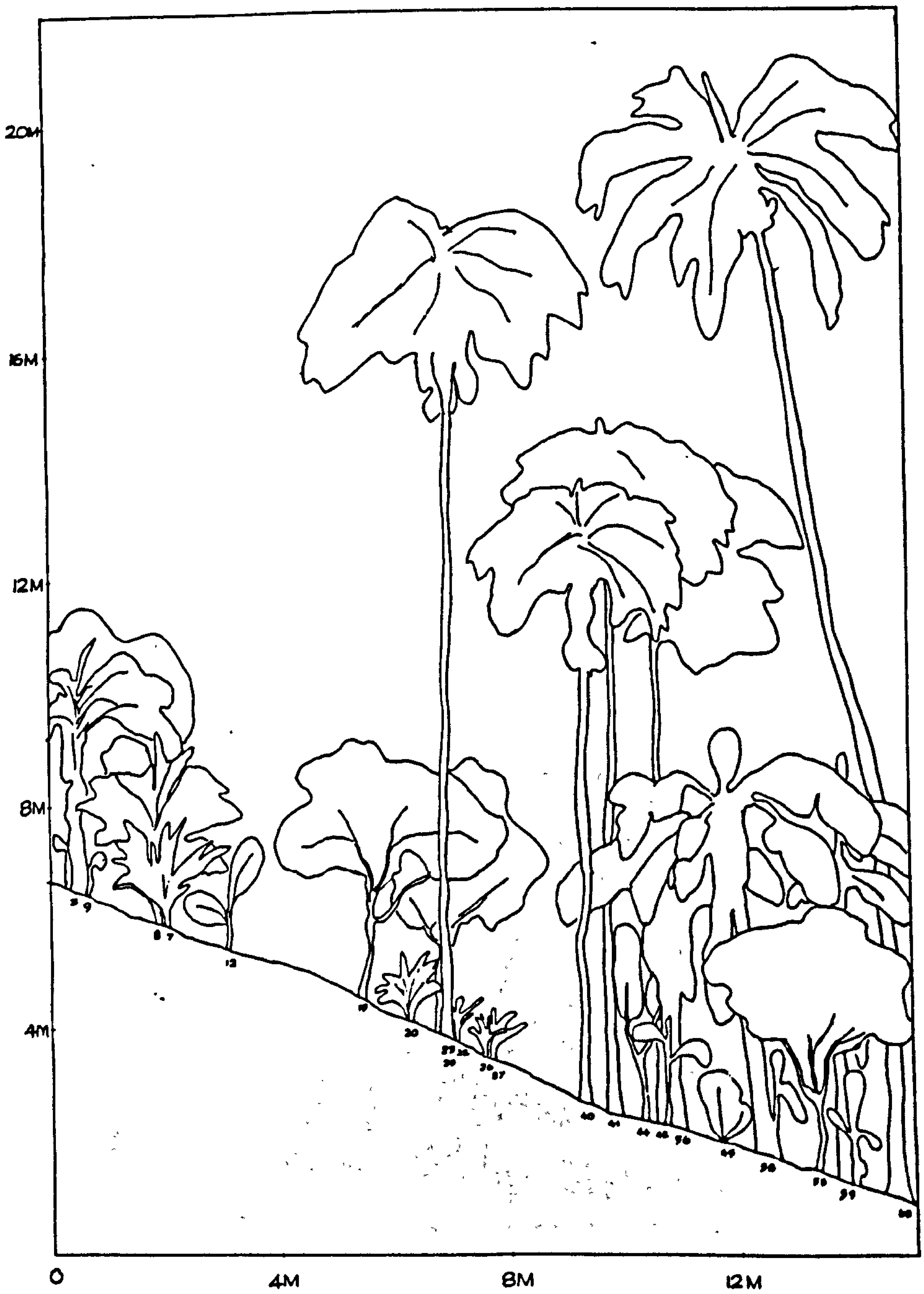
(e) Profile 5

Key: 1, 6, 7, 15, 24, 27 and 28-Coffee, 2-Papaw, 5, 21 and 22-*Kiriala*, 8-Artichoke, 13, 23, 29 and 30-Pepper / *Gliricidia*, 14 and 16-*Karapincha*, 25-Coconut



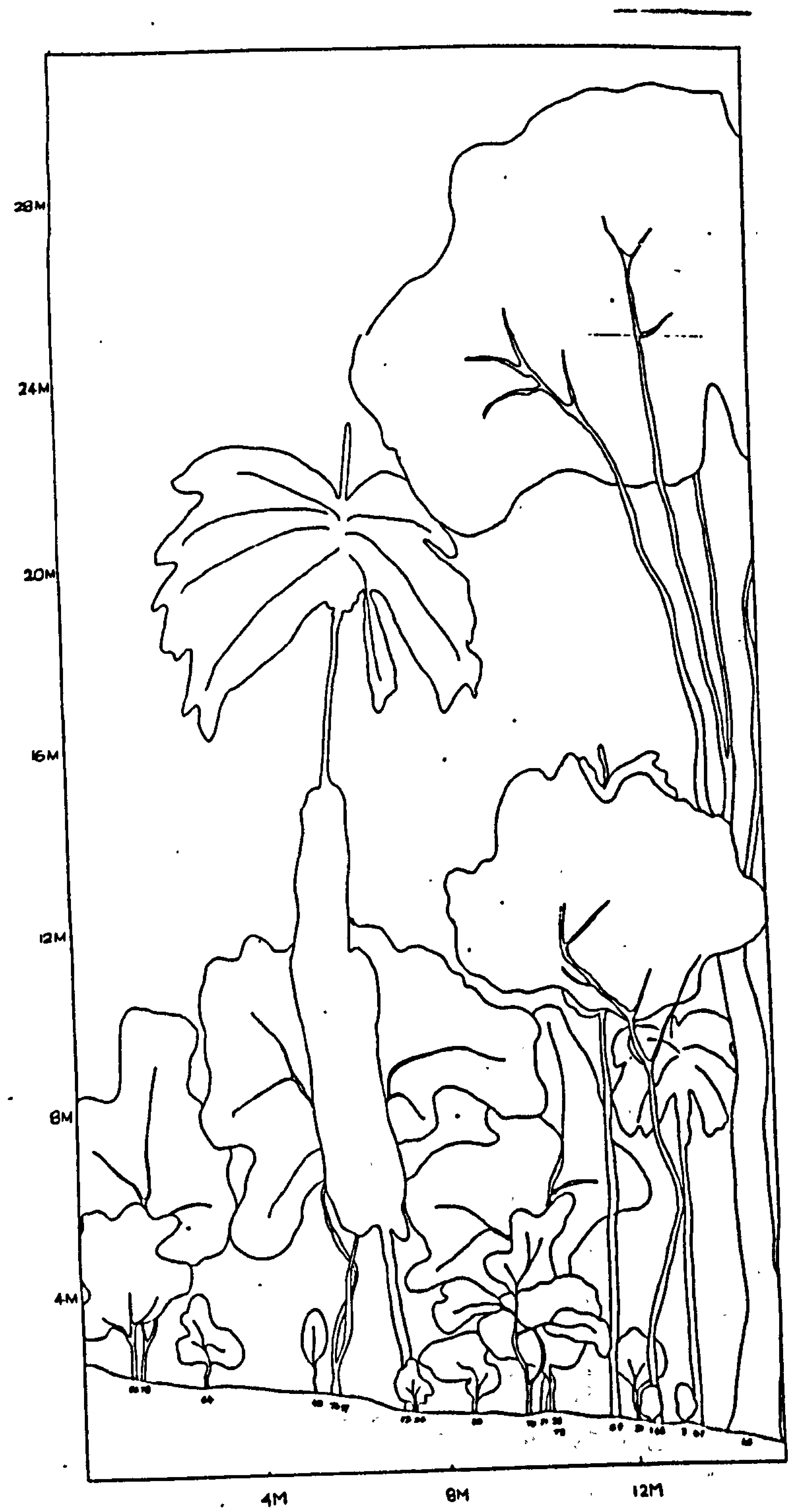
(f) Profile 6:

Key: 1 and 4-Pepper / *Gliricidia*, 3-Clove, 5 and 7-Coconut, 6 and 8-Coffee, 11-Jak, 12-*Kiriala*



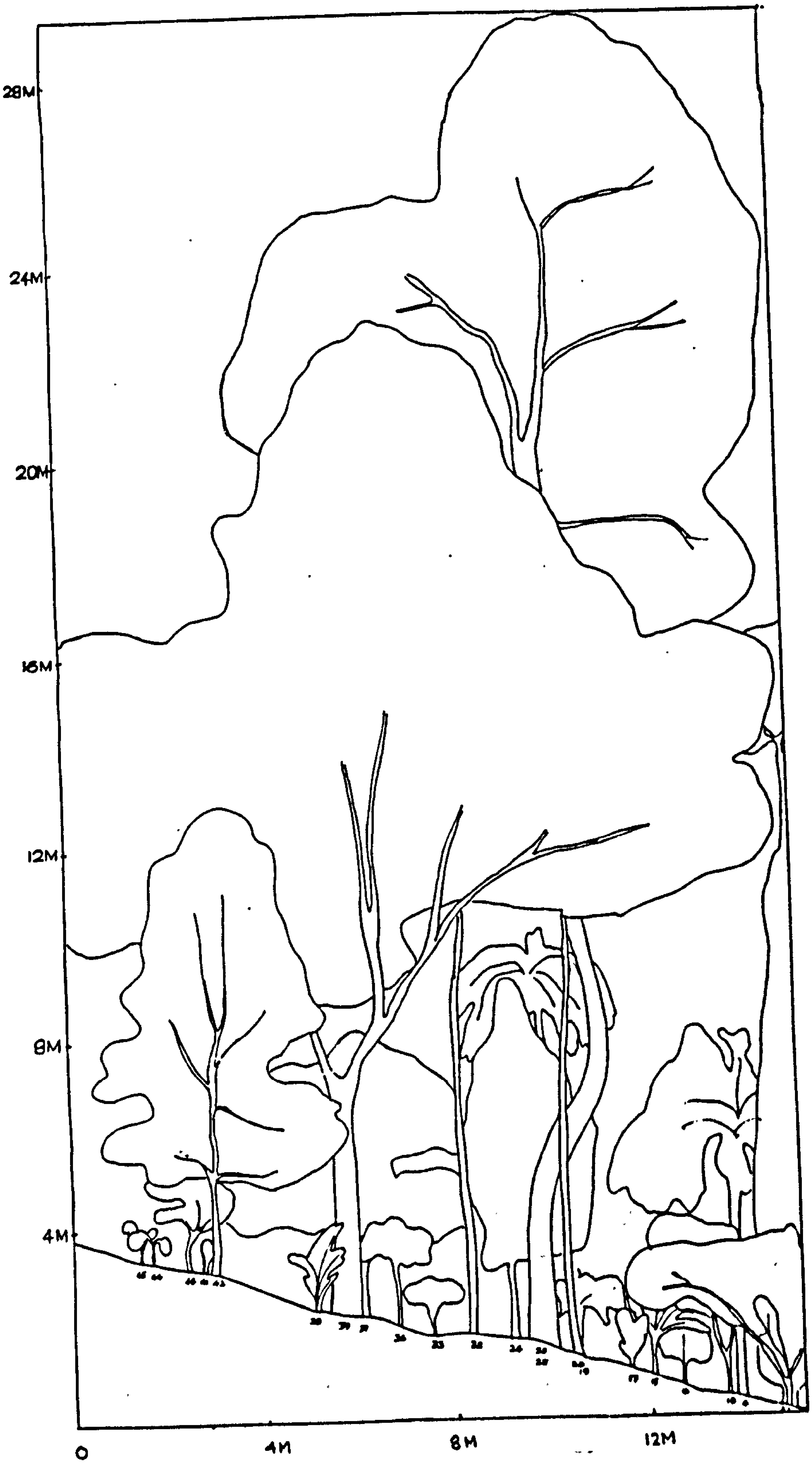
(g) Profile 7

Key: 3, 56, 58 and 59-Banana, 7, 8, 20, 22, 23, 26 and 27-Arecanut, 9, 40, 41, 42-Pepper / Arecanut, 12 and 44-*Gliricidia*, 19 and 55-Coffee, 29-Pepper / coffee, 45-*Dothalu*, 62-Coconut



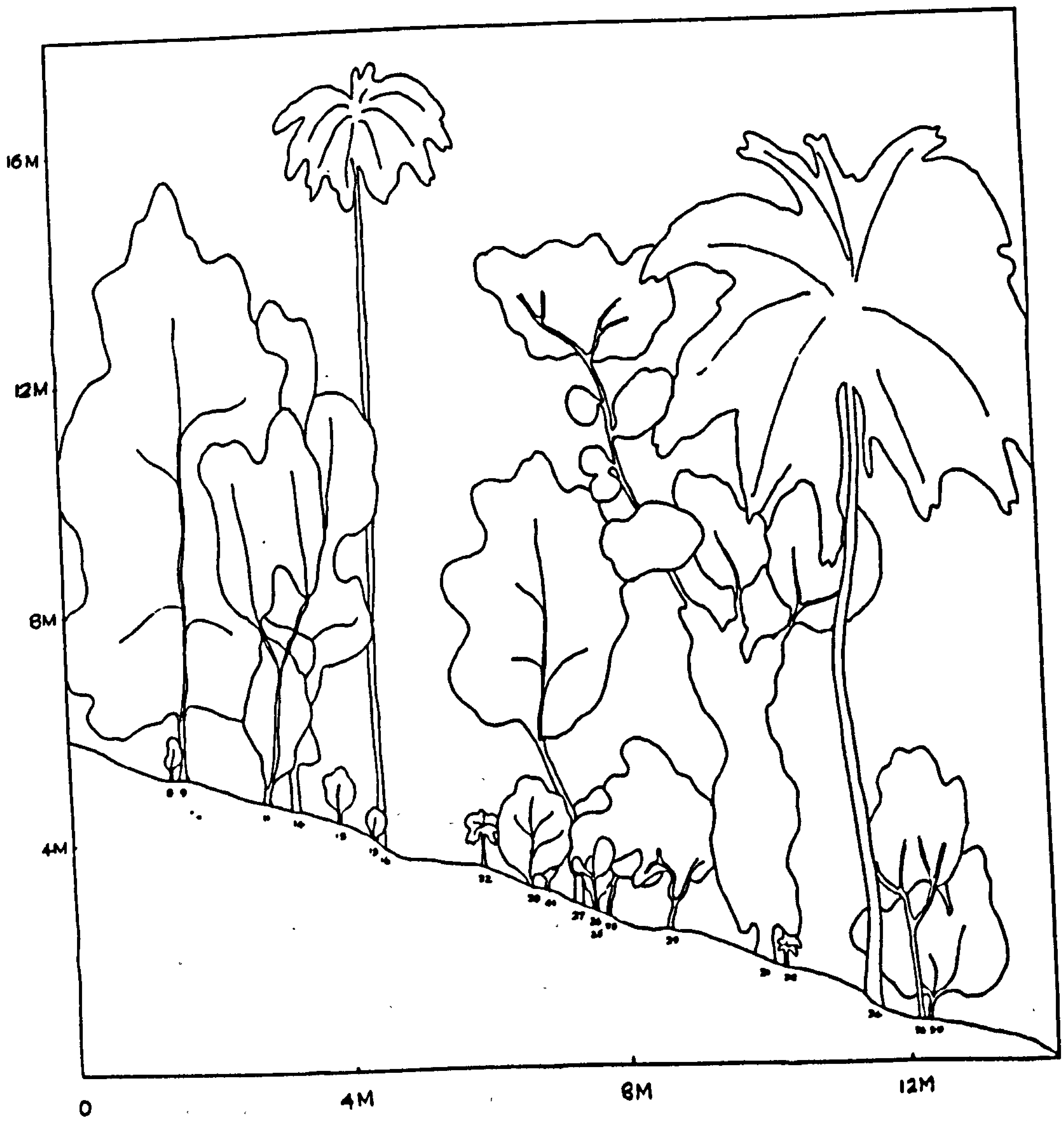
(h) Profile 8

Key: 1-*Nithulla*, 2-*Budelia*, 21-*Kududavula*, 28-*Pota* / coffee, 33-*Bakamunu gammiris* / *Budelia*, 35-*Katu-anoda*, 40-*Uguressa*, 56, 71 and 72-Cocoa, 64-*Kirivel*, 65-Jak, 67 and 69-Arecanut, 68-*Gini-sapu*, 70-Pepper / cocoa, 73-Pepper / coconut, 76, 77 and 78-Coffee



(i) Profile 9

Key: 1, 12, 13, 15, 33, 36-Coffee, 2-Pepper / Jak, 4-*Anoda*, 17-*Gliricidia*, 19, 20, 32-Arecanut, 23-*Cannas*, 24 and 42-Clove, 28 and 39-Bread fruit, 37-Nutmeg, 38-*Kitul*, 41-*Jambu*, 43-Cocoa, 44-*Kirlala*, 45-*Rambutan*



(j) Profile 10

Key: 8-*Nolabe*, 9-Clove, 11, 14, 28-Pepper / *Gliricidia*, 13, 16, 22-Arecanut, 15-*Lunu-midella*, 20-Mahogany, 25-*Kududavula*, 26-*Hawari-nuga*, 27-*Gini-sapu*, 29 and 35-Coffee, 31-*Kahata* / Pepper, 32-*Kitul*, 34-Coconut, 36-*Gliricidia*, 41-*Rambutan*

Appendix 4 Importance value of dominant species in the forestgarden types of homegardens.

LUS-1 KHG	FG type	Coconut	Arecanut	Coffee	Pepper	Cocoa	Clove	Nutmeg	Banana	*Gliricida*	Jak	*Gini-sapu*	Tea	*Halmilla*	Mahogany
1	a	16.9*	3.4	32.2*	-	-	11.9*	-	-	-	-	6.8	-	-	-
	b	27.8*	8.3	-1	-	13.9*	-	30.6*	-	-	8.3	-	-	-	-
	c	16.7*	18.8*	4.2	-	-	12.5*	-	-	-	-	20.8*	-	-	-
	d	10.2*	18.6*	-	-	6.8	-	-	25.4*	-	5.1	15.3*	-	-	-
I		17.9	14.2	5.6	-	3.4	6.2	7.7	6.4	-	3.4	12.5	-	-	-
2	a	4.6	36.9*	4.6	-	26.2*	-	-	-	-	4.6	-		-	-
	b	9.1	20.0*	5.5	-	-	-	-	21.8*	-	-	-	-	27.3*	-
	c	-	12.2*	21.6*	10.8*	-	-	-	-	32.4*	-	-	-	-	-
	d	8.9	5.4	-	21.4*	17.9*	-	-	-	21.4*	-	-	-	-	-
I		5.4	22.3	7.3	6.4	14.1	-	-	4.4	10.7	1.8	-	-	5.5	-
3	a	-	24.1*	19.0*	5.1	-	-	-	25.3*	-	6.3	-	-	-	-
I			24.1	19.0	5.1	-	-	-	25.3	-	6.3	-	-	-	-
4	a	8.1	16.1*	29.0*	-	6.5	14.5*	-	-	-	-	4.8	-	-	-
	b	20.8*	8.3	-	-	-	-	-	45.8*	-	-	-	-	-	-
I		11.3	14.2	21.8	-	4.9	10.9	-	34.4	-		3.6		-	-
5	a	13.6*	5.1	-	-	-	-	-	44.1*	-	8.5	5.1	-	-	-
	b	6.9	-	25.0*	15.3*	16.7*	-	-	6.9	20.8*	-	-	-	-	-
	c	12.1*	4.8	21.7*	9.6	2.4	-	-	-	14.5*	-	-	-	-	-

I		11.5	4.1	18.6	9.0	4.4	-	-	8.5	13.1	1.4	0.9	-	-	-
6	a	14.5*	-	17.4*	10.1*	-	8.7	-	-	17.4*	11.6*	-	-	-	-
	b	15.9*	12.7*	31.7*	-	4.8	-	-	-	-	-	-	-	-	-
I		14.9	4.2	22.1	6.7	1.6	5.7	-	-	11.5	7.7	-	-	-	-
7	a	3.7	18.5*	16.0*	7.4	-	-	-	14.8*	11.1*	6.2	-	-	-	-
	b	5.8	27.9*	-	14.0*	-	-	-	-	24.4*	-	-	-	-	-
I		4.2	20.9	12.0	9.1	-	-	-	11.1	14.4	4.7	-	-	-	-
8	a	15.2*	39.4*	6.1	-	12.1*	-	-	4.6	-	7.6	-	-	-	-
	b	14.0*	14.0*	17.5*	7.0	14.0*	-	-	-	10.5*	8.8	-	-	-	-
	c	21.3*	38.3*	6.4	-	25.5*	-	-	-	6.4	-	-	-	-	-
I		15.7	23.9	9.5	4.2	15.9	-	-	0.9	5.9	6.8	-	-	-	-
9	a	17.0*	10.6*	-	-	-	21.3*	25.5*	-	-	6.4	-	-	-	-
	b	-	25.9*	14.8*	-	18.5*	11.1*	-	-	-	14.8*	-	-	-	-
	c	27.8*	13.9*	-	-	8.3	-	-	-	-	-	-	-	-	-
I		11.2	19.1	7.4	-	11.3	10.9	6.4	-	-	9.0	-	-	-	-
10	*a*	7.9	*14.3**	*11.1**	4.8	-	4.8	-	-	14.3*	9.5	11.1*	-	-	-
	b	6.1	-	8.2	-	4.1	25.5*	-	-	-	-	34.7*	-	-	-
	c	17.4*	6.5	-	-	-	-	-	45.7*	13.0*	-	-	-	-	-
I		9.8	8.8	7.6	2.4	1.0	8.5	-	11.4	10.4	-	4.8		14.2	-
<u>LUS-2</u> KHG	FG type	Coconut	Arecanut	Coffee	Pepper	Cocoa	Clove	Nutmeg	Banana	*Gliricidia*	Jak	*Gini-sapu*	Tea	*Halmilla*	Mahogany
1	a	20.0*	-	40.0*	-	7.5	7.5	-	-	-	7.5	-	-	-	-

I		20.0	-	40.0	-	7.5	7.5	-	-	-	7.5	-	-	-	-
2	a	-	9.5	-	12.7*	-	-	-	-	31.8	-	-	28.6*	-	-
	b	-	-	46.2*	-	7.7	-	15.4*	-	-	12.8*	-	-	-	-
	c	30.3*	9.1	-	-	6.1	36.4*	-	-	-	-	-	-	-	-
I		10.1	6.2	15.4	4.2	4.6	12.1	5.1	-	10.6	4.3	-	9.5	-	-
3	a	22.7*	6.8	-	-	-	-	-	-	13.6*	-	-	36.4*	-	-
	b	12.8*	-	46.2*	-	-	-	-	-	-	-	15.4*	-	-	-
I		15.3	1.7	34.7	-	-	-	-	-	3.4	-	11.6	9.1	-	-
4	a	14.3*	8.6	54.3*	-	-	-	-	-	-	-	-	-	-	-
	b	21.1*	5.3	-	-	-	-	-	-	15.8	-	-	39.5*	-	-
I		18.4	6.6	21.7	-	-	-	-	-	9.5	-	-	23.7	-	-
5	a	12.2*	-	-	-	19.5*	-	-	29.3*	-	7.3	-	-	-	-
	b	8.3	-	16.7*	11.1*	-	-	-	-	27.8*	13.9*	-	-	-	-
I		10.3	-	8.4	2.2	9.8	-	-	14.7	13.9	10.6	-	-	-	-
6	a	10.2*	8.2	8.2	20.4*	-	-	-	-	36.7*	-	6.1	-	-	-
	b	8.3	22.2*	-	-	30.6*	-	-	-	-	13.9*	-	-	-	-
I		9.1	16.6	3.3	8.2	18.4	-	-	-	14.7	8.3	2.4	-	-	-
7	a	17.2*	-	27.6*	-	-	-	20.7*	-	-	10.3*	-	-	-	-
I		17.2	-	27.6	-	-	-	20.7	-	-	10.3	-	-	-	-
8	a	16.1*	19.4*	-	-	9.7	38.7*	-	-	-	-	-	-	-	-
	b	7.7	30.8*	7.7	-	-	-	-	-	-	7.7	-	25.6*	-	-
I		11.9	24.5	3.9	-	4.9	19.4	-	-	-	3.9	-	12.8	-	-

9	a	7.5*	7.5*	30.0*	-	-	27.5*	-	-	-	-	7.5	-	-	-
I		7.5	7.5	30.0	-	-	27.5	-	-	-	-	7.5	-	-	-
10	a	13.9*	33.3*	5.6	-	-	16.7*	-	-	-	8.3	-	-	-	-
	b	23.3*	9.3	37.2*	-	7.0	-	-	-	-	-	4.7	-	-	-
I		20.0	17.1	26.4	-	4.6	5.5	-	-	-	2.7	3.1	-	-	-
<u>LUS-3</u> KHG	FG type	Coconut	Arecanut	Coffee	Pepper	Cocoa	Clove	Nutmeg	Banana	*Gliricidia*	Jak	*Gini-sapu*	Tea	*Halmilla*	Mahogany
1	a	24.4*	7.3	12.2*	-	7.3	-	-	36.6*	-	7.3	-	-	-	-
I		24.4	7.3	12.2	-	7.3	-	-	36.6	-	7.3	-	-	-	-
2	a	6.3	12.5*	-	12.5*	-	-	-	16.7*	29.2*	-	-	-	-	-
	b	15.7*	-	-	21.8*	-	-	-	-	41.2*	-	-	-	-	-
I		11.0	6.3	-	17.1	-	-	-	8.4	35.2	-	-	-	-	-
3	a	8.1	13.5*	27.0*	-	-	32.4*	-	-	-	-	-	-	-	-
	b	17.9*	10.7*	-	-	-	35.7*	-	-	-	17.9*	-	-	-	-
I		11.3	12.4	17.8	-	-	33.2	-	-	-	5.9	-	-	-	-
4	a	-	6.3	31.3*	18.8*	6.3	-	-	-	25.0*	-	-	-	-	-
	b	28.6*	-	-	28.6*	-	-	-	-	21.4*	-	-	-	-	-
I		21.5	1.6	7.8	26.2	1.6	-	-	-	22.3	-	-	-	-	-
5	a	24.4*	-	4.9	-	-	-	-	36.6*	-	7.3	9.8	-	-	-
	b	18.9*	-	15.1*	-	3.8	22.6*	-	-	-	15.1*	-	-	-	-
I		22.3	-	8.2	-	1.3	7.5	-	24.2	-	9.8	6.5	-	-	-
6	a	12.5*	15.0*	-	22.5*	-	-	-	-	32.5*	-	-	-	-	-

	b	13.5*	8.1	-	-	-	-	-	40.5*	8.1	8.1	-	-	8.1	-
I		13.3	9.5	-	4.5	-	-	-	32.4	13.0	6.5	-	-	6.5	-
7	a	13.9*	8.3	-	-	5.6	33.3*	16.7*	-	-	-	-	-	-	-
	b	10.6*	-	27.7*	-	-	19.1*	-	-	-	10.6*	8.5	-	-	-
I		12.7	5.5	9.1	-	3.7	28.3	11.0	-	-	3.5	2.8	-	-	-
8	a	17.9*	-	17.8*	-	39.1*	-	-	-	-	10.3*	-	-	-	-
I		17.9	-	17.8	-	39.1	-	-	-	-	10.3	-	-	-	-
9	a	-	12.2*	-	24.5*	-	-	-	22.5*	24.5*	-	-	-	-	-
	b	-	-	32.3*	25.8*	-	-	-	-	25.8*	-	-	-	-	-
I		-	9.8	6.5	24.8	-	-	-	18.0	24.8	-	-	-	-	-
10	a	-	-	-	10.3*	-	-	-	53.9*	15.4*	-	-	-	-	-
I		-	-	-	10.3	-	-	-	53.9	15.4	-	-	-	-	-
<u>LUS-4</u> KHG	FG type	Coconut	Arecanut	Coffee	Pepper	Cocoa	Clove	Nutmeg	Banana	*Gliricidia*	Jak	*Gini-sapu*	Tea	*Halmilla*	Mahogany
1	a	12.8*	30.8*	-	-	20.5*	-	-	-	-	20.5*	-	-	-	-
I		12.8	30.8	-	-	20.5	-	-	-	-	20.5	-	-	-	-
2	a	8.3	-	11.1*	-	-	33.3*	22.2*	-	-	-	-	-	-	-
	b	14.7*	23.5*	23.5*	-	-	-	-	-	8.8	14.7*	-	-	-	-
	c	-	9.8	29.3*	19.5*	-	-	-	-	24.4*	-	-	-	-	-
I		7.7	11.1	21.3	6.5	-	11.1	11.1	-	11.1	4.9	-	-	-	-
3	a	-	35.3*	31.4*	-	-	-	-	-	-	-	15.7*	-	-	-
	b	15.6*	12.5*	31.3*	-	-	-	-	-	18.8*	-	-	-	-	-

I		9.4	21.6	31.3	-	-	-	-	-	11.3	-	-	-	-	-
4	a	9.1	-	-	-	-	18.2*	18.2*	-	-	9.1	-	-	-	24.2*
I		9.1	-	-	-	-	18.2	18.2	-	-	9.1	-	-	-	24.2
5	a	19.6*	9.8	5.9	-	-	-	-	35.3*	-	-	11.6*	-	-	-
	b	14.7*	-	35.3*	-	8.8	-	-	23.5*	-	-	-	-	-	-
I		17.2	4.9	20.6	-	4.4	-	-	29.4	-	-	5.8	-	-	-
6	a	10.3*	13.8*	37.9*	-	-	-	-	-	-	17.2*	-	-	-	-
	b	21.6*	-	13.5*	10.8*	-	-	-	-	21.6*	13.5*	-	-	-	-
I		13.1	10.4	31.8	2.7	-	-	-	-	5.4	16.3	-	-	-	-
7	a	21.6*	-	-	-	-	-	-	29.7*	-	-	-	-	-	32.4*
I		21.6	-	-	-	-	-	-	29.7	-	-	-	-	-	32.4
8	a	12.2*	19.5*	-	-	31.7*	-	-	-	14.6*	-	-	-	-	-
I		12.2	19.5	-	-	31.7	-	-	-	14.6	-	-	-	-	-
9	a	24.2*	-	30.3*	-	-	-	-	-	-	9.1	12.1*	-	-	-
I		24.2	-	30.3	-	-	-	-	-	-	9.1	12.1	-	-	-
10	a	21.1*	-	31.6*	-	-	-	-	-	-	13.2*	13.2*	-	-	-
I		21.1	-	31.6	-	-	-	-	-	-	13.2	13.2	-	-	-

Key: *I*- Importance values of species for the homegarden, *- Sign indicates the dominant species of forest garden types, FG-Forestgarden, [1]*I*=0
Species names are given in Appendix 2.

Appendix 5 The definite clause grammar.

Formal_sentence ==> Statement **if** Formal_conditions.
Formal_sentence ==> Statement.
Statement ==> Cause **causes1way** Effect.
Statement ==> Cause **causes2way** Effect.
Statement ==> Attribute_statement.
Statement ==> **not**(Attribute_statement).
Statement ==> **link**(influence, Thing, Thing).
Statement ==> **link**(Link, Object, Object).
Statement ==> **link**(Link, Process_bit, Process_bit).
Statement ==> **comparison**(Attribute, Object, Comparison, Object).
Formal_conditions ==> Formal_conditions **or** Formal_conditions.
Formal_conditions ==> Formal_conditions **and** Formal_conditions.
Formal_conditions ==> Statement.
Formal_conditions ==> Action_bit.
Formal_conditions ==> **att_value**(Action_bit, Attribute, Value).
Attribute_statement ==> **att_value**(Object, Attribute, Value).
Attribute_statement ==> **att_value**(Process_bit, Attribute, Value).
Attribute_statement ==> **att_value**(Action_bit, Attribute, Value).
Cause ==> Attribute_statement.
Cause ==> Process_bit.
Cause ==> Action_bit.
Action_bit==>action(Action_name, Object, Object).
Action_bit==>action(Action_name, Object).
Effect ==> Attribute_statement.
Effect ==> Process_bit.
Process_bit ==> **process**(Process).
Process_bit ==> **process**(Object, Process).
Process_bit ==> **process**(Object, Process, Object).
Thing ==> Object.
Thing ==> Process_bit.
Attribute ==> {something that appears in the attribute glossary}.
Process ==> {something that appears in the process glossary}.
Link ==> {something that appears in the link glossary}.
Object ==> Atomic_object.
Object ==> **part**(Object, Atomic_object).
Atomic_object ==> {Something that appears in the keyword hierarchies}
Action_name ==> {something that appears in the action glossary }
Comparison ==> **greater_than / less_than / same_as different_from**
Value ==> **increase / decrease / change / no_change**
Value ==> **range**(X,Y) {where X and Y are atoms}
Value ==> >X / <X / =X / <=X / >=X {X is an atom}
Value ==> X {atom}

Key: Terms in bold are reserved terms in the grammar, terms starting with a capital letter are variables'==>' means 'can take the form of'.

Source: Walker *et al*, (1994)

Appendix 6 English translation of the non-leading questions developed for evaluation of representativeness of knowledge base.

1. Targeted knowledge: Attributes considered by farmers for classification of trees for pruning for improvement of volume and quality of wood

a. Should this tree species be pruned or not ?

Species	Prune	Not prune	Don't know
Kenda			
Wana-sapu			
Hawari-nuga			
Gini-sapu			
Halmilla			
Ketakela			

b. Why is this tree species pruned or not ?

Species	Reasons for pruning	Reasons for not pruning	Reasons for not knowing
Kenda			
Wana-sapu			
Hawari-nuga			
Gini-sapu			
Halmilla			
Ketakela			

2. Targeted knowledge: The attributes of the upperstorey tree species recognised by farmers as causing a shade effect of different magnitude on crops

a. Which of the following tree species casts heavy or light shade on understorey crops ?

Species	High shade intensity	Low shade intensity	Don't know
Nutmeg			
Mahogany			
Kenda			
Lunu-midella			
Wana-sapu			
Hawari-nuga			

b. Give reasons for the answer ?

Species	Reasons for causing high shade intensity	Reasons for causing low shade intensity	Reasons for not knowing
Nutmeg			
Mahogany			
Kenda			
Lunu-midella			
Wana-sapu			
Hawari-nuga			

3. Targeted knowledge: Crop attributes recognised by farmers to be influenced by the changing light intensity

a. Would it be advantageous to reduce overhead shade when the following understorey crops are grown ?

Species	Reducing shade is advantageous	Reducing shade is not advantageous	Don't know
Pepper			
Coffee			
Cocoa		High shade	

b. Please give reasons for the answer ?

Species	Reasons for keeping open canopy	Reasons for opening of canopy is not necessary	Reasons for not knowing
Pepper			
Coffee			
Cocoa			

4. Targeted knowledge: The attributes of the upperstorey tree species recognised by farmers as causing a soil nutrient enrichment effect of different magnitude on crops

a. Do you expect high or low soil nutrient content (i.e. *Saru bava*) under the following tree species?

Species	High nutrient content	Low nutrient content	Don't know
Lunu-midella			
Jak			
Tamarind			
Gini-sapu			
Gliricidia			

b. Please give reasons for the answer ?

Species	Reasons for high nutrient content	Reasons for low nutrient content	Reasons for not knowing
Lunu-midella			
Jak			
Tamarind			
Gini-sapu			
Gliricidia			

Appendix 7 English translation of the questionnaire developed for the evaluation of the representativeness of the knowledge base using a leading questioning approach.

Section A

The following twenty intermediate statements were selected from the core knowledge by drawing random numbers.

1. an increase in upperstorey tree crown height causes an increase in understorey light intensity
2. branches which grow under high light intensity grow faster than the branches which grows under low light intensity
3. after trees attain maximum height the branches begins to get thicker rapidly
4. decrease in the number of branches in the trunk causes a decrease in knotty wood proportion
5. pruning upperstorey trees causes sun scorch on understorey crop leaves
6. an increase of branch length causes an increase of intensity of twisting trunk (due to winds)
7. a decrease in branch number causes decrease in taper of the tree trunks
8. pruning branches causes decrease in knotty wood proportion of tree trunks
9. pruning branches causes an increase in the tree height growth rate
10. contacting of heartwood with water causes the stem to rot
11. a decrease in crown density of upperstorey trees causes an increase in light intensity of understorey
12. increase in litter layer thickness causes a decrease in rate of soil erosion
13. decrease in sunlight received by the understorey causes a decrease in flower number produced of the understorey crops if crop is pepper or coffee
14. an increase in light intensity of the understorey causes an increase in air temperature inside the KFGs
15. an increase in the diameter of the branches retained by the tree causes an increase in trunk knotty wood proportion
16. removal of side branches of the bend side of the tree causes an increase in the straightness of tree
17. an increase of shade intensity causes an increase of rate of self pruning of tree if tree is *gini-sapu* or mahogany
18. an increase in moisture stress causes an increase in rate of leaf fall of crops
19. increase of the trunk length of the tree causes a decrease in the strength of the trunk
20. removal of branches from the tree crown causes decrease in crown density

Test of representativeness

Farmers were asked to indicate their agreement or disagreement to the above sentences by selecting one of the following:

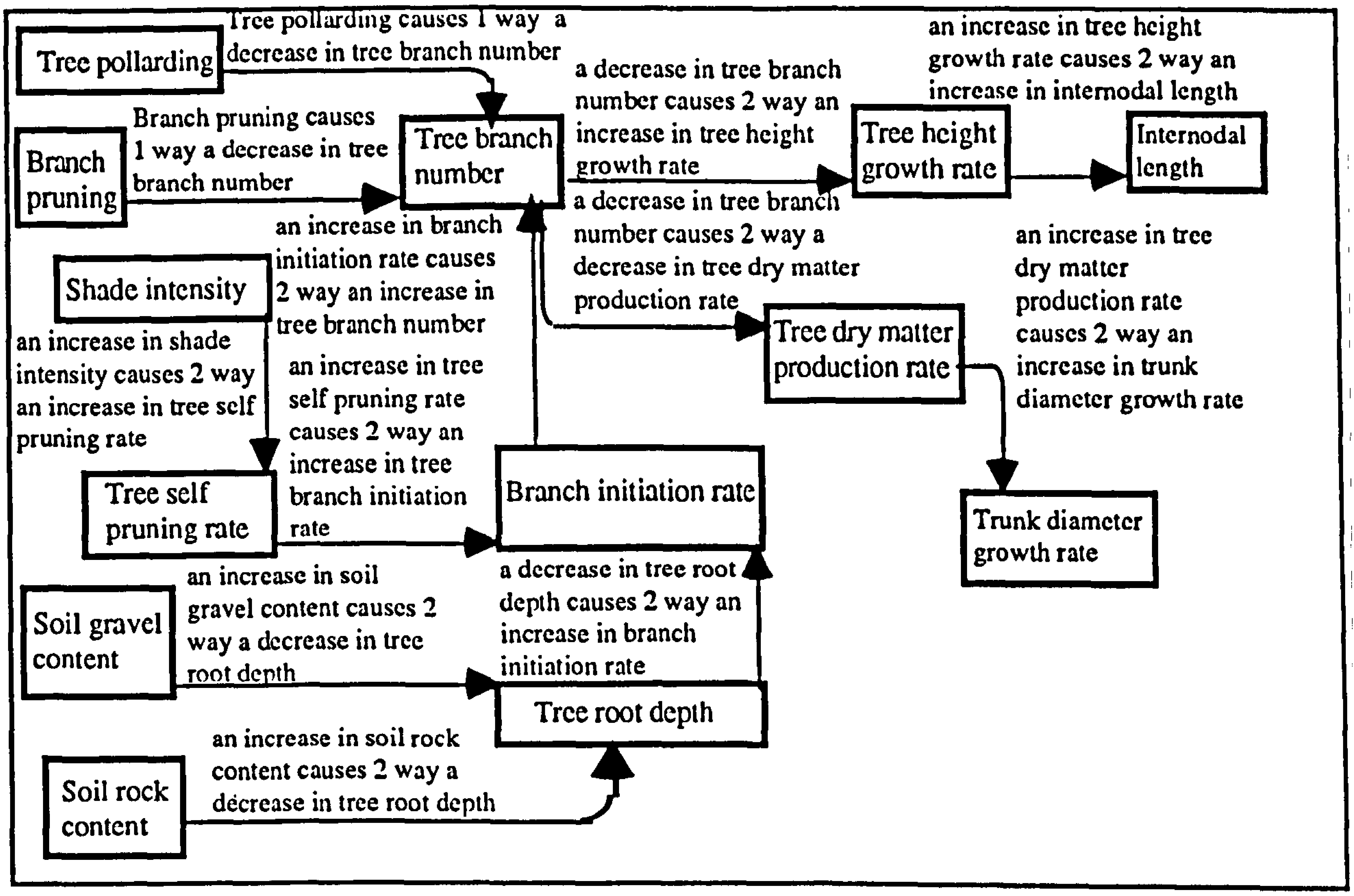
i. Agree
ii. Agree with conditions
iii. Disagree
iv. Don't know

The proportion of farmers in agreement with original statement (i.e. selected i of the above) were used as an indicator of the representativeness of the knowledge base.

Section B

The intention of this section was to evaluate the link sets of statements that were grouped into causal chains in the analysis of the content of the knowledge base. The conclusions that are drawn and reasoning process illustrated are therefore examined with relation to those statements. If the informants agree with the option that is equivalent to the original statement from four answers provided, then confirms that statement. If an informant confirms all the statements in the statement set then this confirms the conclusions drawn and the reasoning process of the causal chain.

Statement set 1.



i. branch pruning causes a decrease in tree branch number
a. tree branch number not changed by pruning.
b. tree branch number decreases by pruning.
c. tree branch number increases by pruning.
d. don't know.
ii. pollarding tree causes a decrease in the branch number
a. branch number not changed by pollarding.
b. branch number increases by pollarding.
c. branch number decreases by pollarding.
d. don't know
iii. an increase in branch initiation rate causes an increase in tree branch number
a. an increase in branch initiation rate causes a decrease in tree branch number
b. an increase in branch initiation rate causes an increase in tree branch number
c. an increase in branch initiation rate causes no change in tree branch number
d. don't know.
iv. a decrease in tree branch number causes an increase in tree height growth rate
a. a decrease in tree branch number causes a decrease in tree height growth rate
b. a decrease in tree branch number causes an increase in tree height growth rate
c. a decrease in tree branch number causes no change in tree height growth rate
d. don't know.

v. an increase in branch self pruning rate causes an increase in branch initiation rate

a. an increase in branch self pruning rate causes a decrease in branch initiation rate
b. an increase in branch self pruning rate causes an increase in branch initiation rate
c. an increase in branch self pruning rate causes no change in branch initiation rate
d. don't know.

vi. an increase in shade intensity causes an increase in tree self pruning rate

a. an increase in shade intensity causes a decrease in tree self pruning rate
b. an increase in shade intensity causes an increase in tree self pruning rate
c. an increase in shade intensity causes no change in tree self pruning rate
d. don't know.

vii. a decrease in tree branch number causes a decrease in tree dry matter production rate

a. a decrease in tree branch number causes an increase in tree dry matter production rate
b. a decrease in tree branch number causes a decrease in tree dry matter production rate
c. a decrease in tree branch number causes no change in tree dry matter production rate
d. don't know

viii. an increase in soil rock content causes a decrease in tree root depth

a. an increase in soil rock content causes an increase in tree root depth
b. an increase in soil rock content causes a decrease in tree root depth
c. an increase in soil rock content causes no change in tree root depth
d. don't know.

ix. an increase in tree dry matter production rate causes an increase in tree diameter growth rate

a. an increase in tree dry matter production rate causes an increase in tree diameter growth rate
b. an increase in tree dry matter production rate causes a decrease in tree diameter growth rate
c. an increase in tree dry matter production rate causes no change in tree diameter growth rate
d. don't know.

x. an increase in soil gravel content causes a decrease in tree root depth

a. an increase in soil gravel content causes a decrease in tree root depth
b. an increase in soil gravel content causes an increase in tree root depth
c. an increase in soil gravel content causes no change in tree root depth
d. don't know

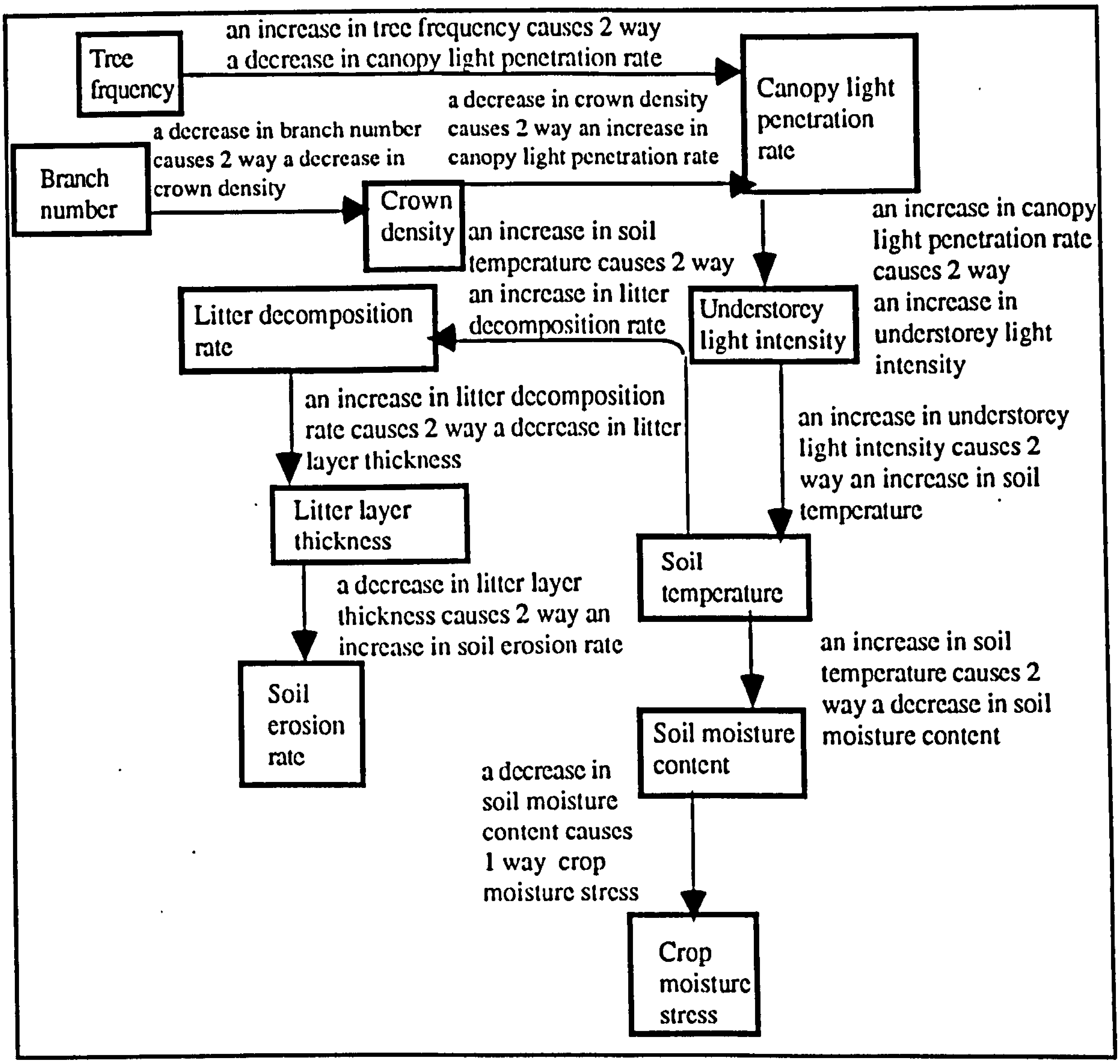
xi. an increase in tree height growth rate causes an increase in internodal length

a. an increase in tree height growth rate causes a decrease in internodal length
b. an increase in tree height growth rate causes an increase in internodal length
c. an increase in tree height growth rate causes no change in internodal length
d. don't know.

xii. a decrease in tree root depth causes an increase in branch initiation rate

a. a decrease in tree root depth causes a decrease in branch initiation rate
b. a decrease in tree root depth causes an increase in branch initiation rate
c. a decrease in tree root depth causes no change in branch initiation rate
d. don't know.

Statement set 2

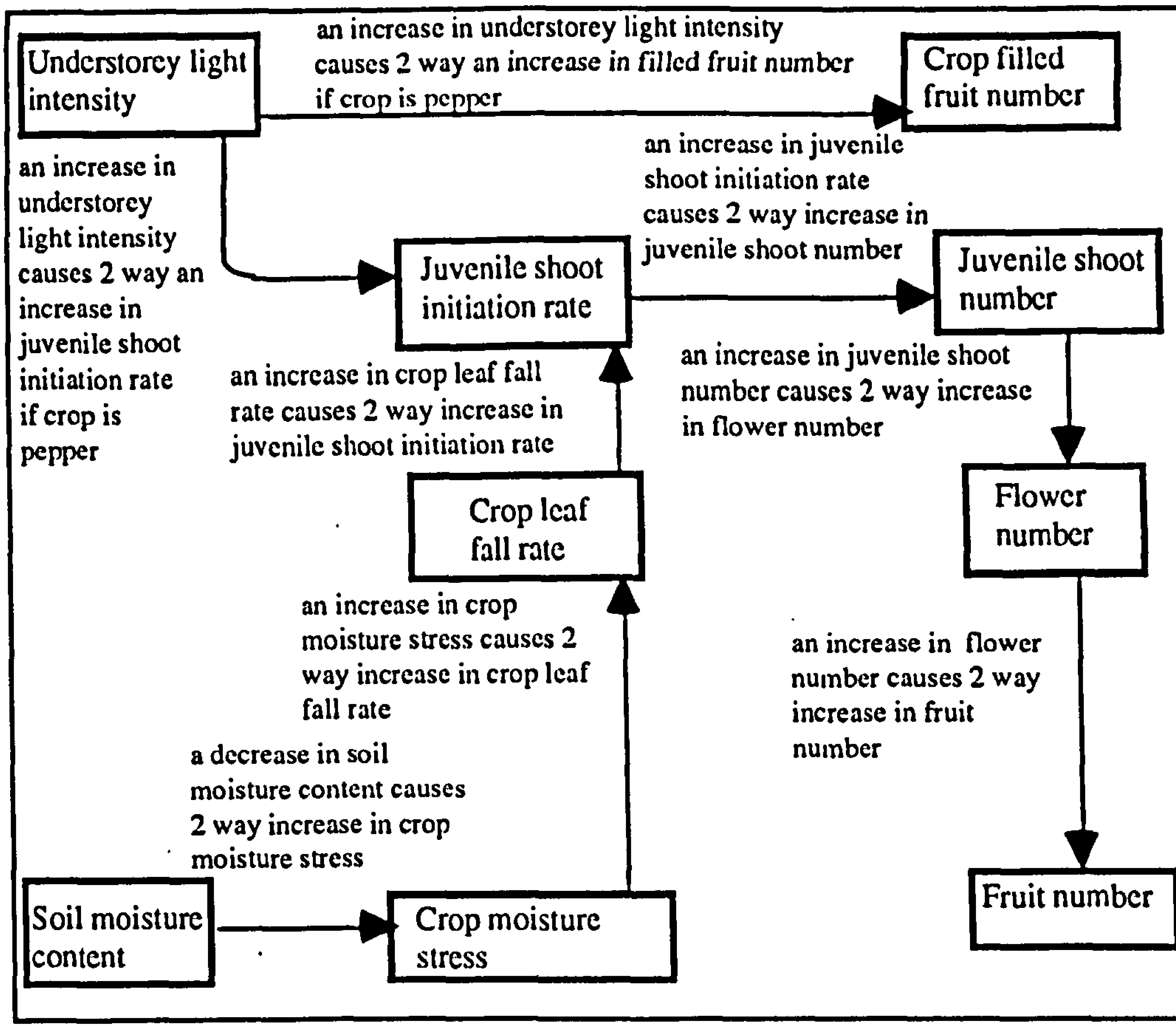


i. a decrease in branch number causes a decrease in crown density
which of the following occur when branch number decreases:
a. crown density increases
b. crown density decreases
c. crown density does not change
d. don't know

ii. a decrease in crown density causes an increase in canopy light penetration rate
which of the following occur when crown density decreases:
a. canopy light penetration rate increases
b. canopy light penetration rate decreases
c. canopy light penetration rate does not change
d. don't know

iii. an increase in tree frequency causes a decrease in canopy light penetration rate
which of the following occur when tree frequency increases:
a. canopy light penetration rate increases
b. canopy light penetration rate decreases
c. canopy light penetration rate does not change
d. don't know
iv. a decrease in soil moisture content causes an increase in moisture stress to the crop
which of the following occur when soil moisture content decreases:
a. crop moisture stress
b. crop moisture stress does not change
c. don't know
v. an increase in soil temperature causes an increase in litter decomposition rate
which of the following occur when soil temperature increases:
a. litter decomposition rate increases
b. litter decomposition rate decreases
c. litter decomposition rate does not change
d. don't know
vi. an increase in litter decomposition rate causes a decrease in litter layer thickness
which of the following occur when litter decomposition rate increases:
a. litter layer thickness increases
b. litter layer thickness decreases
c. litter layer thickness does not change
d. don't know
viii. an increase in understorey light intensity causes an increase in soil temperature
which of the following occur when understorey light intensity increases:
a. soil temperature increases
b. soil temperature decreases
c. soil temperature does not change
d. don't know
ix. an increase in soil temperature causes a decrease in soil moisture content
which of the following occur when soil temperature increases:
a. soil moisture content increases
b. soil moisture content decreases
c. soil moisture content does not change
d. don't know
x. a decrease in litter layer thickness causes an increase in soil erosion rate
which of the following occur when litter layer thickness decreases:
a. soil erosion rate increases
b. soil erosion rate decreases
c. soil erosion rate does not change
d. don't know

Statement set 3.



i. an increase in flower number causes an increase in fruit number
which of the following occur when flower number increases:
a. fruit number increases
b. fruit number decreases
c. fruit number does not change
d. don't know

ii. an increase in juvenile shoot number causes an increase in flower number
which of the following occur when juvenile shoot number increases:
a. flower number increases
b. flower number decreases
c. flower number does not change
d. don't know

iii. an increase in juvenile shoot initiation rate causes an increase in juvenile shoot number
which of the following occur when juvenile shoot initiation rate increases:
a. juvenile shoot number increases
b. juvenile shoot number decreases
c. juvenile shoot number does not change
d. don't know

iv. moisture stress crop causes an increase in crop leaf fall rate
which of the following occur when the crop is under moisture stress:
a. crop leaf fall rate increases
b. crop leaf fall rate decreases
c. crop leaf fall rate not changes
d. don't know

v. an increase in understorey light intensity causes an increase in juvenile shoot initiation rate of pepper
which of the following occur when understorey light intensity increases:
a. juvenile shoot initiation rate of pepper decreases
b. juvenile shoot initiation rate of pepper increases
c. juvenile shoot initiation rate of pepper does not change
d. don't know

vi. an increase in crop leaf fall rate causes an increase in juvenile shoot initiation rate
which of the following occur when crop leaf fall rate increases:
a. juvenile shoot initiation rate decreases
b. juvenile shoot initiation rate increases
c. juvenile shoot initiation rate does not change
d. don't know

vii. a decrease in soil moisture content causes an increase in crop moisture stress
which of the following occur when soil moisture content decreases:
a. crop moisture stress increases
b. crop moisture stress decreases
c. crop moisture stress does not change
d. don't know

viii. an increase in understorey light intensity causes an increase in filled fruit number of pepper
which of the following occur when understorey light intensity increases:
a. filled fruit number of pepper increases
b. filled fruit number of pepper decreases
c. filled fruit number of pepper does not change
d. don't know

Appendix 8 Local terms related to pruning of trees.

Local term	English meaning
Arana / aramba	Gardens with high tree density and closed canopy
Aratuwa	Heartwood
Athu keteemal athu kandu bama	Pruning of branches
Aul -heraya / kossa	Spiral grain
Bara-gathiya	Density
Burul- lee	Medium quality wood
Debal bedenewa	Forking of branches
Dirakadaya	Portion decayed
Diya-potta	Outer bark
Gaha balaweema	Decrease in tree vigour
Gaha hedagahageneema	Developing the form of tree
Gaha peedeema	Maturity of tree (tree will reach its maximum heightand produce final set of side branches at the top)
Getaya	Knot
Haiya-gathiya	Hardness
Iri-madaya	Soft part of stem (sapwood)
Kabala	Rotten stem
Kada	Trunk / bole
Kanda panuva	Insect larvae feeding on tree trunks
Karatiya	Tip of the crown
Kola-gote	Dense crown
Mas-pirenawa	Development of heartwood in the side branches
Mudun dalla	Apical bud
Palena-gathiya	Cleavage
Panu gedi	Stem canker
Pathalweema / athu vihideema	Spreading of branches
Pinsendu lee	Low quality wood
Pohora-gathiya	Manure quality
Potta theri -gehenawa	Tearing / splitting of bark from the stem
Rambaweema	Softening of stem due to rotting
Saru-bava	Soil nutrient content
Thattuwak	A set of basal branches removed at a pruning cut
Thawwa	The hole created during the fall of a knot
Thada lee	High quality wood
Vadala	Shaded (closed) condition
Wata adi	Girth of stem in feet
Wata athu	Side branches
Wata galavenewa	Falling off of dead and loose knots
Watura / heentha urana gathiya	Permeability of wood

Appendix 9 Light quality (Red /Far red) ratio of the selected sites with different light intensities in the five KHGs.

MAFP	Light intensity level 1					Light intensity level 2					Light intensity level 3					Light intensity level 4				
	R1	R2	R3	R4	R5	R1	R2	R3	R4	R5	R1	R2	R3	R4	R5	R1	R2	R3	R4	R5
0	0.96	0.97	0.98	0.99	0.92	0.71	0.89	0.76	0.75	0.81	0.50	0.43	0.38	0.47	0.36	0.14	0.10	0.23	0.12	0.07
1	0.95	0.90	0.93	0.98	0.94	0.75	0.87	0.78	0.73	0.82	0.51	0.45	0.34	0.39	0.34	0.16	0.07	0.18	0.17	0.10
2	0.93	0.95	0.92	0.97	0.95	0.78	0.80	0.71	0.78	0.83	0.50	0.48	0.32	0.44	0.35	0.14	0.09	0.15	0.18	0.12
3	0.92	0.92	0.95	0.92	0.95	0.69	0.82	0.73	0.70	0.79	0.58	0.39	0.39	0.47	0.40	0.09	0.12	0.24	0.10	0.10
4	0.94	0.88	0.90	0.96	0.99	0.72	0.79	0.79	0.69	0.76	0.56	0.44	0.31	0.49	0.45	0.11	0.11	0.17	0.16	0.08
5	0.89	0.95	0.91	0.94	0.91	0.70	0.82	0.67	0.67	0.82	0.60	0.46	0.36	0.37	0.31	0.15	0.09	0.19	0.15	0.05
6	0.95	0.92	0.94	0.97	0.96	0.73	0.83	0.70	0.71	0.78	0.48	0.47	0.37	0.39	0.30	0.14	0.10	0.20	0.16	0.11
7	0.99	0.90	0.96	0.92	0.97	0.69	0.86	0.73	0.74	0.74	0.53	0.39	0.35	0.42	0.37	0.16	0.12	0.26	0.09	0.12
8	0.95	0.95	0.92	0.94	0.91	0.73	0.92	0.68	0.70	0.75	0.57	0.45	0.40	0.48	0.41	0.10	0.09	0.18	0.17	0.09
9	0.90	0.98	0.93	0.93	0.98	0.75	0.78	0.71	0.72	0.79	0.54	0.47	0.40	0.41	0.40	0.12	0.08	0.19	0.14	0.07

Key: R- Replicate, MAFP- Months after field planting

Appendix 10 Plant height under different conditions at monthly intervals from field planting.

i. One month after field planting.

Factor A	Light levels	Level 1 (100% intensity)		Level 2 (50-75% intensity)		Level 3 (25-50% intensity)		Level 4 (0-25% intensity)	
Factor B	Soil type	Imported	Local	Imported	Local	Imported	Local	Imported	Local
Factor C	With	11.65	12.25	13.35	13.00	10.10	10.20	10.05	10.00
Root barriers	Without	11.95	11.95	11.40	12.11	9.20	8.90	9.60	10.15
Co-variate	R/FR ratio	0.96		0.79		0.42		0.14	

* Analysis of variance procedure indicated that effects of main factors B and C, and also the co-variate were non-significant (P=0.05)

ii. Two months after field planting.

Factor A	Light levels	Level 1 (100% intensity)		Level 2 (50-75% intensity)		Level 3 (25-50% intensity)		Level 4 (0-25% intensity)	
Factor B	Soil type	Imported	Local	Imported	Local	Imported	Local	Imported	Local
Factor C	With	17.00	17.60	17.25	14.55	11.10	11.45	11.10	11.40
Root barriers	Without	18.00	16.65	14.65	14.15	11.05	10.65	11.40	11.20
Co-variate	R/FR ratio	0.95		0.79		0.42		0.14	

*Analysis of variance procedure indicated that effects of main factors B and C, and also the co-variate were non-significant (P=0.05)

iii. Three months after field planting.

Factor A	Light levels	Level 1 (100% intensity)		Level 2 (50-75% intensity)		Level 3 (25-50% intensity)		Level 4 (0-25% intensity)	
Factor B	Soil type	Imported	Local	Imported	Local	Imported	Local	Imported	Local
Factor C	With	25.50	24.10	22.00	21.60	12.55	13.40	12.21	13.31
Root barriers	Without	25.30	21.90	21.45	21.65	12.15	12.68	13.40	13.75
Co-variate	R/FR ratio	0.94		0.76		0.43		0.14	

*Analysis of variance procedure indicated that effects of main factors B and C, and also the co-variate were non-significant (P=0.05)

iv. Four months after field planting.

Factor A	Light levels	Level 1 (100% intensity)		Level 2 (50-75% intensity)		Level 3 (25-50% intensity)		Level 4 (0-25% intensity)	
Factor B	Soil type	Imported	Local	Imported	Local	Imported	Local	Imported	Local
Factor C	With	34.50	37.61	28.85	26.65	14.85	14.20	-	-
Root barriers	Without	38.25	35.20	27.90	28.75	14.30	14.25	-	-
Co-variate	R/FR ratio	0.93		0.75		0.45		0.13	

*Analysis of variance procedure indicated that effects of main factors B and C, and also the co-variate were non-significant (P=0.05)

v. Five months after field planting.

Factor A	Light levels	Level 1 (100% intensity)		Level 2 (50-75% intensity)		Level 3 (25-50% intensity)		Level 4 (0-25% intensity)	
Factor B	Soil type	Imported	Local	Imported	Local	Imported	Local	Imported	Local
Factor C	With	41.75	41.80	31.65	30.10	15.85	15.45	-	-
Root barriers	Without	43.00	40.95	31.85	31.80	15.60	15.20	-	-
Co-variate	R/FR ratio	0.93		0.74		0.44		0.13	

*Analysis of variance procedure indicated that effects of main factors B and C, and also the co-variate were non-significant (P=0.05)

vi. Six months after field planting.

Factor A	Light levels	Level 1 (100% intensity)		Level 2 (50-75% intensity)		Level 3 (25-50% intensity)		Level 4 (0-25% intensity)	
Factor B	Soil type	Imported	Local	Imported	Local	Imported	Local	Imported	Local
Factor C	With	47.15	46.50	33.95	33.10	16.80	16.35	-	-
Root barriers	Without	47.75	46.40	33.35	34.00	16.65	16.20	-	-
Co-variate	R/FR ratio	0.94		0.75		0.41		0.14	

*Analysis of variance procedure indicated that effects of main factors B and C, and also the co-variate were non-significant (P=0.05)

vii. Seven months after field planting.

Factor A	Light levels	Level 1 (100% intensity)		Level 2 (50-75% intensity)		Level 3 (25-50% intensity)		Level 4 (0-25% intensity)	
Factor B	Soil type	Imported	Local	Imported	Local	Imported	Local	Imported	Local
Factor C	With	54.80	51.00	36.07	36.35	17.98	17.25	-	-
Root barriers	Without	53.75	52.61	34.80	36.30	17.50	17.20	-	-
Co-variate	R/FR ratio	0.95		0.75		0.41		0.15	

*Analysis of variance procedure indicated that effects of main factors B and C, and also the co-variate were non-significant (P=0.05)

viii. Eight months after field planting.

Factor A	Light levels	Level 1 (100% intensity)		Level 2 (50-75% intensity)		Level 3 (25-50% intensity)		Level 4 (0-25% intensity)	
Factor B	Soil type	Imported	Local	Imported	Local	Imported	Local	Imported	Local
Factor C	With	70.75	65.08	42.85	41.60	20.10	20.05	-	-
Root barriers	Without	65.48	65.55	40.80	41.11	19.85	20.25	-	-
Co-variate	R/FR ratio	0.94		0.76		0.44		0.14	

*Analysis of variance procedure indicated that effects of main factors B and C, and also the co-variate were non-significant (P=0.05)

ix. Nine months after field planting.

Factor A	Light levels	Level 1 (100% intensity)		Level 2 (50-75% intensity)		Level 3 (25-50% intensity)		Level 4 (0-25% intensity)	
Factor B	Soil type	Imported	Local	Imported	Local	Imported	Local	Imported	Local
Factor C	With	90.50	84.80	51.95	52.22	22.70	22.50	-	-
Root barriers	Without	81.03	79.25	50.18	50.72	23.25	22.75	-	-
Co-variate	R/FR ratio	0.94		0.75		0.46		0.29	

*Analysis of variance procedure indicated that effects of main factors B and C, and also the co-variate were non-significant (P=0.05)